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Science & Technology Trends

Quarterly Review

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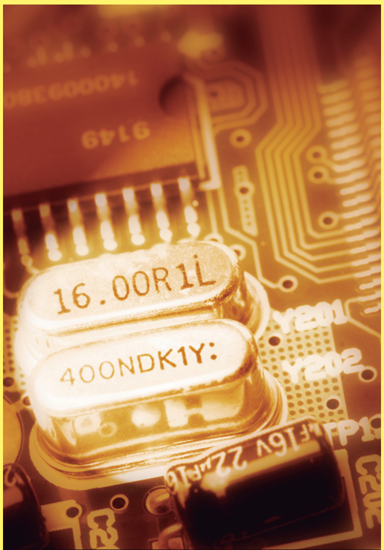

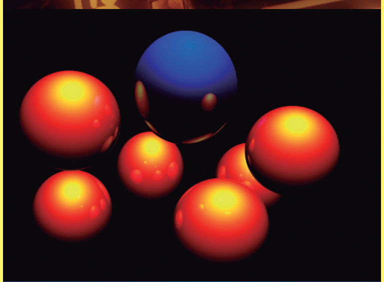

Foreword

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 3000 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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Executive Summary

Life Sciences

1 Fostering and Status of Scientists and Technical Experts in Drug Development

p.11

In response to the globalization of the pharmaceutical industry, an agreement at The International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH) has set global standards for the efficacy, safety and quality of drugs. To meet these standards, it is urgently necessary for Japan to strengthen its international competitiveness and improve its drug development environment. Pharmaceuticals can be classified into ethical drugs and over-the-counter drugs (OTC: drugs available at pharmacies and drugstores), the former accounting for about 90% of production[1,2]. Japan has the second largest pharmaceutical market (i.e. development opportunities) in the world, but in terms of sales by country, Japan ranks fourth or fifth among the six countries with drug-development technologies. In response to the ICH agreement, the Pharmaceutical Affairs Law will be revised in April 2005, and after this revision, foreign products are likely to increase their share of the Japanese market. There is great concern that Japan will become an "underdeveloped country" that only manufactures off-patent generic drugs.

Since a long time is needed for drug development (from 10 to 17 years) with a low success rate (one in 11,000) as well as the corporate efforts required, it is important that the government emphasizes drug development research and supports human resource development in this area. Meanwhile, the six-year program for pharmaceutical departments and universities, which will be implemented in 2006, aims to educate pharmacists who specialize in patient compliance instructions, medication history management and risk management for drug-induced suffering. Thus, it is likely that fostering "drug development professionals," which has been the role mainly assumed by pharmaceutical departments and universities, will become even more difficult in Japan.

In the U.S., which is the world-leading drug developing country, NIH research and technology transfer budgets have been organized in an environment where universities, companies and venture capital companies can all participate in drug development. The NIH research budget has actually supported 40% of the pharmaceuticals that have been commercialized. Although the country has no educational institution specializing in human resource development in the drug development area, its flexible curricula and the recruitment of teaching staff beyond departments have fostered human resources interested in drug development. In Japan, companies have individually managed information concerning drug development, from the discovery of pharmaceutical seeds to their commercialization. Human resource development has been conducted alongside pharmacist education in small-scale pharmaceutical departments and universities (about 80 students per grade per department in former national universities). Venture capital companies dedicated to pharmaceutical seed discovery have not been nurtured, and the drug development environment in Japan is in marked contrast with that in the U.S..

Japan has ten original products with annual global sales of 1 billion dollars.

Japan also has certain university-launched products that have been internationally accepted. This suggests that Japan's drug-development technology has the potential to improvement.

Taking advantage of the implementation of the six-year courses for pharmaceutical departments and universities in 2006, we should establish a completely new system (departments) for intensive education in the following five subjects: (1) chemical and biological foundations for developing novel pharmaceutical seeds (compounds); (2) chemical and biological methods for manufacturing novel pharmaceuticals; (3) pharmacology for discovering novel effects and the efficacy of pharmaceuticals; (4) pharmaceutics for exploring novel DDSs (drug delivery systems) suitable for individual drugs; and (5) toxicology for assessing safety and toxicity.

This system would foster human resources who can synthesize organic compounds (Subjects (1) and (2)), can handle not only cells and microorganisms but also animals and are strong in biostatistics" (Subjects (3), (4) and (5)), as is demanded by pharmaceutical manufacturers. This should greatly contribute to the domestic pharmaceutical industry, which would lead to economic revitalization and independence of people's health from foreign pharmaceutical industries.

(Original Japanese version: published in January 2005)

2 Trends in Food Allergy Research

p.26

The incidence of allergic diseases continues to increase, mainly in developed countries, and has grown into a serious problem. In particular, food allergy often develops during infancy and can affect a child's growth or trigger an "allergic march," i.e., the progressive development of various allergies. Therefore, early prevention and treatment are recommended for food allergy. The second Science and Technology Basic Plan depicts the "realization of a nation securing a comfortable, safe and high quality of life." Research and development of anti-allergic food can contribute to realizing such a nation and should therefore be promoted.

The development of food allergy involves complex interactions between genetic factors and diet and other environmental factors, which must be considered when conducting research and development in this area.

Research aimed at overcoming food allergy includes the food-oriented approach: the development of hypoallergenic food and antiallergic food. Hypoallergenic food is essential for patients with food allergies to prevent the development of allergic symptoms, to improve their diet and eliminate the risk of nutritional disorders. To date, several hypoallergenic foods have been developed and commercialized, but further research is required for developing foods that are effective against various allergens and preventing any loss of taste, or decline in nutritional and commercial value. Currently, the development of hypoallergenic food is being attempted, using a proteome analysis-based approach, which enables the comprehensive identification of structures commonly found in various allergens. Meanwhile, there have been attempts to develop food that can prevent allergy by utilizing the mucosal immune system in the gut, such as tolerogenic peptides or probiotics. There are great expectations for such foods, as they can interact directly with the body to suppress allergic reactions. Nevertheless, the development of such foods is still in the research phase, and several issues remain to be resolved before their practical application.

Future tasks include characterizing food allergens, establishing allergenicity evaluation systems, understanding the mechanism of food allergy development, and confirming the relationship between food allergy and environmental factors. While these are indeed important tasks to be addressed through research, it is even more important to establish a system for assessing the efficacy and safety of newly developed food products and to find appropriate ways to apply them for patients with food allergy. Future progress in research and development requires not only the resolution of individual research questions, but also discussion of ways to evaluate the efficacy and safety of anti-allergic foods, and their application to allergic diseases. Therefore, cooperation with the medical profession is essential for the research and development of food products.

(Original Japanese version: published in February 2005)

Information and Communication Technologies

3 Applying Nanotechnology to Electronics

— Recent Progress in Si-LSIs to Extend Nano-Scale —

p.36

Nano-scale materials for nanotechnology have been prepared using two techniques: top-down and bottom-up methods. The top-down method is applied to process macro-scale materials into a smaller size just as a semiconductor process does, whereas the bottom-up method is applied to integrate molecules or atoms into nano-scale materials just as a living organism synthesizes proteins.

The bottom-up method was recently successfully combined with the top-down method by researchers at universities and companies in the U.S., showing that nanotechnology is being smoothly extended to conventional electronics. The bottom-up method is epitomized by self-assembly, which plays an important role in nanotechnology, together with prospective applications in ionics and electronics. In addition to primitive assemblies of materials, nanotechnology is moving forward to electronic devices and their integration, in which an LSI design is being explored.

Nanotechnology is presented as a realistic, promising technology for the future due to recent progress in this field, where nanotechnology is combined with conventional Si-based electronics.

Long-term investment based on a well-planned strategy is essential for successful materialization of next-generation technologies, such as nanotechnology, where planning should include impressive success in industry, signifying the bright future of the technology.

Although the pros and cons of the top-down and bottom-up methods have been discussed in Japan, new ideas for combining both have not been well studied, except for research in industry (NEC, etc.). The recent progress in the U.S. that tries to combine both methods is suggestive, and is unveiling a new paradigm of nanotechnology indicating realistic applications in industry.

(Original Japanese version: published in January 2005)

4 Trends in High-End Computing in United States Government

p.46

The government of the United States of America is engaged in various efforts to maintain its leadership in high-end computing (HEC). Particularly noteworthy are the activities of the HEC Revitalization Task Force, which includes diverse federal agencies. The government formed this Task Force as a special project under the auspices of National Science and Technology Council (NSTC) in March 2003. The Task Force subsequently released the "Federal Plan for High-End Computing," which aims to enable the USA to maintain its leadership in science and technology.

Underlying this action is an awareness that even though high-end computing is essential to science and technology development, national security, and international competitiveness, the high-end computing systems used for federal missions are not always meeting computing requirements. Detailed investigations on high-end computing in Japan were conducted in the course of establishing the plan.

The plan comprises three parts.

(1) Research and development: A roadmap for key technologies over the next 5 to 10 years, emphasizing sustained system performance in practical application and incorporating challenging research and development.

(2) Resources: Relieving the shortage of high-end computing facilities and establishing leadership system facilities with leading-edge computing capability.

(3) Procurement: Efficient procurement by federal agencies, emphasizing total cost of ownership (TCO) and sustained system performance.

The plan was completed in May 2004.

Regarding this plan, the 108th US Congress debated at least three bills with "Revitalization of High-End Computing" in their names during 2004. Of these, the Department of Energy High-End Computing Revitalization Act of 2004 was passed in November. The law specifies the implementation of research on multiple architectures and on system software for high-end computing, the establishment and operation of leadership-system related facilities, the creation of a high-end software development center, and the transfer for technology to the private sector.

To maintain its global leadership in science and technology, the US Government now strongly promotes a strategy centered on high-end computing.

(Original Japanese version: published in February 2005)

5 R&D Trends of LSI Design Technology
— Bottleneck at Development of System LSIs that rule Value-Added Electronic Devices —

p.61

The value of electronic appliances is becoming governed by system LSIs that are incorporated with increasingly more elements and functions. In contrast, the technology to design sophisticated LSIs in a short turn around time is becoming essential to keep pace with the shorter life-cycle of appliances. LSI development is thus more heavily dependent on design technology than manufacturing, and is facing a bottle-neck in the former domain.

LSI design technology is comprised of technology used to design and to support, of which the latter is called LSI design methodology. Thanks to the contribution of electronic design automation, LSI design methodology has displayed considerable progress every decade, abstracting the design description method: in the 1970s, layout diagram of elements; in the 1980s, circuit diagrams using symbols; and in the 1990s, text-style language. Design technology has therefore progressed alongside software technology development.

However, design technology in Japan, where highly abstracted description first took root, shows little progress, since the description is becoming more highly abstracted. Moreover, the extent of design research presented by companies, universities, and institutions in Japan, is seen to be on a downward trend at Design Automation Conference (DAC), a prestigious conference in this field. Currently, the number of accepted presentations from Japan represents 2% of the whole, although the total number of presentations from Japan (mainly in the shape of company contributions) was 10%.

The share of DAC presentations from universities is 70%, representing their important role in developing design technology. Universities have a competitive edge in the development of design technology, which is heavily dependent on ideas rather than huge investment in equipment. U.S. universities began to increase the number of accepted presentations at DAC after beginning the LSI test-production service and industry-academy collaboration. Taiwan, meanwhile, following success in semiconductor manufacturing, has been rapidly developing their own LSI design technology, with the backing of the government. Other countries and areas are also developing similar technology, leaving Japan trailing behind them.

More researchers in this field, where a shortage has been detrimental to R&D, are necessary in Japan. In the short run, it may be possible to employ researchers from industry or foreign countries. In the longer term, university education related to computer science or engineering should be reinforced to produce engineers and researchers capable of developing design technology.

A new LSI design methodology is developed, powered by competitive design technology, and should progress through the development of essential LSIs within a country. For example, the development of original technologies used in security-related LSIs, one of the basic technologies in the ubiquitous network, is involved in a proposed development to construct a secure network environment, made possible by electronic money, identity recognition, and encryption.

(Original Japanese version: published in March 2005)

Environmental Sciences

6

Science and Technology Trends in Fire Protection and Disaster Management

— A Consideration of Characteristics and Directions in Science and Technology for Safety and Peace of Mind—

p.75

The White Paper on Fire and Disaster Management compiled annually by the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications brings together information on a truly wide variety of disasters and accidents, including fires, accidents at hazardous materials facilities and complexes, windstorms and floods, wildfires, earthquakes, and accidents related to gases, toxins, deleterious substances, and nuclear power. In the FY 2005 policy on the allocation of resources such as budgets and personnel for science and technology (Council for Science and Technology Policy, May 26, 2004), strategic and comprehensive promotion of science and technology for new efforts concerning national and social problems was established as a new area of strategic emphasis. The comprehensive and cross-sectional promotion of science and technology to build a safe society that provides peace of mind is one example of this policy. To build a safe society that provides peace of mind, the causes of accidents and disasters must be understood, and full discussion on prevention and response after occurrence must take place. Science and technology is necessary for this to happen. Fire protection and disaster management S&T is interdisciplinary research that spans all the priority fields designated in the second Science and Technology Basic Plan. A PDCA cycle connected with the prevention of disasters before they occur through prior response, after-the-fact response, and causal analysis should be formed.

In the near future, concern for safety and peace of mind will include fire protection and disaster management in an aging society, contradictions between environmental protection and a safe society that provides peace of mind, damage from crimes such as arson and from terrorism, accidents accompanying aging infrastructure, and natural disasters such as major earthquakes. In addition, with advances in fuel-cell vehicles and other technologies in recent years, conventional firefighting methods may no longer be sufficient. Research on special combustion behavior and firefighting is therefore essential, as are prevention technologies.

To link the results of fire protection and disaster management science and technology with achieving a safe society that provides peace of mind, the public must be able to understand and use these results. The utilization of science and technology to prevent accidents before they happen is a matter of course, but at the same time, people must be educated so that they can properly understand, manage, and use them. Various budgets are allocated for research directly linked to technology, but funds should be allocated for preventative education and so on in the same way. As with pure scientific research, the results may not be tangible, but this education is essential in constructing a safe society that provides peace of mind. One can easily imagine that when an earthquake occurs, damage will vary widely by location. Therefore, providing all residents in a given area with disaster drills through virtual reality and other simulations can be effective from the perspective of damage mitigation.

Currently, the evaluation of researchers by their results is increasingly widespread and becoming more important. In most such researcher evaluations, changing research fields may not be advantageous because it can cause a temporary drop in publications and presentations. To foster interdisciplinary researchers, it is therefore desirable to devise evaluation methods that integrate contributions over time into building a safe society that provides peace of mind.

In addition, the market scale is small, so there is little incentive to develop equipment in accordance with the frontline needs of fire protection, and it is difficult to adopt the most advanced results of research in science and technology to combat disasters. This would contribute to an effective and efficient research system with full-fledged cooperation among industry, academia, and government, as well as intra-governmental cooperation. Such a system of intra-governmental cooperation could enable the fruits of fire protection and disaster management science and technology to enter the general market, expanding the target market for research and development. Because the environmental resistance and performance required for frontline fire protection activities is equivalent to or greater than that required by military technology, the scientific and technical issues to be solved are advanced. At the same time, however, the cost effectiveness required is closer to that of the civil sector.

Compared with the United States of America, the world's policeman that leads in science and technology through its military technology, Japan may be able lead the world in fire protection through breakthroughs in the science and technology of disaster prevention and mitigation, contributing to the global community. To effectively utilize fire protection and disaster management S&T and contribute its achievements to society, the creation of such visions and systems is vital.

(Original Japanese version: published in March 2005)

Frontier

7 Effectiveness of the Quasi-Zenith Satellite System in Ubiquitous Positioning

p.88

In our future information society, accurate positional information at any time and at any place will be available as a matter of course. For this purpose, a variety of research targeted at “ubiquitous positioning” has already begun in many countries. Here in Japan, the Ministry of Internal Affairs and Communications has launched a policy, scheduled to be completed by April of 2007, to build a high-performance infrastructure, providing police and fire fighting agencies with enhanced emergency communication capability for improved safety and freedom from care. Considering that mobile phones are used in more than half of police notifications, high-precision positioning of the transmitter using Global Positioning System (GPS) will greatly streamline the handling of accidents and crimes. The lack of means for the accurate and speedy locating of the transmitter has long been a bottleneck in mobile phone usage in this area. Mobile terminals with automatic positional information transmission capability using GPS will enable security agencies including police to reach the spot much more quickly.

The GPS that will play a fundamental role in this policy uses time-base signals from four or more GPS satellites (NAVSTAR satellites launched by U.S.). However, acquisition of the required number of GPS signals for accurate positioning can be severely hindered where mountainous terrain and densely populated urban canyons block signal propagation. This has been often pointed out as major blind side in GPS utilization.

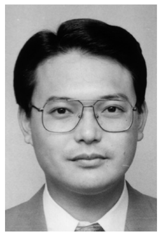
The Quasi-Zenith Satellites System (QZSS) is a constellation of three satellites that orbit the earth on different geosynchronous orbital planes, with at least one satellite positioned near the zenith at all times in low to middle latitude on the same line of longitude. The three satellites round the earth reciprocating northern and southern hemisphere with their orbits cutting a figure of “8” when projected on the earth's surface centered on a certain longitude. QZSS is a multi-functional satellite system that can function as a communication, broadcasting and observation system, as well as providing positioning information.

Near-zenith satellites will compensate for the blind sides of GPS satellites, enabling GPS positioning to concentrate on enhanced emergency communication, as well as providing a variety of applications such as human navigation, railway traffic control, and land survey. The total system will be a major component that constitutes the basic infrastructure of a country. It will also provide substantial business opportunities to the aerospace industry in Japan. However, the simultaneous implementation of communication and broadcasting capability in addition to positioning may hinder the timely completion of the system, as it will entail vast development efforts in satellite technology and the establishment of a development framework. Compared to these additional functions, the positioning capability has higher priority in terms of urgency and social importance as basic infrastructure for Japan, and it will be a major driving force in renovating the structure of society and producing new values. I propose that the first QZSS complements and augments the GPS to enable secure, rapid development and the early start of operation. As part of this effort, establishment of a governmental organization that will preside over all positional information utilization in Japan, as the Interagency GPS Executive Board does in U.S.A., is essential for the promotion of the QZSS.

(Original Japanese version: published in January 2005)

1

Fostering and Status of Scientists and Technical Experts in Drug Development



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1 Introduction

The development of good medicines greatly contributes to improving QOL and reducing medical costs by reducing the number of operations, shortening treatment time and hospital stays and lowering recurrence rates. According to WHO, there is no effective therapy for three-quarters of the world's diseases, and novel drugs need to be developed. Meanwhile, the globalization of the pharmaceutical industry has set global standards for the efficacy, safety and quality of drugs. To meet these standards, it is urgently necessary for Japan to strengthen its international competitiveness and improve its domestic environment for drug development. By advancing our drug development technology and leading the worldwide pharmaceutical industry, Japan could compensate for its lack of natural resources with intellectual property, maintain independence from foreign companies in terms of medical supplies and safety assessments, and take the initiative in health and sanitation. Moreover, fostering human resources in the drug development area is an important task for an aging society, since senior citizens are the most frequent users of medicines.

2 Status and issues of drug development

2-1 Process of drug development — product development with high risk —

The first step in drug development is to screen a wide range of materials including naturally occurring organic compounds, synthetic products, biological materials and microbial metabolites for pharmacologically active substances and discover novel physiologically active substances with the potential to become medicine. The properties, chemical structure and action mechanisms of the novel substance are then studied in detail. These days, genome information is also utilized at this stage. The initial stage takes two to three years.

In the next step, the substance screened in the previous step is subjected to non-clinical studies on its effectiveness (efficacy), safety (toxicity), pharmacokinetics (absorption, distribution, metabolism and excretion), stability, etc. In safety evaluations, the substance is tested for acute, sub-acute and chronic toxicity and teratogenicity. The non-clinical study stage takes from three to five years.

An investigational new drug that has passed non-clinical studies is then subjected to three stages of clinical trial: Phase I, performed on healthy, male subjects, Phase II, performed on a small number of patients, and Phase III, performed on a larger number of patients. Clinical trials are conducted in medical institutions, adopting the double-blind test using pharmacologically inactive placebos. The test results are statistically processed to assess the efficacy of the drug. The clinical trial stage takes from three to seven years.

For investigational new drugs whose effectiveness, safety and quality have been approved through the above studies, the pharmaceutical

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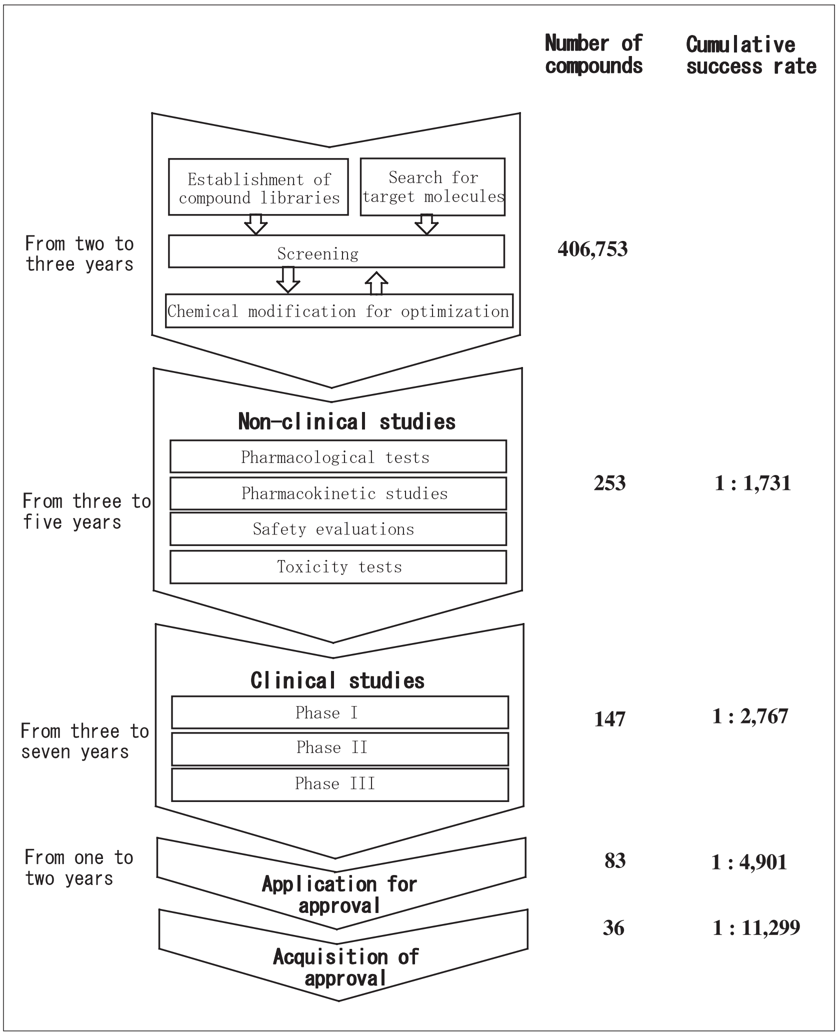
company will submit an application for manufacturing approval to the Ministry of Health, Labor and Welfare. Drugs that pass the examinations by Pharmaceuticals and Medical Devices Agency and the Pharmaceutical Affairs and Food Sanitation Council are approved as pharmaceutical products. This approval stage takes one or two years. In total, 10 to 17 years are required for drug development, and less than one per 11,000 drugs (data for Years 1998 to 2002 provided by the 17 member companies of the Japan Pharmaceutical Manufacturers Association) qualifies at all these stages to become a product. Therefore, the development of pharmaceuticals involves a high risk (Figure 1)[1,2].

2-2 Drug development in Japan — Dependence of Japanese medicine on foreign products —

In Japan, drug development has been encouraged since the enforcement of the substance patent system in 1980[3]. Japan's development capacity has increased with the expansion of the market, which gave birth to several world-class drugs in the 1990s. As mentioned earlier, drug development is very time-consuming and offers a low success rate, which is reflected in the high research expenses; accounting for 8.6% of domestic drug sales revenue.

This proportion is incomparably high compared to those in other manufacturing industries, being 2.5 times larger than the average (3.01%) for all industries. The proportion is even higher than those in the communications/electronics/electric measuring instrument (5.67%) and automobile (4.09%) industries, both of which spend large amounts on research and development (Figure 2). The pharmaceutical industry has a 10% share of the total research expenses of all industries (data provided by the Statistics Bureau of the Ministry of Internal Affairs and Communications)[4]. Moreover,

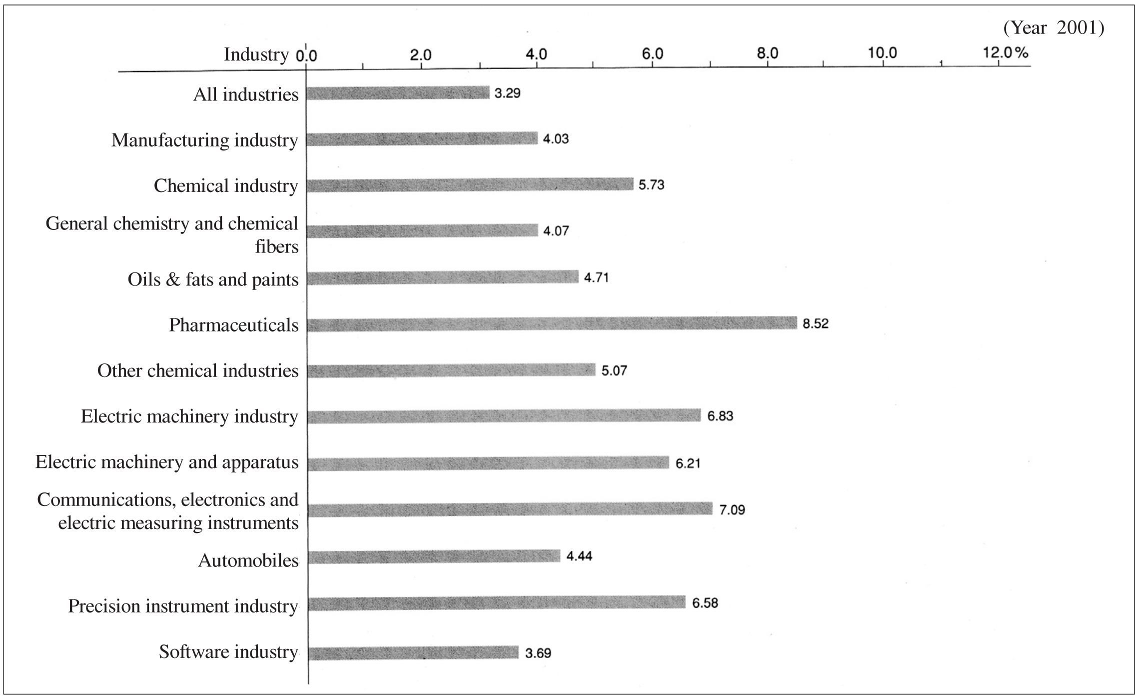
Figure 1 : Drug development process and success rates



drug research expenses including development costs correspond to 13% of total drug sales. The industry spends 23% of the research expenses on basic research, which is markedly higher compared to those in other industries (the average for all industries is 5.8%) (Table 1).

A large proportion of research expenses used by basic research reflects the peculiarity of the pharmaceutical industry in terms of patents. In the automobile and electrical appliance industries, each product involves hundreds or thousands of patents. Each patent has only minor influence, so existing patents rarely interfere with product development. Meanwhile, in the pharmaceutical industry, only one basic patent exists for each product except for formulation patents. To be approved as a new product, a drug must not be covered by an existing patent (Figure 3). In other words, a drug cannot be developed without conducting basic research, compelling

Figure 2 : Proportion of research expenses to sales by industry (Year 2001)[2]



Source: "Survey of Research and Development" by the Ministry of Internal Affairs and Communications

Table 1 : Composition ratio of research expenses by industry and application (Year 2001)[2]

(Unit: %)

Industry	Basic research	Applied research	Development research
All industries	5.8	20.4	73.9
Manufacturing industry	5.7	20.0	74.3
Chemical industry	15.7	25.2	59.1
General chemistry and chemical fibers	10.7	26.4	62.9
Oils & fats and paints	7.3	25.7	67.0
Pharmaceuticals	23.0	24.5	52.6
Other chemical industries	6.3	24.6	69.1
Electric machinery industry	3.8	19.2	77.0
Electric machinery and apparatus	5.2	26.1	68.6
Communications, electronics and electric measuring instruments	3.2	16.6	80.2
Automobiles	1.9	13.0	85.1
Precision instrument industry	1.8	24.6	73.6
Software industry	1.3	7.4	91.3

Source: "Survey of Research and Development" by the Ministry of Internal Affairs and Communications

Figure 3 : Intellectual property rights for different products (schematic diagram)[5]

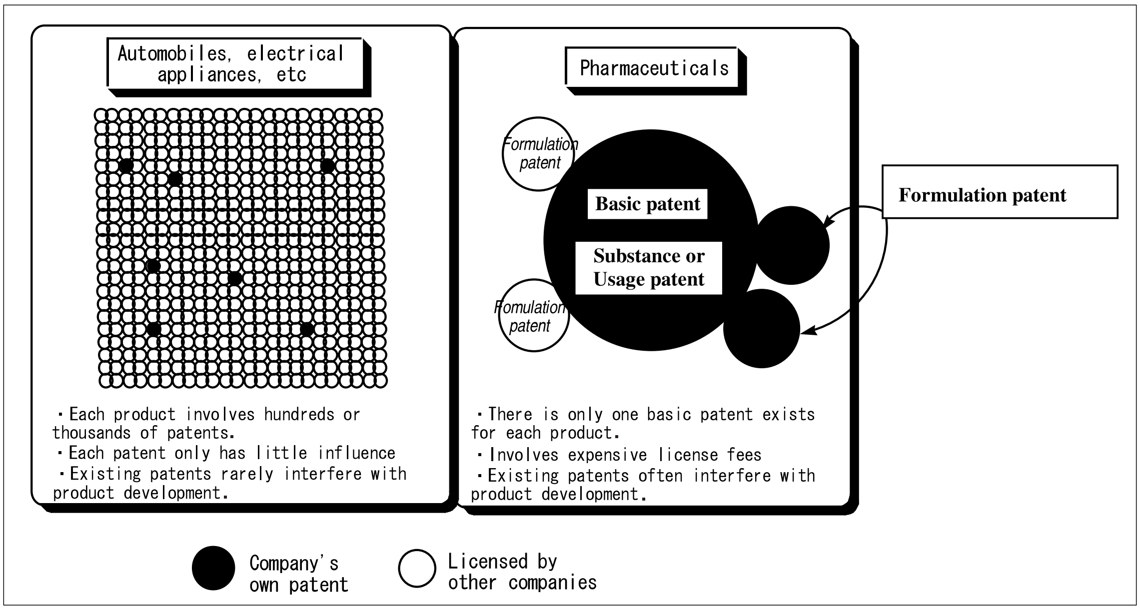
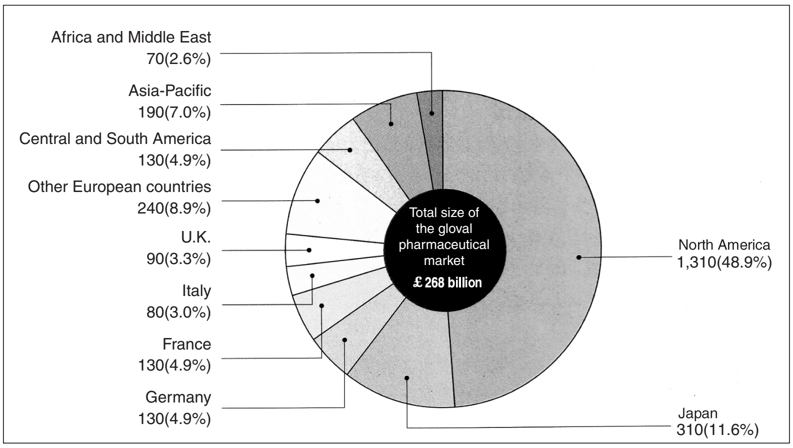


Figure 4 : Size of ethical drug markets in the world (Year 2001)[2]



Source: GlaxoSmithkline Annual Report 2002

the pharmaceutical industry to emphasize basic research.

Despite the efforts of domestic pharmaceutical manufacturers, who have spent a lot on research and perform all phases of clinical trials in Japan, to obtain manufacturing and marketing approval, domestic products constitute only 40% of the pharmaceuticals, with sales of 2 billion yen or more in the domestic market. However, about 60% of such domestic products have yet to be approved in the U.S., the U.K., Germany or France[6]. This demonstrates the vulnerability of Japan's drug development technology where profit can only be made in the domestic market.

Under these circumstances, an agreement at The International Conference on the Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH) (November 2000) has validated applications for manufacturing approval in Japan based on non-clinical and clinical studies conducted overseas (adopted for applications submitted after July 1, 2003). In response to the ICH agreement, the Pharmaceutical Affairs Law will be revised in April 2005. Today, 11 out of 31 drug products with global sales of 2 billion dollars or more are not marketed in Japan[7], but after this revision, foreign products including these 11 are likely to increase their share of the Japanese market[8].

Meanwhile, the Japanese pharmaceutical market makes up 12% (20% in fiscal year 1994) of the global market. It is the second largest after the U.S. market, corresponding to the collective total of the German, French and British markets put together (Figure 4)[2]. In future, Japan will

Table 2 : Contents of the core curriculum for pharmaceutical education and number of pages devoted to each of them

Core curriculum for pharmaceutical education		Number of pages
Professional pharmaceutical education		
Studying physical pharmacy		7
Studying chemical pharmacy		9
Studying biological pharmacy		11
Health and environment		5
Medicines and Diseases		13
Drug development	Formulation	2
	Drug development and manufacturing	**4**
Pharmacy and Society		3
Practical on-site training	**Hospital and pharmacy pharmacists**	**14**
Graduation training	Problem solving	2

be an important market and an arena for a hot technological race in the medical care industry.

Despite this large market (i.e. development opportunities), there is great concern that Japan will fall behind in the drug development area and become an "underdeveloped country" that only manufactures off-patent generic drugs. To avoid this, the government must emphasize drug development research and support human resource development in this area.

2-3 Gap between the new curriculum for pharmaceutical departments and universities (hereafter, represented as pharmaceutical universities) and human resource development in the drug development area

To date, Japanese pharmaceutical manufacturers have mainly assigned graduates from pharmaceutical universities to drug development. As mentioned above, basic research constitutes a significant proportion of drug development (Table 1), so fostering superior human resources engaged in basic research is essential to medicinal science. Meanwhile, the six-year program for pharmaceutical universities, which will be implemented in 2006, aims to educate professionals in patient compliance instruction, medication history management and risk management for drug-induced suffering[9]. From an international viewpoint, six-year educational programs to qualify as a pharmacist predominate over four-year programs, so in this sense, Japan should have introduced the six-year programs much earlier[10]. The new curriculum for pharmaceutical education in Japan will emphasize clinical pharmacy rather than basic research. "The Model Core Curriculum for Pharmaceutical Education," announced by the Pharmaceutical Society of Japan in August 2002[11], devotes only four pages to "The Development and Production of Pharmaceuticals"; corresponding to only one-third of the pages (14 pages) devoted to "Practices of Pharmacists in Hospitals and Pharmacies" (Table 2).

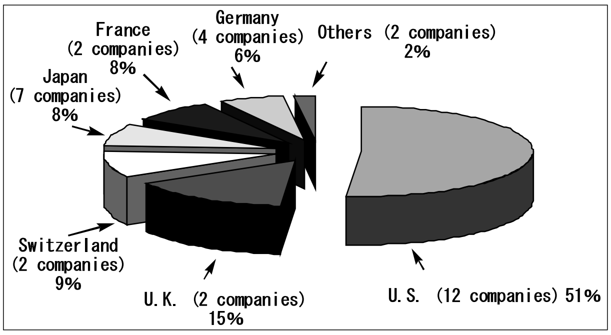
In addition, there are some defenses of the coexistence*1 of six-year programs and the "four (undergraduate) plus two (graduate)" -year programs that have been approved as an interim measure for the next twelve years. This suggestion is justified by negative opinions*2 and concerns about the transition into the six-year programs. Moreover, if a university shifts into a six-year program with its current number of students, the number of teaching staff would be twice that currently required, of which one-sixth must have at least 5 years of working (clinical) experience. Therefore, the coexistence of the two programs is also supported by school administrators who do not wish the number of teaching staff to increase.

Nevertheless, the aim of pharmaceutical education reform is not to improve Japan's international competitiveness in the drug development area. Thus, it is likely that fostering "drug development professionals" will be even more difficult in Japan over the next twelve years.

3 Drug development in the U.S.[12,13]

The level of a country's drug development technology can be inferred from the sales of domestic pharmaceutical manufacturers in the global market. Japan has the second largest pharmaceutical market in the world, and the Japanese pharmaceutical industry shares fourth place with France in terms of total sales, followed by Germany by a narrow margin (Figure 5)[5,7].

Figure 5 : Sales shares of top 31 companies with sales of 2 billion dollars or more by country[5,7]

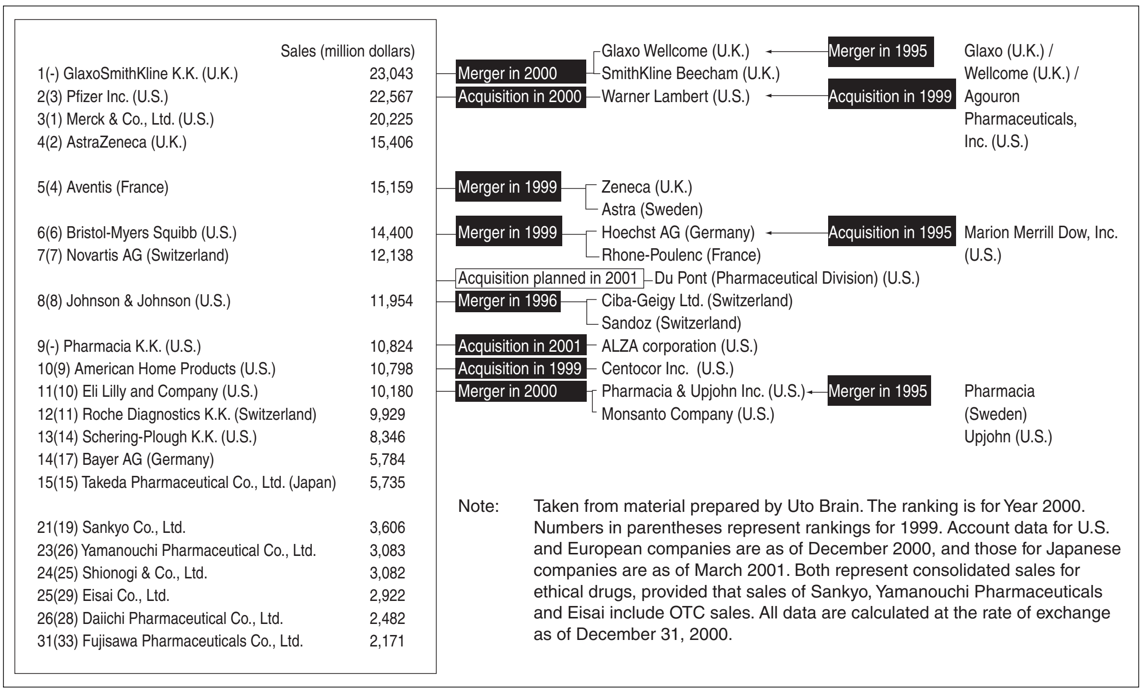


Comparing sales among individual pharmaceutical manufacturers in the world (Figure 6), U.S. and European companies head the list. Takeda Chemical Industries, Ltd. ranks 15th; the highest of the Japanese companies. Of the top 14 companies, seven are from the U.S.; each of these companies has three or four world-class products[6], which allows them to recover R&D expenses and ensures the availability of budget for development for the next generation.

The fact that both the domestic and foreign pharmaceutical industries spend from 10 to 20% of their sales revenue on research and development (Table 3) suggests a close correlation between the amounts of sales and R&D expenses respectively; thus, the level of drug development research could be raised by increasing sales. However, a closer look at life science policies reveals that the U.S. could not have established such a strong drug development capability just by creating megacorporations through mergers in the 1990s (Figure 6)[12,13].

The life science research budget of the U.S. government is divided among the National Institutes of Health (NIH), The National Science Foundation (NSF) and the Department of Energy (DOE). NIH (27 billion dollars per year) is allocated 95% or more of the total life science research budget, of which 80% is provided to other institutions as "NIH grants," "research contracts" and "cooperative agreements." Ninety-percent of these grants are allocated to universities and other non-profit organizations,

Figure 6 : Ranking of major pharmaceutical manufacturers of the world by sales and reorganization of the industry[6]



Source: *Asahi Shimbun* issued on August 5, 2001

Table 3 : Proportion of R&D expenses to sales of major pharmaceutical manufacturers of the world (Year 1999)[6]

Ranking	Company name	R&D expenses (million dollars)	Proportion of sales (%)
1	Pfizer Inc. (U.S.)	4,036	14.7
2	Aventis (France)	3,228	16.4
3	AstraZeneca (U.K.)	2,923	15.8
4	Novartis AG (Switzerland)	2,831	13.1
5	Johnson & Johnson (U.S.)	2,600	9.5
6	Roche Diagnostics K.K. (Switzerland)	2,521	13.7
7	Merck & Co., Ltd. (U.S.)	2,068	6.3
8	Glaxo Wellcome (U.K.)	2,056	14.9
9	Bayer AG (Germany)	2,001	7.8
10	Bristol-Myers Squibb (U.S.)	1,843	9.1
11	Eli Lilly and Company (U.S.)	1,784	17.8
12	American Home Products (U.S.)	1,740	12.8
13	SmithKline Beecham (U.K.)	1,649	12.1
14	Pharmacia & Upjohn Inc. (U.S.)	1,434	19.8
15	Abbott Laboratories (U.S.)	1,194	9.1
16	Schering-Plough K.K. (U.S.)	1,191	13.0
17	Sanofi-Synthelabo Inc. (France)	851	17.0
	Takeda Pharmaceutical Co., Ltd. (Japan)	692	8.4
	Sankyo Co., Ltd. (Japan)	578	10.9

Source: "Pharmaceutical Affairs Handbook 2001" by Jiho, Inc.

which is an exceptionally high proportion of the total R&D budget, of which 46% is allocated to industries and only 34% to universities. NIH recognizes that basic research constitutes a significant area in life science, i.e. the area engaged in the development of pharmaceuticals and therapies. The institute considers that raising the level of basic research in domestic universities and making them introduce pharmaceutical seeds to companies will improve the developmental capacity of domestic pharmaceutical manufacturers[12]. In fact, the NIH research budget has supported 40% (43 out of 107) of the novel active ingredients that have been marketed from 1998 through 2000.

In addition, NIH internally conducts research activities using 15% of its research budget, employing 2,000 researchers with MDs and 2,800 with PhDs in other areas of natural science. This shows that the institutes' policy, which emphasizes basic research, has been conserved since its foundation. The results of the basic research are reflected in the clinical practice of providing the best therapies (and pharmaceuticals) to patients; meanwhile, information gathered through clinical practice is fed back to the basic research. This approach has worked effectively, and NIH has produced 112 Nobel Prize winners (in Medicine and Chemistry) since its foundation in 1935.

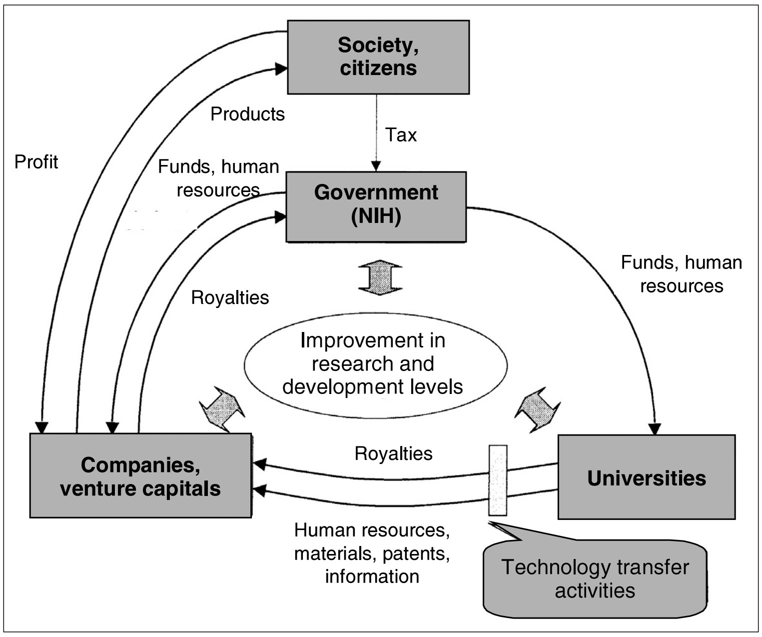
This shows that successful pharmaceutical (drug) development is a product of policies promoting basic research in life science.

In addition, NIH has contributed to technology transfer and the clinical development of new drugs by allocating a budget to technology transfer programs such as the Bayh Dole Act, CRADA (Cooperative Research and Development Agreement) and SBIR/STTR.

The Bayh Dole Act has enabled universities to retain the title to inventions made under NIH (government)-funded research programs. It led to the development of drugs such as Epogen and Procrit, both of which were discovered in Columbia University through NIH-funded research programs and were commercialized by Amgen, Ltd. and Johnson & Johnson, respectively. Each of these products had annual sales of 500 million dollars in 2000.

CRADA is a system involving direct

Figure 7 : Innovation cycle in U.S. life science research[12]



collaboration between NIH and profit-oriented organizations. CRADA grants the partner corporation the option of acquiring an exclusive license to any invention made under the cooperative research. NIH seems to fulfill its missions by supporting research that can return profit to society through commercialization, rather than by acquiring license income. Moreover, the research results achieved under CRADA for clinical development represent high-quality data and can be used when applying for FDA approval. CRADA has contributed to the development of products such as Taxol, Glivec and Endostatin, which are molecular-targeted drugs with excellent efficacy in cancer therapy.

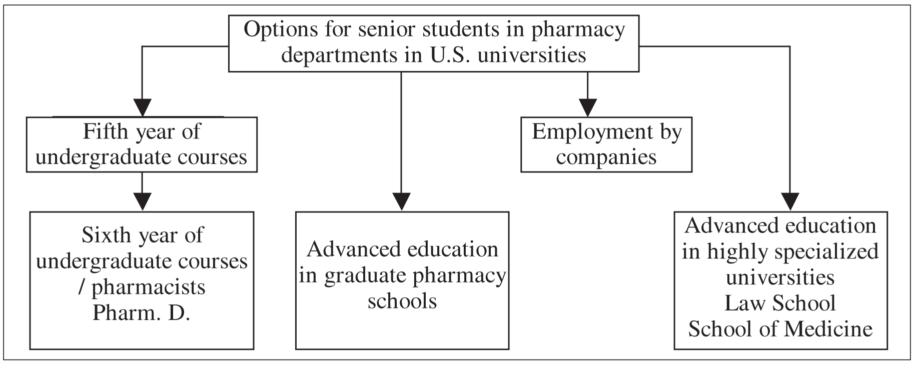
SBIR/STTR support venture capital companies in promoting the discovery of pharmaceutical seeds. Since it takes a long time (from 10 to 17 years) before a seed becomes a product and brings profits, NIH grants are attractive to venture capital companies with limited funding, despite the high competition rate. Moreover, the tough competition for the grants indirectly benefits the winners, e.g. by raising their stock prices.

Together with the research budget, the technology transfer budget of NIH has created an environment in which universities, companies and venture capital companies can participate in drug development (Figure 7)[12].

As can be seen, the flows of funds, human resources and information in the U.S. drug development are different from those in Japan. In Japan, most competitive funds are allocated to universities, and virtually none to drug development in companies. Commercialized drugs developed under government-funded programs are substantially limited to orphan drugs (drugs for intractable diseases with few patients). Companies have individually developed human resources and have managed information concerning drug development, from the discovery of pharmaceutical seeds to their commercialization. Venture capital companies dedicated to pharmaceutical seed discovery have not been nurtured. As can be seen, the drug development environment in Japan is in marked contrast with that in the U.S..

As mentioned above, U.S. universities are supported by the government in launching many pharmaceutical seeds. The success of the system can also be attributed to the educational systems and human resource recruitment in pharmaceutical universities and graduate schools. As explained earlier, the United States basically adopts six-year educational programs for the pharmaceutical universities as in other developed countries, but many universities allow their students the option of graduating in four years to receive a bachelor's degree (BS). As a consequence, many students who have studied for four years in pharmaceutical universities take doctoral courses in other graduate schools

Figure 8 : Career options for senior students in pharmacy departments in U.S. universities



University of Mississippi (1999) as an example

(Figure 8)[14].

This personnel exchange is also seen among teaching staff; since professors from science and technology departments are often employed as faculty members of pharmaceutical departments, and vice versa. Moreover, faculty members are allowed to serve concurrently in both departments. In this environment, they can share academic interests to expand mutual academic areas, dramatically increasing the opportunities for pharmaceutical seed discovery[15].

4 World-class pharmaceuticals developed by Japanese manufacturers

In the global pharmaceutical market, 31 products have annual sales of 2 billion dollars or more; most of them are drugs for chronic diseases including antihyperlipidemic agents (statin agents), antiulcer agents (proton pump inhibitors) and antidepressants (selective serotonin reuptake inhibitors, serotonin and noradrenaline reuptake inhibitors). Among them, three are original Japanese products: the antiulcer agent “lansoprazole” from Takeda Pharmaceutical Co., Ltd., the antihyperlipidemic agent “pravastatin” from Sankyo Co., Ltd. and the therapeutic agent for prostatic hyperplasia “tamsulosin” from Yamanouchi Pharmaceutical Co., Ltd. In addition, seven more Japanese products are listed among products with annual sales of 1 billion dollars or more (Table 4)[7].

So far, the vulnerability of Japanese drug development capability has been emphasized. However, antihyperlipidemic agents, which are original Japanese products, have top global sales by therapeutic category. These products were developed utilizing Japanese fermentation technology, which gained international recognition in 1970-1990s.

These drugs are called statin agents and reduce blood cholesterol levels by inhibiting cholesterol biosynthesis. Their sales have grown in proportion to the spread of lifestyle-related diseases.

The developmental process of these drugs has important clues essential to drug development. It is introduced here as an example for those discussing guidelines for human resource development in the area of drug development[16,17].

Research into statin agents started in the 1960s following a suggestion by Dr. Hamao Umezawa. The discoverer of kanamycin (an antibiotic) suggested that “screening microbial products for enzyme inhibitors should lead to drug discovery.” Numerous microbial products were screened, and in 1973, a substance (compactin) that specifically inhibits HMG-CoA reductase, a rate-determining enzyme in cholesterol biosynthesis, was discovered in a metabolite of *Penicillium citrinum* (green mold found on rice grains produced in Kyoto). However, compactin did not lower blood cholesterol levels in pharmacological in vivo tests using rats, and the research was abandoned for more than two years. Then, another research group, about to slaughter their old experimental chickens, heard about this situation and provided their chickens for an in vivo test. The dramatic effects of compactin observed in the chickens convinced the researchers to continue their research. Moreover, administration of the compound to dogs led

Table 4 : Original Japanese products (for 2001: 1 billion dollars or more)[7]

Manufacturer	Ingredient	Efficacy
Takeda Pharmaceutical Co., Ltd.	lansoprazole	anti-ulcer PPI
Sankyo Co., Ltd.	pravastatin	antihyperlipidemic statin
Yamanouchi Pharmaceutical Co., Ltd.	tamsulosin	prostatic hyperplasia
Takeda Pharmaceutical Co., Ltd.	leuproreline acetate	prostatic cancer, etc.
Daiichi Pharmaceutical Co., Ltd.	levofloxacin	antibiotics
Takeda Pharmaceutical Co., Ltd.	pioglitazone	type II diabetes
Taisho Pharmaceutical Co., Ltd.	clarithromycin	antibiotics
Takeda Pharmaceutical Co., Ltd.	candesartan	antihypertensive AIIRB
Eisai Co., Ltd.	rabeprazole	anti-ulcer PPI
Eisai Co., Ltd.	donepezil	Alzheimer's disease

Figure 9 : Key points in the development of pravastatin (therapeutic agent for hypercholesterolemia)

1)	Discovery of the active substance	⇒	Discovery of compactin, an HMG-CoA reductase inhibitor
2)	*In vivo* pharmacological evaluation	⇒	No effect observed in rats, efficacy observed in chickens
3)	Resolution of drug kinetics	⇒	Discovery of a highly active, low toxicity substance from the urine of compactin-administered dogs
4)	Establishment of a large-scale synthetic method	⇒	Establishment of a two-step fermentation method
5)	Safety and toxicity evaluations	⇒	Toxicity assessment of compactin, safety assessment of pravastatin

to the discovery of another substance-inhibiting cholesterol biosynthesis from their urine. This substance, which was more effective and less toxic than compactin, was later approved as a product (pravastatin). For commercial production, a two-step fermentation method has been adopted, where compactin produced by *P. citrinum* is converted into pravastatin by an Australian soil actynomycetes, *Streptomyces carbophilius*.

The development of pravastatin was essential in arteriosclerosis research. Using the pravastatin precursor, compactin, Goldstein and Brown revealed the regulation mechanism of cholesterol metabolism and won the Nobel Prize for Medicine in 1985.

The success of pravastatin development can be attributed to the organic linkage of each stage listed in the previous page (Figure 9).

Interestingly, a British pharmaceutical manufacturer (Beecham Group, Plc.) isolated compactin from *P. brevicompactum* around the same time as Sankyo Group, but could find only weak antifungal activity. This is a good example of the big difference between the discovery of a new compound and the development of a new drug.

5 Pharmaceuticals developed through university research

In the guidance brochure "For students who start to study pharmaceutical sciences," The Pharmaceutical Society of Japan claims that pharmaceutical science is an academic area based on chemistry, biology and physics and that its mission is to contribute to "drug-development chemistry," "clinical pharmacy," "hygienic pharmacy" and "life science"[18].

Despite this consensus, "drug development (chemistry)" has been left to pharmaceutical manufacturers, while pharmaceutical chemistry taught in universities has mainly focused on teaching organic chemistry to develop novel synthetic methods. Thus, compared to the U.S., only few pharmaceutical seeds have been discovered in Japanese university laboratories. However, since the foundation of this area, Japanese researchers have conducted extensive research on the active ingredients of medicinal plants or crude drugs. This research has contributed to the development of certain products, two of which are introduced as

Figure 10 : Structural formulas of camptothecin and irinotecan

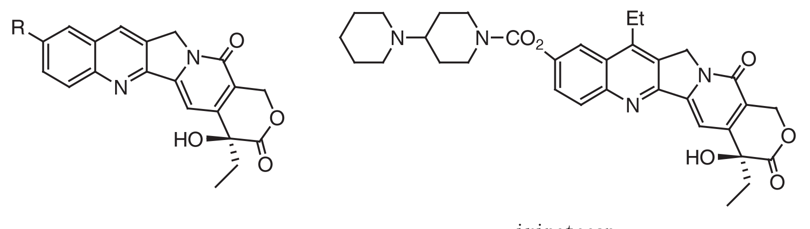
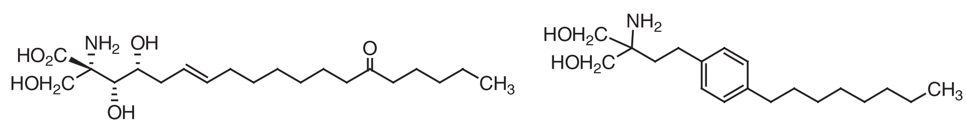


Figure 11 : Structural analogy between myriocin and FTY720



examples.

The first example is irinotecan, a typical university-launched drug that has been approved in more than 100 countries. This anticancer drug was developed through joint research between Tadashi Miyasaka, a professor emeritus at Showa University, and a company (Yakult Honsha Co., Ltd.) and has annual sales of 900 million dollars (2003)[19].

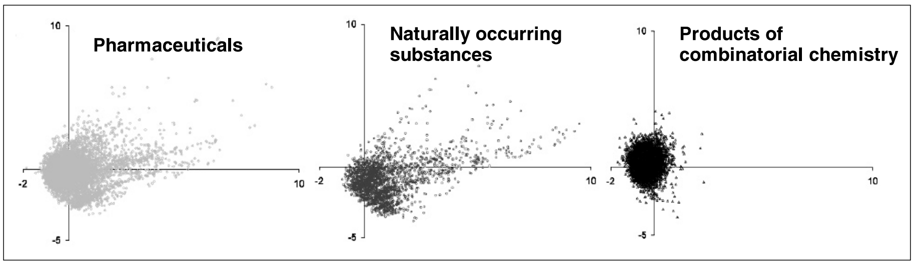
Irinotecan was produced through the chemical modification of a substance called camptothecin, which had been isolated from the Chinese tree *Camptotheca acuminata*. Camptothecin inhibits the propagation of experimentally transplanted tumors, but its use as a medicine was once abandoned due to its severe side effects including myelosuppression and hemorrhagic cystitis. Miyasaka focused on a trace component (Figure 10, the compound shown on the left in which R = OH) isolated from the same plant, which was structurally similar to camptothecin but had lower toxicity, and produced many derivatives of this naturally occurring substance. After individually assessing their antitumor activities, he finally reached irinotecan, which had few side effects, sufficient solubility in water for intravenous administration and a long half-life time in plasma (Figure 10). Later, it was found out that irinotecan is a completely new type of drug that acts by inhibiting DNA topoisomerase I. In 1994, the substance was approved as a drug for lung, ovarian and cervical cancers and was released by Yakult Honsha Co., Ltd., which mainly cooperated in evaluating the drug efficacy. In 1995, it received approval for additional indications including stomach, colon and rectal cancers and recurrent breast cancer. Today, this drug is the first choice for treating rectal cancer in the U.S. and European countries.

Another example is an investigational drug named FTY720, which is an immunosuppressant developed by Tetsuro Fujita, a professor emeritus at Kyoto University. The drug was developed from myriocin, which had been isolated from Chinese caterpillar fungus which is traditionally used in Chinese medicine[20].

In studying the components of *Trichoderma polysporum* that damage shiitake mushrooms, Fujita noticed that this fungus had the same name as that of a fungus producing the immunosuppressant, cyclosporin A*3. He also found out that a peptide analogue he had isolated from this fungus had been reported as a component of Chinese caterpillar fungus, so he examined the components of Chinese caterpillar fungus and discovered myriocin. As well as assessing the immunosuppressive activity, he worked with researchers of Taito Co., Ltd. and Yoshitomi Pharmaceutical Industries, Ltd. (the current Mitsubishi Pharma Corp.) to simplify its chemical structure, and he synthesized FTY720 (Figure 11).

Using FTY720 as an immunosuppressant in organ transplantation is currently being studied overseas by Novartis Pharma Co., Ltd. The drug is also expected to serve as an investigational drug

Figure 12 : Comparison of physical property distributions among pharmaceuticals, naturally occurring substances and products of combinatorial chemistry[22, 23]



to treat autoimmune diseases.

These examples suggest that, of original Japanese pharmaceuticals, those accepted internationally have been developed from seeds discovered in areas such as fermentation technology, natural products chemistry and organic synthesis, which are specialties of Japan[21]. This suggestion is supported by the following data. In the past decade or so, drugs have been developed through combinatorial chemistry; however, a recent report shows that naturally occurring substances have physical property distributions similar to those of pharmaceuticals, while products of combinatorial chemistry are less diverse and have physical property distributions dissimilar to those of pharmaceuticals (Figure 12)[22].

6 The necessity of establishing a new educational system for fostering human resources in the drug development area (Suggestion)

So far, this article has reviewed the technological status of drug development in Japan and the fostering of human resources who would be engaged in this area[24]. By 2010, the number of domestic pharmaceutical manufacturers will decrease to between 3 and 5 companies. Japan's current level of drug-development technology does not match that in U.S. and European countries, so Japan must open to meet global standards in the pharmaceutical industry.

Meanwhile, Japan has ten original products with annual global sales of 1 billion dollars (Table 4). There are some university-launched products that have been accepted internationally. This suggests that, although currently vulnerable, Japan's drug-development technology has the potential to improvement[25]. Although there are certain other unsolved issues such as the reforming of public consciousness towards clinical trials, it is urgently necessary to take advantage of the implementation of six-year programs for pharmaceutical education in 2006 to establish a new educational environment focusing on the fostering of drug development professionals.

To date, there are about 18,000 researchers working for pharmaceutical manufacturers (announced by Ministry of Health, Labor and Welfare)[5], which is about half that in the U.S. on a population basis. Assuming that the average working life of a researcher is about 20 years (ages 25 through 45), we must educate an average of at least 900 researchers per year in the drug development area. This means that we would need at least 1,500 new researchers per year to match the U.S.

According to the pharmaceutical manufacturers, Japan is currently lacking those who "can synthesize organic compounds," "can handle (not only microorganisms and cells but also) animals" and "are strong in biostatistics." The first two categories are accompanied by "dirty, dangerous and demanding" jobs, which should be avoided by young people. In addition, pharmaceutical graduates prefer work at hospitals and pharmacies to work involving drug development. Consequently, pharmaceutical manufacturers recruit students from life science departments, providing biotechnology-oriented education, but these departments do not provide sufficient lectures or training sessions on "organic synthesis" and "animal handling" in their curricula. Thus, these departments cannot educate the human resources truly required by pharmaceutical manufacturers.

As intellectual property, pharmaceutical products are protected by four types of patent, i.e. "substance patent", "process patent", "usage patent" and "formulation patent". Thus, drug development exploits novel substances (compounds), manufacturing processes (synthetic processes), usage (pharmacological effects/efficacy) and preparations (formulations). To be approved as pharmaceuticals, their safety must be confirmed through non-clinical and clinical studies. From these aspects, establishing a completely new system (departments) is suggested for intensive education in the following five subjects:

(1) Chemical and biological foundations for developing novel pharmaceutical seeds (compounds)
(2) Chemical and biological methods for manufacturing novel pharmaceuticals
(3) Pharmacology for discovering novel effects and the efficacy of pharmaceuticals
(4) Pharmaceutics and pharmacokinetics for exploring novel DDSs (drug delivery systems) suitable for individual drugs
(5) Toxicology for assessing safety and toxicity

Here, the "new system" does not refer to the "four plus two"-year courses that will be established in many universities based on their existing curricula; instead, it refers to an educational/research environment capable of providing human resources, patents and information directly to the pharmaceutical industry.

The first two subjects in the above list would foster those who "can synthesize organic compounds," and the latter three would foster those who "can handle animals" and "are strong in biostatistics." Furthermore, growing expectations of genome analysis outcomes forecast the protection of "the usage of genome-based pharmaceuticals" as intellectual property. Considering this future trend, we should also add bioinformatics to the above list as well as conventional molecular biology. Bioinformatics is essential to all the subjects in the list, but Japan lags behind other countries in this area.

7 Conclusions

Pharmaceuticals are life science-based products with the highest added value. From research, and development through manufacturing and marketing, they are produced under strict regulations including GLP (Good Laboratory Practice), GCP (Good Clinical Practice), GMP (Good Manufacturing Practice) and GPMSP (Good Post-Marketing Surveillance Practice). They require higher R&D expenses and longer R&D periods compared to those for products of other industries. Therefore, the equation that "drug development technology = search for novel bioactive substances + biotechnology" is insufficient for developing excellent drugs.

The University of Tokyo, Kyoto University and Kitasato University have established a program for educating experts in clinical trials, which are required for commercializing pharmaceuticals (Nihon Keizai Shimbun issued on December 6, 2004). The program is expected to improve the level and efficiency of clinical trials as well as the level of evaluating new drugs for approval. If we can take advantage of this program to improve the environment surrounding the drug development process, from pharmaceutical seed discovery through investigational drug development, Japan could achieve a remarkable breakthrough in its drug development technology and develop world-class pharmaceuticals. After the introduction of the six-year programs in April 2006, pharmaceutical education, which has fostered both "pharmaceutical manufacturer personnel" and "pharmacists," will lose its balance and greatly lean towards "pharmacist education." This will make fostering drug development professionals even more difficult.

Therefore, we should leave the education of pharmacists as medical workers to pharmaceutical universities shifting into the six-year program, and establish a completely new educational system (university departments etc.) that can directly provide human resources, seeds and information to the pharmaceutical industry to protect Japan's "drug development technology as intellectual property" and "health in an aging society."

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Notes

*1 In the first twelve years from 2006, those who have finished "four (undergraduate) plus two (graduate)"-year educational programs in pharmaceutical universities and have further taken clinical pharmacy courses and practical training at hospitals or pharmacies, which are required for graduating from six-year courses, will be qualified to take the National Examination for Pharmacists. Thereafter, however, those who have finished the "four (undergraduate) plus two (graduate)"-year educational programs will not be qualified to take the National Examination. In other words, special exemptions would apply to those who have finished the two-year courses in graduate schools in the first twelve years from 2006.

*2 The expression "negative opinions" may be misleading, but since the government has legislated "the qualifying of pharmacists = six-year education in pharmaceutical science departments = improved quality of pharmacists," "human resource development in the drug development area" should be clearly separated from "the licensing of pharmacists." Many authorities concerned claim that "four-year educational programs are necessary for providing diverse career options for graduates from pharmacy colleges," but these halfway measures discussed in *1 will not lead to "successful human resource development in the drug development area." Refer to lines 5-7 on p.144 and lines 2-7 on p.145 in the above reference[10].

*3 It was later found that the fungus belonged to *Tolypocladium inflatum*.

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(Original Japanese version: published in January 2005)

2

Trends in Food Allergy Research

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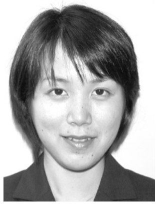
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Junko Shimada *(Life Science and Medical Research Unit)**
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Koko Mizumachi *(Affiliated Fellow)****

1 Introduction

The incidence of allergic diseases such as food allergy, atopic dermatitis, bronchial asthma and cedar pollenosis continues to increase, mainly in developed countries, and has grown into a serious problem worldwide. In particular, food allergy, often developed during infancy, can affect a child's growth or trigger an “allergic march,” i.e., the progressive development of various allergies. Consequently, early prevention and treatment are recommended for food allergy.

The incidence of food allergy continues to increase year by year. In 1997, a questionnaire survey conducted by the Ministry of Health and Welfare (currently Ministry of Health, Labour and Welfare) revealed a high incidence of food allergy not only among children (8.6% among children aged 3) but also among adults (9.3%) (Food Allergy Study Group Report for 1997, 1998). Conventionally, food allergy developed during childhood has been the major concern, but an increasing number of adults are developing allergies to seafood and fruit, and cross-reactivity (i.e., reactivity against structurally common antigens) with cedar pollen is suggested. Thus, we should urgently study and understand food allergy and find fundamental solutions.

The second Science and Technology Basic Plan (approved at the Cabinet meeting on March 30, 2001) depicts the “realization of a nation securing a comfortable, safe and high quality of life” as one of the three “pictures of the nation and of the science and technology policy to be attained.” Research and development of food products that are effective against food allergy can contribute to realizing such a nation and should therefore be promoted.

The development of allergic diseases seems to involve complex interactions between genetic factors and diet and other environmental factors. We must consider the genetic diversity of the human race when conducting research and development in this area.

This article summarizes the status and mechanism of food allergy and presents trends in research on hypoallergenic and immunosuppressive food products.

2 Food allergy

2-1 What is food allergy?

Food allergy is an exaggerated immune response induced by the misrecognition of orally ingested food as a foreign substance. It is a hypersensitive reaction that damages the self, with symptoms that can include diarrhea, abdominal pain, hives and eczema. Severe cases of food allergy can induce anaphylactic shock[*1], which may lead to death. People show allergies to different kinds of food and experience different symptoms depending on their physical condition. Moreover, food allergy can also be induced through cross-reaction[*2]. Complex interactions between the body and allergens (substances causing allergy) result in a variety of responses and symptoms, making the prophylaxis and

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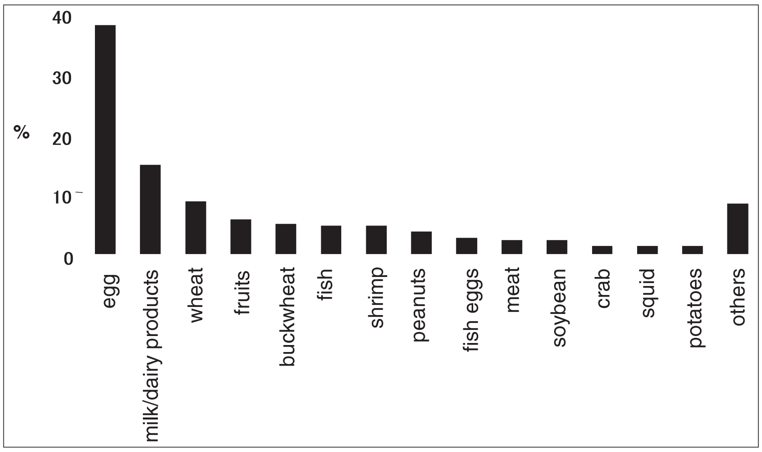
Figure 1 : Foods that can cause allergy



Based on a survey conducted in 2001 on 2,434 subjects who visited medical institutions for symptoms developed within 60 minutes after food ingestion.
Source: Reference[4].

treatment of food allergy difficult.

The development of food allergy involves both genetic and environmental factors. Genes involved in the immune system show genetic diversity, and a high degree of genetic polymorphism, which is responsible for our individual constitutions, is found between Japanese people and Western people[1-3]. Infectious disease history during childhood, exposure to environmental pollutants, antigen levels and diet are possible environmental factors related to allergy. In addition, the hygiene hypothesis*3 suggests that the increase in allergic diseases can be attributed to the decreased incidence of infections during childhood due to improvements in living standards and public health.

2-2 Food allergens

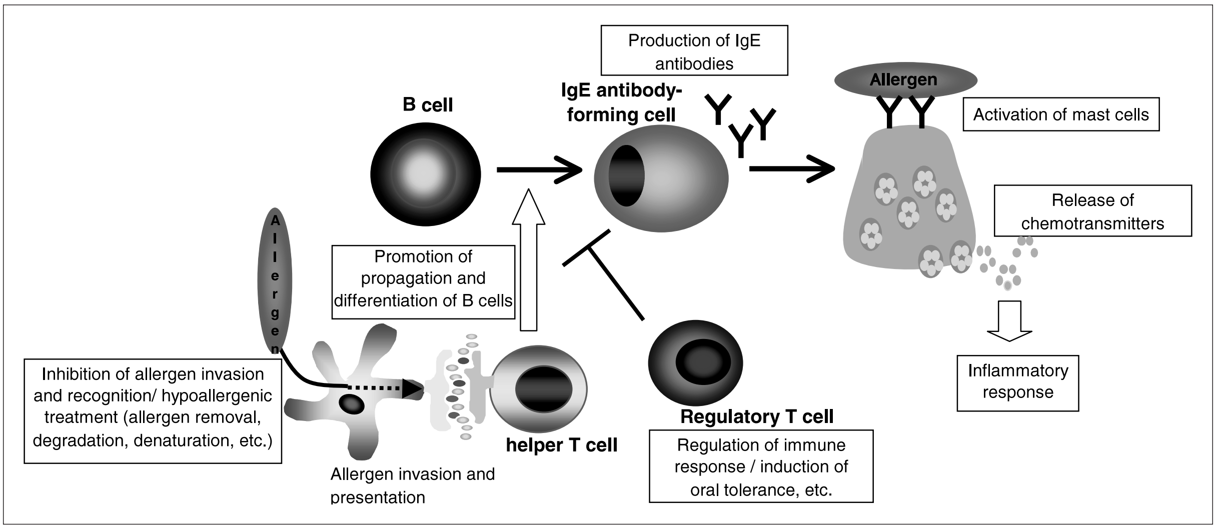
Food allergy is caused by various foods including eggs, milk, wheat, beans, buckwheat, fruit, seafood and meat (Figure 1)[4]. The kinds of food causing allergy vary by age; eggs and milk are the most common allergens among infants, but most overcome these allergies as they grow up. Meanwhile, food allergies in adults are mainly caused by seafood or fruit.

To prevent exposing people allergic to specific food allergens to health risks, labeling has become mandatory for food products containing such allergens. The food labeling system came into force in April 2002, based on the Food Sanitation Law revised in April 2001 in response to "A report on the discussion concerning the food labeling system (1998)." According to the incidence and severity of allergies, foods are categorized into two groups; labeling is compulsory for the first group of five foods (eggs, milk, wheat, buckwheat and peanuts) and encouraged for the second group of nineteen other foods (abalone, salmon roe, prawn, oranges, crab, kiwifruit, beef, walnuts, salmon, mackerel, soybeans, chicken, pork, matsutake mushrooms, peach, yam, apple and gelatin). A report suggesting the addition of bananas to the second group was submitted in July 2004. Despite the establishment of this compulsory labeling system, allergen contamination during manufacturing and accidents due to oversight caused by confusing labels have been reported. Thus, it is essential to popularize the system, improve the distribution channels that provide the necessary information to the people who need it, and develop techniques for detecting contamination with allergens.

2-3 History of food allergy research

Food allergy has been recognized since pre-Christian times; Lucretius of Greece once said, "One man's food might be another man's poison." In the 18th and 19th centuries, wheat asthma and hay fever (a kind of pollenosis) were recognized among bakers. In the early 20th century, Pirquet proposed the concept of allergy (defined as "a temporarily, quantitatively and qualitatively altered capacity of the body to react

Figure 2 : Immune mechanism underlying immediate allergy



to external antigens"), a rather broad definition covering the entire immune response. The current definition of allergy is much narrower: "a disease mediated by the immune response induced by an otherwise harmless antigen."

In Japan, the Japanese Society of Allergology was established in 1952 and started research on the diagnosis and treatment of food allergy.

2-4 Mechanism of the immune response

The food we eat is digested and absorbed by our stomachs and intestines. Food contains an enormous variety of foreign proteins, which are foreign substances (i.e., not "self") to our bodies, but usually, inappropriate immune reactions are suppressed by the gastrointestinal immune system or the mucosal immune system in the gut. The failure of this system can result in allergic reactions.

(1) Mechanism of allergy development

Most cases of food allergy are the 'immediate' type in which symptoms develop within 2 hours after the causal food has been ingested. Food allergens absorbed through the digestive tract induce immediate reactions in the alimentary canal mucosa, since this is where they make direct contact with the body. This leads to cardinal symptoms such as vomiting, abdominal pain and diarrhea. In addition, the allergens absorbed through the digestive tract are systemically delivered via the blood vessels to induce symptoms such as rhinitis in the respiratory tract or symptoms such as hives and angioedema on the skin. They also seem to be involved with the development of atopic dermatitis or anaphylactic shock, which is accompanied by systemic symptoms such as breathing difficulty and decrease in blood pressure, and damages various organs.

Such symptoms are the result of the inflammatory response induced by the reaction between the allergens and immunocompetent cells. Allergens ingested and absorbed by the body are taken up by the antigen-presenting cells, which are then recognized by T-cells. The T-cells activate the B-cells and convert them into the IgE antibody-forming cells that produce the IgE antibodies that bind to the mast cells. Allergenic stimulation induces degranulation, i.e., the release of chemotransmitters such as leukotriene and histamine from the mast cells, and these chemotransmitters trigger an inflammatory response, inducing the allergic reaction.

Healthy individuals are equipped with certain mechanisms that suppress the inflammatory response. For example, the Th1/Th2 balance (balance between two types of T-cells, Th1 and Th2) is adequately maintained in healthy individuals to suppress IgE antibody production; however, in patients with food allergy, the Th1/Th2 balance shifts toward Th2-dominant immunity, allowing IgE antibody to proceed out of control.

(2) Oral tolerance

Food contains a vast range of foreign proteins, which are foreign substances (i.e., not "self") to our bodies. The antigenic regions of proteins are mostly degraded by digestive enzymes during food digestion, but a small proportion may be absorbed by the body without losing antigenicity. Nevertheless, our bodies do not produce excessive immune responses against the orally ingested, digested and absorbed food antigens. This phenomenon is called oral tolerance[5,6].

People have made practical use of oral tolerance from time immemorial. Japanese lacquer craftsmen eat the lacquer to prevent lacquer poisoning. In experiments using mice or guinea pigs, the oral administration of an antigen before the subcutaneous or intraperitoneal injection of the same antigen can suppress immunoglobulin production and anaphylactic shock.

Oral tolerance is an excellent system for obtaining the required nutrients without inducing an excessive immune response against food antigens that are otherwise foreign substances to our bodies. In patients with food allergy, this system may fail to function properly for a number of reasons. Therefore, it is necessary to understand the mechanism of oral tolerance and find an effective approach for inducing the phenomenon. However, a complete understanding of the mechanism has been hindered because of the variety of contents in our digestive tracts, i.e., various microbes and miscellaneous antigens derived from food and other things, as well as the variety of immunocompetent cells involved in oral tolerance.

(3) Mucosal immunity in the gut

The digestive tract forms “an exterior environment within the body”; it is continuously exposed to large quantities of foreign substances such as food and microbes via the mucosa. It can be considered to be a huge immune organ that acts in the front line of the biological defense system. In adults, the total area of the intestinal mucosa is 300-400 m2 (1.5 times larger than a tennis court), and the intestines hold a total population of more than 1014 microbes (about 1kg). The microbial composition can change depending on factors such as race, food habits, age, physiological/pathological status, stress and drug use. The microflora in the intestine (gut microflora) are significantly affected by the host's nutritional status, physiological functions, age, carcinogenesis, immune system, infection history, etc. It is also reported that gut microflora differ between children with and without allergy.

The digestive tract distinguishes useful substances, e.g., food or microbes that normally inhabit the intestine, from harmful substances, e.g., pathogenic microbes. Based on this distinction, it prevents invasion by, or eliminates antigens harmful to the body and promotes absorption of the required nutrition.

In patients with food allergy, the digestive tract cannot distinguish between useful and unwanted substances properly. Some food ingredients or microbes have been reported to enhance the making of proper distinctions, but further research is required to understand the detailed mechanism and to specify effective food ingredients and microbes.

3 Trends in research and development for overcoming food allergy

The development of food allergy could be prevented by blocking any of the steps in the allergic reaction sequence, from allergen absorption to inflammatory reaction. For example, food allergy can be prevented by blocking allergen invasion/recognition, T-cell activation, binding of allergens with IgE antibodies or release of chemotransmitters.

The first step towards conquering food allergy is understanding the mechanism of the immune response and finding ways to block the allergic reaction induced by the allergens that have entered the body. Meanwhile, to prevent allergens from entering the body, research has been conducted on removing or reducing allergens in food products. Furthermore, the use of food to enhance the immunoregulatory function inherent in the body has also been studied.

Of the various research efforts aimed at overcoming food allergy, this chapter describes the food-oriented approach, starting from research and development on hypoallergenic food developed by breaking the antigenic structures in food. Hypoallergenic food products have been developed to prevent allergic reactions by blocking the incorporation of allergens into the body. Thus, research related to anti-allergic food, which prevents or suppresses food allergy, is introduced from the viewpoints of immunoregulation and immunosuppression.

3-1 Trends in research and development of hypoallergenic food

Currently, food allergy is mainly treated symptomatically through medication and removal of the causal food. However, the elimination of allergen-containing food from the diet of growing infants is undesirable, as it may lead to nutritional deficiency or developmental disturbance. The development of hypoallergenic food through the degradation or denaturation of allergens is essential to prevent nutritional disorders or growth disturbance and to maintain a rich and varied diet. Therefore, it is required that hypoallergenic food is nutritionally identical to normal food and shows minimum allergenic activity.

(1) Hypoallergenic food developed to date

To date, several methods for reducing allergens in crops or food products have been developed and applied to commercial products. One such example is “Fine Rice,” which has been developed through joint research between Shiseido, the Faculty of Agriculture of The University of Tokyo and the School of Medicine of Yokohama City University, and was commercialized in 1991. Fine Rice has been produced through the protease treatment of rice, which has led to the decomposition of globulin, an allergenic protein. The product was approved by the Ministry of Health and Welfare as the first “food for specified health uses” in June 1993 and as “food for medical purpose” in June 1997.

Another example of hypoallergenic rice is that developed by Mitsui Toatsu Chemicals, Inc. (currently Mitsui Chemicals, Inc.) and the National Institute for Agro-Environmental Sciences, in which the expression of allergenic proteins has been suppressed by genetic engineering. This hypoallergenic rice reached the stage of open-field cultivation by 1995 but has still not been commercialized.

The development of hypoallergenic crops has also been attempted by screening a variety of mutants produced through radiation mutagenesis for one lacking allergen-encoding genes. The National Agricultural Research Center for Tohoku Region has developed a hypoallergenic soybean variety named “Yumeminori” lacking two of the three major allergens found in soybeans.

Nevertheless, the above-mentioned methods for developing hypoallergenic food have their individual limits; each protease can digest only a limited number of allergens, and the use of proteases with wide substrate specificities could lead to decreased nutritional value due to the loss of useful proteins or reduction of the product value due to rice grain damage. The genetic engineering-based approach cannot be applied to crops containing several allergens because it requires individual engineering of the genes corresponding to each allergen. The radiation mutagenesis-based approach also has its limits; the chance of damaging allergen-encoding genes is low, and evaluation can only be performed on known allergens.

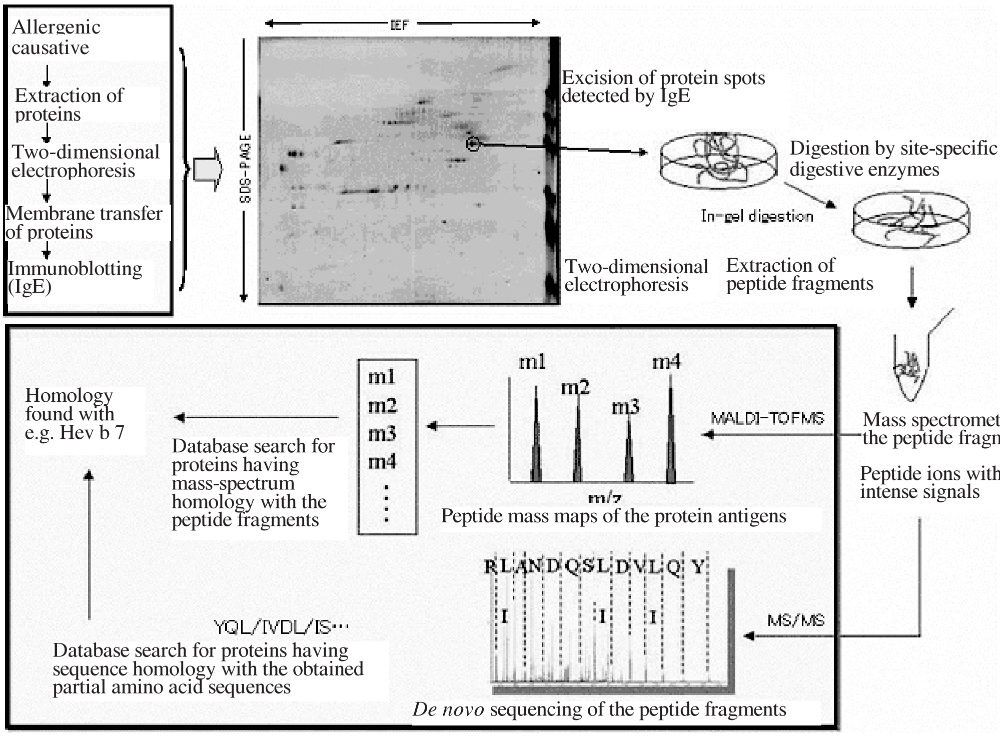
(2) Allergen studies based on proteome*4 analysis

There have also been attempts to develop hypoallergenic food by breaking the chemical structures commonly found among allergenic foods. For example, Buchanan et al. (University of California) reduced the allergenicity of the major allergen in cereals or milk by modifying the structures of the allergy-inducing domains in the allergen using thioredoxin, a reductase that mediates the cleavage of disulfide bonds[7]. Moreover, disulfide bonds in allergen proteins in barley seeds were broken in genetically modified barley plants that express thioredoxin in their storage organs (edible parts)[8]. Thioredoxin is widely distributed among various organisms, so its application to food should involve little risk to health. The enzyme should serve as an important tool for developing hypoallergenic food.

Several allergens can be reduced at once by breaking the structures they share in common that cause allergy. To expand the application of this approach to other allergens, structures

Figure 3 : Allergen studies based on proteome analysis approach

(i) Proteins are extracted from an allergen (food etc.).
(ii) Proteins are separated with two-dimensional electrophoresis and subsequently transferred onto a membrane.
(iii) Proteins are reacted with pooled serum from allergy patients. Protein antigens specifically interacting with IgE antibodies are detected.
(iv) IgE-binding proteins are subjected to mass spectrometry and amino acid sequence analysis.
(v) A database search is performed to identify the proteins.



Source: Reprinted from reference[9] with permission

common to other allergens must be identified, and methods for their safe destruction must be established. As a consequence, proteome analysis has been adopted for the comprehensive detection of allergens.

This approach can detect allergens by comprehensively analyzing the proteins that react with the antibodies found in the serum of patients with allergy. Figure 3 shows an example of this approach.

This method is potentially applicable to the screening of allergens, including food and house dust, and its future looks promising. Structural analysis of the detected allergens and identification of their common molecular structures should contribute to the development of hypoallergenic food. Such structures can be detected efficiently by performing structural analysis on a large number of allergens and establishing a searchable database.

3-2 Trends in research and development of anti-allergic food

In addition to the development of hypoallergenic food, the use of food to achieve immunoregulation and immunosuppression has been studied. Anti-allergic food prevents or controls food allergy by inducing oral tolerance or utilizing gut immunity and anti-allergic food components.

(1) Anti-allergic food based on oral tolerance induction

Oral tolerance is a phenomenon in which proteins in orally ingested food do not induce excessive immune responses, despite the fact that food has a vast amount of antigenic substances containing foreign proteins. Food allergy is induced when a specific allergen is orally ingested and absorbed by the body via the digestive tract. Japanese lacquer craftsmen eat lacquer to prevent lacquer poisoning, but eating the causal food does not prevent food allergy. To apply oral tolerance to preventing food allergy, the causal food must be processed in a certain way before being ingested.

It has been reported that oral tolerance to a certain antigen is induced by the protein itself or by a peptide of the protein. In other words, it may be possible to suppress an allergic reaction by inducing oral tolerance using a peptide that reacts with the T-cell but does not bind to the IgE antibody involved in the allergic reaction.

In mice, this method has successfully induced oral tolerance to milk or egg allergens[6,10].

Although many steps remain before this technique can be applied to human beings, such as determining the appropriate peptides and their optimum doses, these peptides potentially serve as allergy-preventive food that also provides antigen-specific immunotherapy.

(2) Anti-allergic food based on mucosal immunity in the gut

Probiotics are defined as living microbes that improve the microflora in the intestine (gut microflora) and are beneficial to the host, or as food containing such microbes. Microbes such as lactic bacteria in cheese, yogurt and other fermented dairy products improve the storage quality and taste of milk and its nutritional value through proteolysis, lactose degradation and vitamin synthesis. They also improve the gut microflora and have other health effects such as intestinal regulation, normotension and immunostimulation. Moreover, substances such as oligosaccharides enhance the propagation of probiotics.

Recently, probiotics have attracted attention for their effect of enhancing the immunoregulatory function of the digestive tract and suppressing or ameliorating allergic symptoms. There is a difference in gut microflora between people with and without allergy, and smaller numbers of lactobacillus, a kind of lactic bacteria, have been found in the former compared to the latter group. This report has triggered a series of research projects on probiotics including lactic bacteria and the development of probiotic-based products with anti-allergic effects. The consumption of a lactic bacterium called lactobacillus CG by pregnant women and their babies reduced the incidence of atopic dermatitis among these infants at the age of two[12]. In addition, various lactic bacteria and bifidus bacteria have been confirmed to exert anti-allergic actions such as reducing IgE antibodies in mice and humans. Scientific demonstration of the anti-allergic actions of probiotics has enhanced the development of probiotic-related products.

These microbes potentially inhibit the development of allergy through their active interaction with the body. However, their effects are strain-specific, and their mechanisms are poorly understood. Their application requires further research, including evaluation of their safety.

(3) Use of anti-allergic components

One way to prevent the development of food allergy is to suppress the production or action of chemotransmitters such as histamine and leukotriene that trigger the inflammatory response in the allergic reaction sequence. The production or action of chemotransmitters is called anti-allergic action. While hypoallergenic food involves antigen-specific suppression, anti-allergic action works in a non-specific manner, suppressing allergic reactions independent of the allergen type.

Many food components are known to have anti-allergic actions. For example, highly unsaturated fatty acids such as eicosapentaenoic acid and docosahexaenoic acid, which are abundant in fish, suppress leukotriene production, and tea polyphenol suppresses histamine and leukotriene release. Anti-allergic actions have also been reported in tea catechin and caffeine. Additional anti-allergic components have been identified in various foods, including flavonoids, sesamin and perilla leaf extract.

Anti-allergic activity levels differ among the above-mentioned food components and also according to the variety of crop and when they are harvested. For instance, methylated catechin is a tea component showing a strong anti-allergic action, but its content differs among tea varieties (oolong tea, black tea or green tea); little is found in the green tea variety, "Yabukita," but it is abundant in dong-ding oolong and "Benifuuki," a variety developed for black tea. Moreover, the catechin content changes according to the timing of the harvest or during tea processing. Meanwhile, the anti-allergic activity is substantially the same in the leaf extracts of green and red perilla.

Some anti-allergic components are known to act synergistically with others; for example, the combination of sesamin contained in sesame, and-tocopherol, a Vitamin E contained in vegetable oils and fats, exerts a strong anti-allergic effect.

To make effective use of the anti-allergic actions of food consumed daily, there must be further discussion of ways to achieve adequate intake and the synergistic actions of different food components, based on the facts that anti-allergic activities differ according to the variety of crop and when it is harvested, and that the level of active components can be altered by food processing.

4 Conclusions

This article has introduced research and development in hypoallergenic food and the use of food to prevent and control allergy.

Hypoallergenic food is essential for those who have already developed food allergy, from the standpoint of preventing the development of allergic reactions and improving their diet. It also eliminates the risk of nutritional disorders caused by the long-term elimination of food during childhood. Nevertheless, further research is required for developing hypoallergenic food effective against various allergens while maintaining taste and nutritional value.

As for research on food that prevents and controls allergy, the mechanism for oral tolerance induction and interactions between gut microflora and other food antigens in the digestive tract remains to be understood. There are great expectations for such food, as it can directly interact with the body to suppress allergic reactions.

The development of allergic diseases involves complex interactions between genetic factors and diet and other environmental factors. The genes involved in the immune system show significant genetic diversity. A high degree of genetic polymorphism, which is responsible for our individual constitutions (SNP = single nucleotide polymorphism), can be found between Japanese people and non-Japanese people. Thus, it is essential to consider the genotypes and diets of the Japanese for developing anti-allergic food effective in preventing or treating allergy.

Future tasks in food allergy research include characterizing food allergens, establishing allergenicity evaluation systems, understanding the mechanism of food allergy development, and confirming the relationship between food allergy and environmental factors. While these tasks are certainly important, it is even more important to establish a system for assessing the efficacy and safety of newly developed food products that are effective against food allergy. Moreover, it is important to find appropriate ways to apply the knowledge gained, to improve the lives of patients with food allergy.

Pharmaceutical products have evaluation systems for assessing their efficacy and safety prior to approving them as pharmaceuticals. However, food products effective against food allergy are not regarded as pharmaceutical products, so they lack equivalent systems. Allergenic foods that are harmless and beneficial to healthy individuals may be harmful or lethal to certain other individuals, which makes evaluation difficult and hinders the establishment of evaluation systems. Some animal models have been suggested, but symptoms are not developed clearly enough to validate their use. However, even if efficacy and safety could be assessed in mice or other experimental animals, the model could not be directly applied to human beings. Thus, it is important to establish a system for evaluating efficacy and safety in humans.

Future progress in research and development requires not only setting individual research tasks but also discussing the evaluation of the efficacy and safety of anti-allergic foods and their application to allergic diseases. Therefore, cooperation with the medical profession is essential for the research and development of food products.

Glossary

*1 Anaphylactic shock

An uncontrollable allergic reaction that occurs after exposure to a causal allergen. It is associated with acute, systemic, serious, sometimes life-threatening symptoms such as convulsions, breathing difficulty and decrease in blood pressure.

*2 A cross-reaction

A reaction between an antigen and an antibody raised against a different but structurally similar antigen. For example, a person who is allergic to chicken eggs may also develop allergic symptoms when exposed to other avian eggs.

*3 Hygiene hypothesis

A hypothesis proposed in 1989 by Strachan. It was based on a 23-year follow-up survey conducted on 17,414 English subjects for the retention ratios of allergic diseases, the number of family members and the number of siblings. Subjects with more siblings had lower retention ratios of bronchial asthma and eczema, and subjects with later birth orders showed greater suppressive effects against an atopic disposition. Based on these results, Strachan proposed that the increase in allergic diseases can be attributed to the decreased incidence of infections during childhood due to improvement in living standards and public health. A great deal of evidence supporting this hypothesis has been found through epidemiological studies, among which are findings on the Th1/Th2 balance. During the fetal and neonatal periods, immune response relies primarily on the Th2 system, but later, the Th1 system evolves in response to stimulation by infections or harmless microbes, establishing a good balance between the Th1 and Th2 systems. Less exposure to microbes during childhood induces a Th2-dominant immune system, which is more vulnerable to allergic diseases.

*4 Proteome

A proteome is the entire set of proteins expressed in a certain cell or tissue. Proteome analysis consists of two steps, i.e., protein separation and identification. Usually, the proteins are separated by two-dimensional electrophoresis, and target proteins are identified by mass spectrometry.

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3

Applying Nanotechnology to Electronics
—Recent Progress in Si-LSIs to Extend Nano-Scale —

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1 Introduction

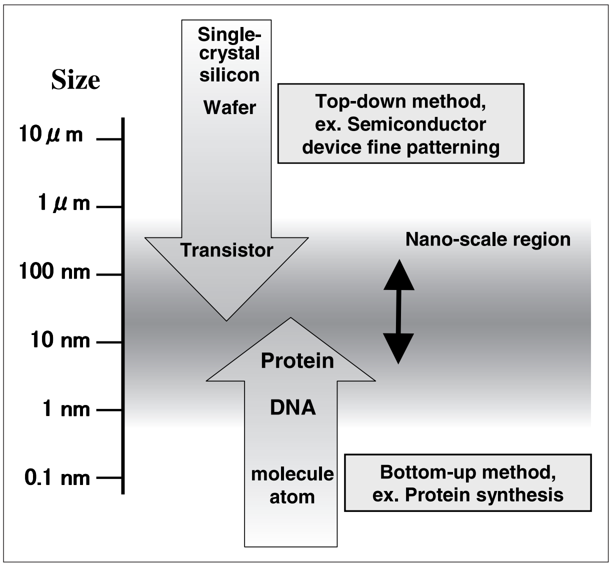
Nanotechnology broadly includes all technologies that handle nano-scale materials, and in a narrow sense, technologies that handle unique phenomena that arise in the 10-to-100-nm size range.

Materials of these sizes have been prepared using two techniques, the top-down and the bottom-up methods[1]. The top-down method is applied to process macro-scale materials into smaller sizes just as in the semiconductor process, whereas the bottom-up method is applied to integrate molecules or atoms into nano-scale materials just as a living organism synthesizes DNA and proteins, and integrates them into a cell, and further, into a body (Figure 1). The design rule of commercially available LSIs has already reached 90 nm[2].

The top-down method plays a major role in research in the U.S. and other foreign countries. Research programs are planned to expand the industrial life span of the Si-LSI technology[3].

Following the “21st Century Nanotechnology Research and Development Act” in the U.S.[4, 5], which plans to assess the application possibility of self-assembly as soon as possible, the bottom-up method has been successfully combined using the top-down method by researchers in U.S. universities and companies, showing that nanotechnology is being smoothly extended to conventional electronics. The bottom-up method is epitomized by self-assembly, which plays an important role in nanotechnology, together with prospective applications in ionics and electronics. In addition to the primitive assembly of materials, nanotechnology is moving forward to electronic devices and their integration.

Figure 1 : Two methods to approach to nano-scale



This paper discusses recent progress and current trends in nanotechnology R&D towards industrial application, referring to publications at conferences and journals relating to Si-LSI technology.

2 Architecture Levels of the Si-LSI Technology

One candidate in constructing an electronic device using the bottom-up method is to combine it with the top-down method. When the device is constructed using not only the bottom-up method, we must examine the following:

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Table 1 : Architecture levels (from 1 to 4) of the Si-LSI technology

No	Architecture level	Example	No. of devices	Technology	Reusable asset
1	Materials	Silicon, High-k dielectrics	<1	Manufacturing	Materials, Manufacturing equipment, Manufacturing factory
2	Single device	Transistor, Capacitor	1		
3	Basic circuit	Logic circuit, Delay circuit	$10 - 10^2$		
4	Functional block	Memory Arithmetic-logic unit	$10^2 - 10^8$	LSI design	Design tools, Electronic design automation, IP

the architecture of the conventional Si-LSI technology, the interface between the bottom-up method and the Si-LSI technology, and the extent of the influence of the bottom-up method on Si-LSI technology.

The architecture levels, which are discussed in the next chapter, are summarized in Table 1, where the levels are classified in four categories: materials, single devices, basic circuits, and functional blocks. An LSI is built incorporating a couple of functional blocks. Some examples of each level are shown in Table 1, as well as the extent of integration compared with a single transistor.

In many cases, Si-LSIs has progressed in establishing new technologies on the basis of conventional technologies, where some conventional technologies survive as long as they are indispensable. These are reusable LSI-design assets including materials, manufacturing equipment, and intellectual property (IPs). Manufacturing equipment and development environments are becoming a huge investment, which can be reduced by the efficient use of the assets. Although carbon-nanotube single-element devices have been demonstrated, we must be aware that there are still many technological (particularly integration) and financial issues to be solved before commercializing the carbon-nanotube devices.

Recent progress in nanotechnology at each level of Si-LSI is discussed in the next chapter.

3 Recent Progress in Nanotechnology in Electronic Devices

As an application of nanotechnology, five research works are discussed. The first three are related to a material and a single element in terms of Si-LSI architecture, and the latter two are related to a basic circuit and a functional block.

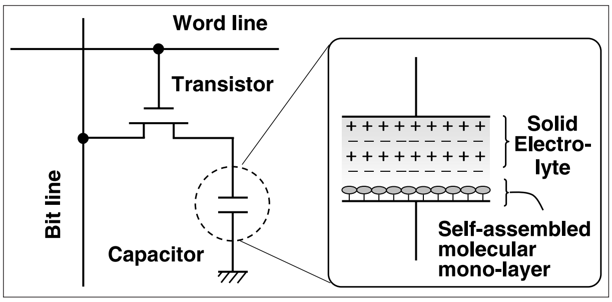
3-1 Molecular Memory

A dielectric film for a DRAM*1 capacitor was fabricated using the bottom-up method of nanotechnology. A primary cell of DRAM comprises a pair, of a transistor and a capacitor, and the transistor (an active element) can be developed based on the scaling rule although the capacitor (a passive element) cannot. As the depth of the dielectric film decreases, the leakage current of the capacitor increases, and as the area of the film decreases, the capacitance decreases. A trench-type capacitor, in which a trench is dug on the surface of a Si substrate, and a stack-type capacitor, in which three-dimensional electrodes of the capacitor are fabricated, have been employed to balance the capacitance and the geometrical area, although this complicates the manufacturing processes of both capacitors, resulting in higher costs.

Prof. Werner G. Kuhr and his colleagues, University of California, proposed a two-layered film as a dielectric film, which comprises a self-assembled monolayer (SAM) and an electrolyte[6]. The film is so designed that its capacitance and electromotive force can be controlled by a redox reaction between the SAM and the electrolyte.

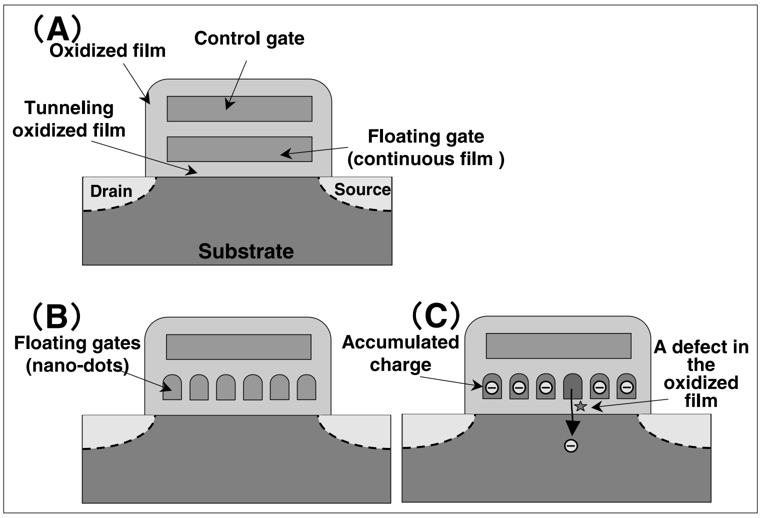
The capacitance of the proposed capacitor,

Figure 2 : Molecular memory applied to DRAM capacitors



source : Prepared by the authors, based on references.[6,7]

Figure 3 : Schematic cross-sections of a flash-memory basic device



which is in contrast to the conventional capacitor fabricated by insulation films such as silicon oxide, is governed by the molecule number in the SAM (or an area of the capacitor) and is independent of applied voltage, showing that the capacitance is more than 10 times the conventional capacitance. The charge retention time of the proposed capacitor is governed by the properties of the molecule, and is more than 10,000 times (more than 10s) that of the conventional capacitor, in which the retention time is governed by charge leakage at the silicon oxide film.

The molecule accommodates multiple states and potentials, which leads to a multiple-value memory and a multiple-value logic gate*2. The SAM is fabricated on a silicon or metal substrate allowing the self-alignment of molecules, and is compatible with the present semiconductor manufacturing equipment. ZettaCore*3 [7], a venture company in the U.S., applied this technology to fabricating a 1 Mbit DRAM, whose electronic characteristics were assessed showing a promising future.

3-2 Fine Processing

Flash memory*4, a major non-volatile semiconductor memory, comprises a unit of a single transistor, in contrast to DRAM that comprises a unit of two elements (one transistor and one capacitor). The flash memory is rapidly expanding its market into commercial products, such as price-sensitive consumer electronics products, owing to its advantages of high integration and low price. Highly integrated flash memory is in big demand for portable devices, such as cellular phones, and can now show static and dynamic images that require larger memory capacity[8].

Flash memory has a size limit in the depth of the tunneling oxidized film (Figure 3A). A floating-gate-type transistor, a typical element of flash memory, stores information using a charge at the floating gate that is fabricated by stacking two gates. A charge is injected through the tunneling oxidized film by applying voltage at the control gate. The tunneling oxidized gate (generally SiO_2) must be sufficiently insulating to store the charge during the guaranteed data retention period (generally 10 years). The depth of the tunneling oxidized film cannot therefore be reduced in accordance with the scaling rule, and is limited to beyond a certain depth. This prevents transistors in flash memory from being miniaturized further and prevents the operating voltage from being reduced, which is essential for reducing power consumption and for sharing a common power supply with other low-operating-voltage components.

A new structure that may solve the problem has been presented, where the floating gate is replaced by a number of nano-dots (non-continuous film) (Figure 3B). A charge-accumulating electrode made of continuous film does not work when the film contains at least one defect, while an electrode made of a non-continuous film works sufficiently even when the film contains a certain amount of defects, although a few fractions of the charge are lost (Figure 3C). The nano-dot tunneling oxidized film provides higher fault tolerance and allows thinner depth of the film[9].

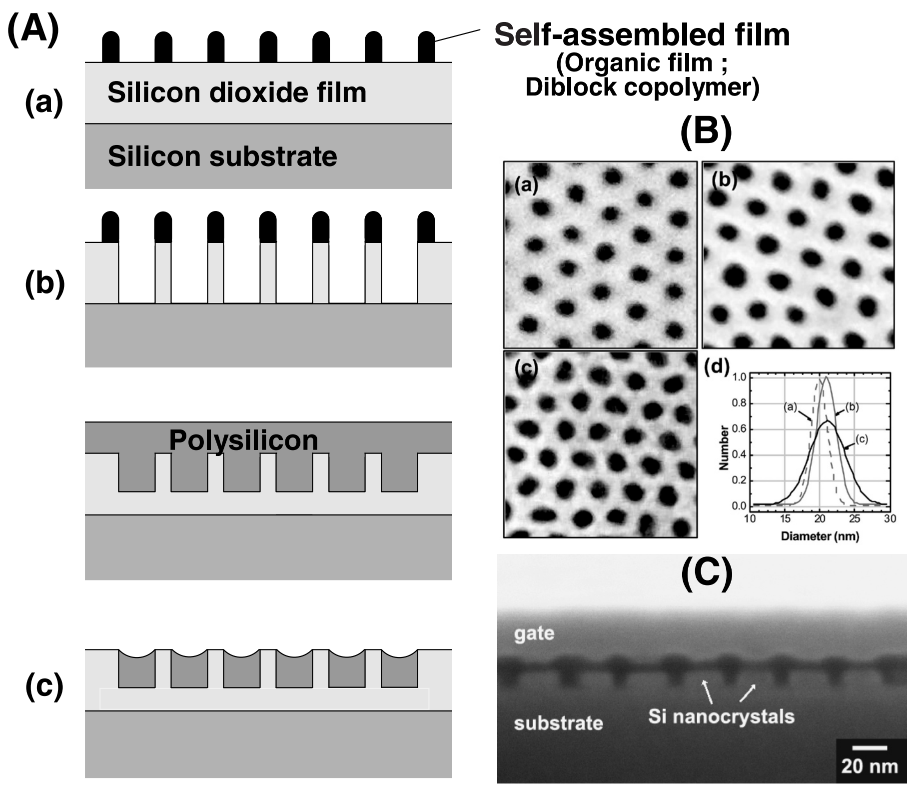
When nano-dots are fabricated using the conventional semiconductor process, the size and geometrical placement of dots are not well controlled as designed, which leads to non-reproducible devices[10]. This suggests that a new technique is needed to fabricate nano-dots of a designed, uniform size.

Researchers at IBM in the U.S., presented a new technique using self-assembly to fabricate silicon nano-dots at the International Electron Devices Meeting in 2003[11].

The researchers developed a new technique to fabricate nano-dots using the self-assembly of organic polymer materials, without using conventional lithography. This technique provides nano-dots with smaller size, higher density, better geometrical precision, and better uniformity than conventional lithography. The high-resolution SEM photograph indicates that silicon nano-dots are fabricated between the control gate (polysilicon) and the substrate (silicon) of a uniform size of about 20 nm (Figure 4).

The researchers in IBM successfully report that a charge-accumulating electrode can be fabricated combining the top-down method (conventional lithography) with the bottom-up method (self-assembly), which solves the problems of the conventional method.

Figure 4 : Fabrication flow of silicon nano-dots



A: schematic cross-sections of each process, B: top-views of A, C: cross-section of the fabricated transistor. In the figure B-d, a: diameter of the self-assembled polymer (broken line), b: diameter of the silicon nano-dots in the middle of formation, c: diameter of the formed silicon nano-dots.

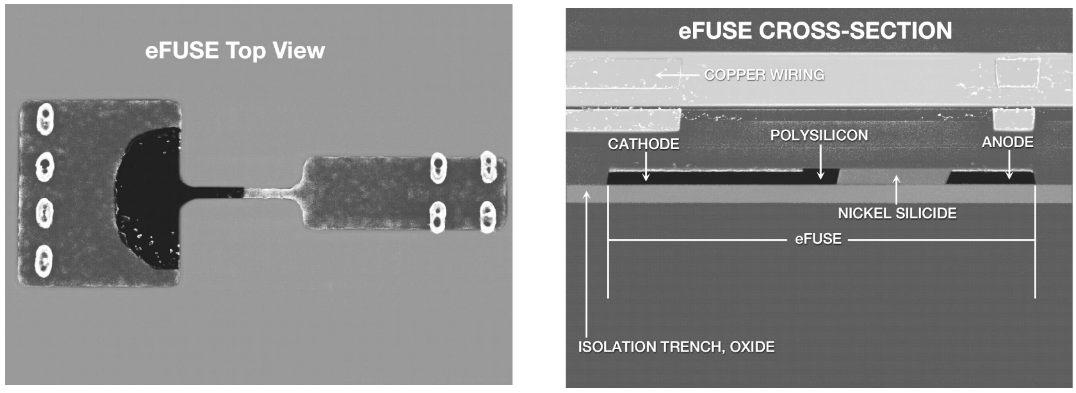
A-a (the first stage): Phase separation in a micro size occurs when the diblock copolymer is heated, where the diblock copolymer is comprised of two polymer blocks hardly soluble each other (polystyrene/poly(methylmethacrylate) (PMMA) = 70/30) . After the phase separation takes place at 180˚C, the PMMA domain is selectively removed by solving in an acetic acid. The honeycomb-like polystyrene formed by self-assembly is left. The size of the honeycomb is governed by molecular size of the diblock copolymer. The black part of B-a, -b, and -c is about 20 nm in diameter and about 40 nm in separation.

A-b (the second stage): A silicon oxidized film is processed in nano-scale using the self-assembled polymer as a mask, which is removed afterwards.

A-c (the third stage): the holes formed by the second stage are filled with silicon applying the conventional semiconductor process. Finally, silicon nano-dots are formed using the self-assembled polymer as a template.

Source: Reference [11]. The schematics were prepared by the authors.

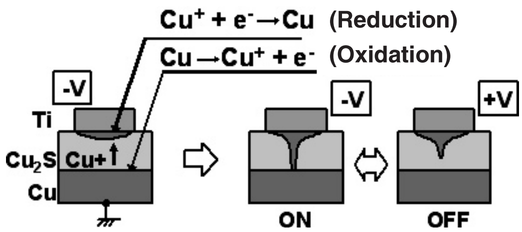
Figure 5 : Photographs of eFuse (left: top view, right: cross-section)



Atom migration occurred at the part where color is changed.

Source: Reference [12]

Figure 6 : Electro-migration switch using metal ions in a solid electrolyte



When a minus voltage is applied to the Ti electrode, Cu is oxidized to Cu+ on its electrode, which dissolves into Cu2S. Cu+ is reduced to Cu on the Ti electrode, which deposits on the electrode as metal Cu. When the deposited Cu forms dendrite to bridge two electrodes, the switch turns on. When a plus voltage is applied to the Ti electrode, the opposite reactions take place to turn the switch off.

Source: Reference [14]

3-3 Electro-Migration Switch Using Ions

Some LSIs are used after changing the wiring among their elements inside, giving priority to either processing speed or low power consumption. The rewiring has conventionally been conducted by thermal cutting using a high electric current or irradiating with a laser beam. Conventional rewiring is non-reversible and may damage neighboring elements, which grows more serious as the patterning becomes finer. As an alternative, transistors are used as reversible switches, although this technique is accompanied by response delay, larger size, and higher power consumption.

Researchers in IBM, U.S.A., presented a new technique using electro-migration (IBM calls it "eFuse") in July, 2004, where circuits are autonomically reconstructed[12].

Electro-migration is the migration of metal atoms in solids when electric current flows at high density, which has been avoided due to the malfunction of LSIs.

The eFuse of IBM uses electro-migration for rewiring elements, cells, and units inside LSIs. The eFuse features reproducible fine wiring (about 100 nm) without damage (Figure 5).

Together with prioritizing both processing speed and low power consumption, the eFuse is designed to repair itself; where a failure is detected, the failure cell or unit is isolated and replaced by another cell or unit. Furthermore, it is designed to avoid failures by wiring resistance being adjusted depending on the load.

IBM is trying to establish an "autonomic" computer that controls and repairs itself. The eFuse, which is a technology based on hardware, contrasts with autonomic computing, which is based on software. IBM considers the so-far-problematic electro-migration as a next-generation technology related to reversible switches or as a technological seed to renovate computer hardware.

NEC Corporation (NEC), the National Institute for Materials Science (NIMS), and the Japan Science and Technology Agency (JST), in Japan, are jointly developing a small, low-resistance switch using dendrite formation in a solid electrolyte. This switch is based on atomic switching in which electrodes are reversibly connected by the electrochemical formation of metal dendrites[13].

A programmable logic circuit, which allows flexible and timely development, is attracting the attention of electronic-device engineers. The conventional programmable circuit has disadvantages, however, and is relatively slow in processing speed and high in power consumption due to the larger size of the programmable switches. The recent progress, as shown above, has the following implications: fabrication without lithography, smaller size (about 1/30 in area), lower wiring resistance (about 1/10), and shorter signal delay (shortened by 20 to 40%).

The atomic switch provides a reversible on/off as well as the eFuse of IBM. Further, the switch has the potential to provide the dynamic programming of logic circuits, in which circuits are re-programmed during operation, as well as static programming, in which circuits are built as designed.

3-4 Device Arrays

It is being attempted to combine conventional integrated circuits, which are even now being miniaturized further using the top-down method, with nano-tubes or nano-wires, which focuses on the elements that need to be further reduced in size[15,16].

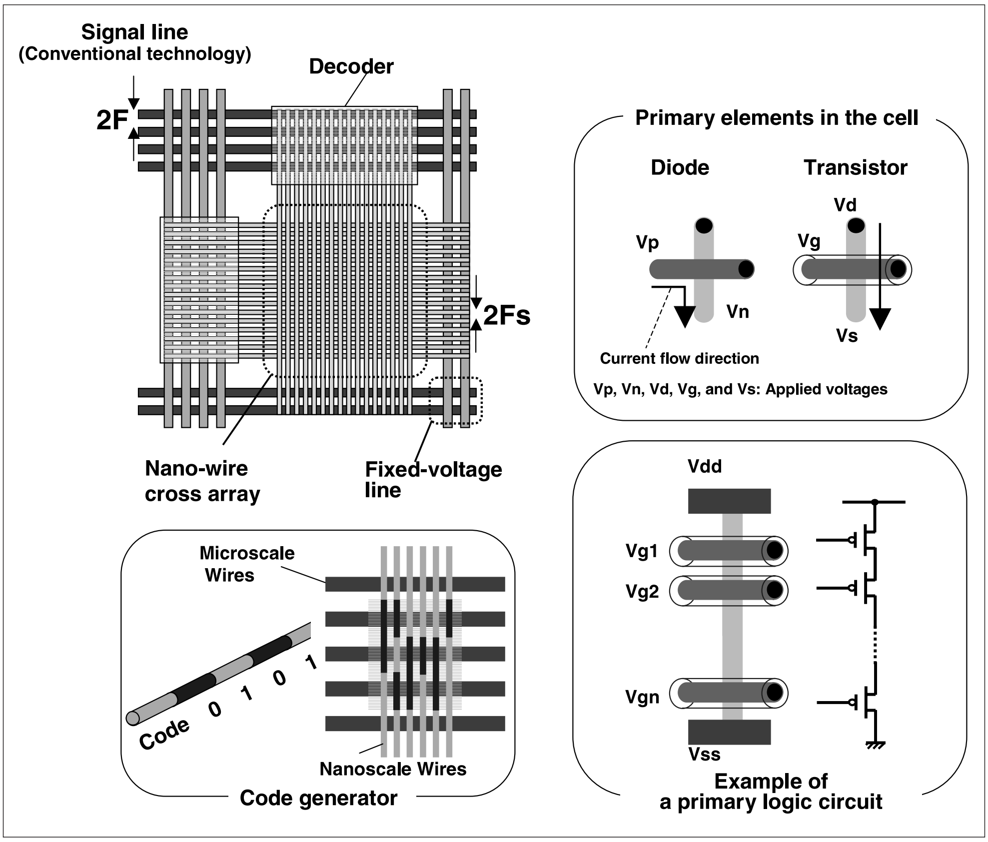
Designed in the architecture above, the LSI accommodates pattern-size Fs (repetitive-size: Fs) in pattern-size F (repetitive size: 2 x F, F > Fs), where the pattern-size F is achieved using conventional lithography, and the pattern-size Fs is achieved without lithography (Figure 7). The periodic pattern fabricated by the pattern-size Fs is ready to construct functional blocks, such as a memory cell or gate arrays, in which transistors are periodically arranged.

A primary device in the cell is a logic circuit built by diodes or transistors that are built by crossing nano-wires.

In this LSI design, the connection between circuits constructed by conventional lithography and arrays of nano-wires, etc. is realized as a key technology. A decoder built using the 2 x Fs repetitive size is proposed for binding the 2 x F and the 2 x Fs, whereas the decoder must be built without using lithography. Doping to nano-wires or nano-imprinting*5 may be a solution.

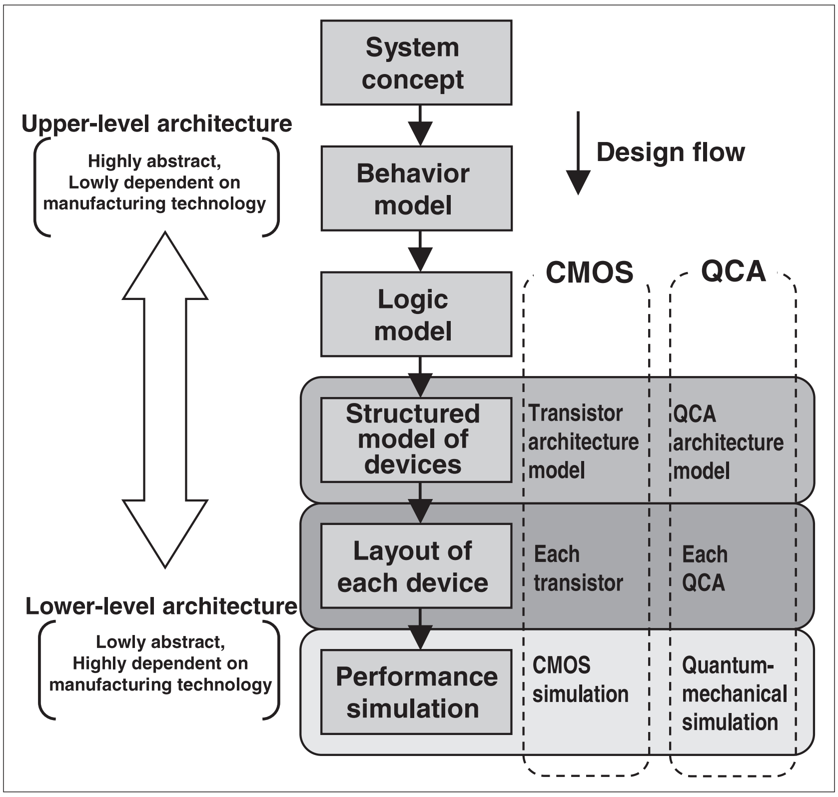
Although this design must be accompanied by technological breakthrough in building the decoder, the research is of significance in clarifying current design obstacles. If

Figure 7 : Circuit architecture based on arrays, such as nano-wires



Source: Prepared by the authors, based on references [15, 16]

Figure 8 : LSI design flow and modifications for being integrated with manufacturing



Source: Prepared by the authors, based on reference [17]

the problems are solved using the present manufacturing technology, the LSI design has the potential for immediate commercialization.

*3-5 QCA*6 Logic LSI*

The present LSI is designed from an upper architecture (highly abstract) to a lower (lowly abstract), where each design step is precisely described. This flow has worked effectively in the design of a large-scale LSIs with some restrictions. Design errors are detected by modeling and verifying at each step, by which effective design is achieved for still-now-expanding LSIs without re-modeling. The described model is dependent on manufacturing technology because this flow becomes less abstract, or more realistic, from the upper to the lower. The present LSIs based on CMOS are likely, at levels lower than the logic circuit in Figure 8, to be modified due to the conditions and limitations of manufacturing technologies.

A design methodology is under development to effectively design a highly integrated system based on QCA[17], whereby the design methodology for LSIs is more or less modified.

QCA is attractive because the element of QCA is potentially reduced in size to less than that of CMOS. Although the architecture of QCA was proposed more than ten years ago, its impressive application to integrated circuits has not yet been reported. The lack of a design methodology for QCA by which functional elements are integrated into a system accounts for some of difficulties facing QCA.

Prof. Steven C. Henderson and colleagues of Valparaiso University, Indiana, U.S.A., have developed a design methodology that builds a structured model of elements and conducts modeling and verification on the lower architecture[17]. For example, a hardware description language*7 has been developed, which is a design tool for constructing a structured model of elements from a logic model. In addition, an integrated design methodology for QCA has been proposed, whereby the layout for each QCA cell in the lower architecture is constructed, and its performance is simulated.

Complicated LSIs have recently been effectively designed in a short period using commercially available, reusable LSI design assets (IP). The IP is placed in a technological intermediate region that is independent of the strategies, manufacturing, etc. of companies, and is mostly commercially available. Further development of the design methodology for QCA, in which the IP and other assets have been well applied, may also contribute to progress in conventional LSI design methodology. A technology to reuse IP plays an important role in effectively integrating elements that are governed by new physical phenomena.

4 Towards Steady Progress in Nanotechnology

Compound semiconductors, represented by GaAs (important for light-emitting devices), were believed to be a replacement for silicon in the field of electronics because of their excellent properties. These semiconductors, however, failed to establish a large industry due to slow progress in related technologies. Excellent in their properties, it is difficult to integrate compound semiconductors. Nanotechnology might be limited in use unless the performance of highly integrated nano-devices is impressive, no matter how impressive the performance of a single nano-element is.

Nanotechnology might not replace all micro-scale technologies immediately. Smooth transition from micro to nano, or the smooth integration of nanotechnology with conventional technologies, is essential. Prof. Nishi of Stanford University, California, U.S., claims that two facets of nanotechnology, “Evolutionary Nano” and “Revolutionary Nano,” should not be confused[18]. Evolutionary Nano is exemplified by the steady miniaturization of Si devices using the top-down method, whereas Revolutionary Nano signifies quantum-leap miniaturization using the bottom-up method. Although Revolutionary Nano is sensationally reported by the mass media, Evolutionary Nano potentially contributes more to industry. There should be a number of technological breakthroughs for Revolutionary Nano to be successfully commercialized. Research assets should be invested more in Evolutionary Nano, which is finally being combined with Revolutionary Nano.

A survey on molecular assembly (Article 5, Section b) in the “21st Century Nanotechnology Research and Development Act” in the U.S. is attracting great attention[4]. The National Research Council will give a final verdict on whether self-assembly can be commercialized as materials or machines at a molecular scale or not at the first triennial meeting[19]. Long-term investment based on well planned strategy is essential for the materialization of next-generation technologies, such as nanotechnology, where planning should include impressive success in industry, signifying the bright future of the technology. The verdict by the National Research Council is a possible case to be tested.

Although the pros and cons of the top-down and bottom-up methods, to fabricate nano-scale materials, have been discussed in Japan, new ideas for combining both have not been well studied, except for research in industry (NEC, etc.). The recent progress in the U.S. that tries to combine both methods is suggestive, and is unveiling a new paradigm of nanotechnology indicating realistic applications in industry.

5 Conclusion

Nano-scale materials for nanotechnology have been prepared using two techniques, the top-down and bottom-up methods. The top-down method is applied to process macro-scale materials into smaller sizes, just as the semiconductor process does, whereas the bottom-up method is applied to integrate molecules or atoms into nano-scale materials, just as a living organism synthesizes proteins.

The bottom-up method has recently been successfully combined with the top-down method by researchers at universities and companies in the U.S., showing that nanotechnology is being smoothly extended to conventional electronics. The bottom-up method is epitomized by self-assembly, which plays an important role in nanotechnology, together with prospective applications in ionics and electronics. In addition to the primitive assembly of materials, nanotechnology is moving forward to electronic devices and their integration, in which LSI design is being explored.

Nanotechnology is presented as a realistic, promising technology for the future due to recent progress in this field, where nanotechnology is combined with conventional Si-based electronics.

Long-term investment based on well planned strategy is essential for materializing next-generation technologies, such as nanotechnology, where planning should include impressive success in industry, signifying the bright future of the technology.

Although the pros and cons of the top-down and bottom-up methods have been discussed in Japan, new ideas for combining both have not been well studied, except for research in industry (NEC, etc.). The recent progress in the U.S. that tries to combine both methods is suggestive, and is unveiling a new paradigm of nanotechnology indicating realistic applications in industry.

Acknowledgments

The authors thank Prof. Yoshio Nishi of Stanford University for his valuable comments.

Glossary

*1 DRAM
A semiconductor memory device that allows random access (read and write). Mainly used for the main memory of a computer.

*2 Status has discrete values
A molecule containing a multi-porphyrin nano-structure has, reportedly, a maximum of eight multiple oxidation states[4]. Porphyrin is an organic pigment.

*3 ZettaCore
A venture company established in 1999 by researchers of University of California and North Carolina State University.

*4 Flash memory
Electrically rewritable non-volatile memory, where all or a block of data can be erased.

*5 Nano-imprint
Application of metal pressing using molds to nanotechnology. A nano-scale printing technology in which a mold with micro-patterns is impressed onto a material such as a plastic film.

*6 QCA
Cellular automata (CA) are, by definition, dynamical finite-state machines. On a regular lattice (repeated structure of points has the same kind of neighborhood), one places a finite-state machine at each point. The machine changes its state as a function of states of its neighbors and its own state. The states of all machines in the lattice are updated synchronously and simultaneously. Cellular automata formed by quantum dots are called quantum cellular automata (QCA). A familiar example of cellular automata is a game of “Othello” in play.

*7 Hardware description language
formal language to describe hardware architecture, in place of circuit schematics, for processing with a computer. Hardware is developed by this language as software is developed.

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(Original Japanese version: published in January 2005)

4

Trends in High-End Computing in United States Government

MINORU NOMURA
Information and Communications Research Unit

1 Introduction

Currently, United States Government research and development on information and communication technologies are conducted based on the Networking and Information Technology Research and Development (NITRD) program coordinated by the National Science and Technology Council (NSTC). Twelve federal agencies participate in the NITRD program consisting of seven Program Component Areas(PCAs). The PCAs related to High-end Computing (HEC) are High-end Computing Infrastructure and Applications (HEC I&A) and High-end Computing Research and Development (HEC R&D)[1, 2].

In March 2003, the HEC Revitalization Task Force("the Task Force") was formed under NSTC as a special project of NITRD. The co-chairs are members from DoD/ODDR&E, the DOE/Office of Science, the National Coordination Office, and the Office of Science and Technology Policy. Other participating agencies include DARPA, DoD/HPCMP, DoD/Missile Defense Agency, DOE/NNSA, the EPA, NASA, the NIST, the NSA, the NSF, the OMB, and so on. The Task Force's report lists 70 names.

The mission of the Task Force is to develop a plan for undertaking and sustaining a robust Federal high-end computing program to maintain US leadership in science and technology fields into the future. In May 2004, the Task Force released the Federal Plan for High-End Computing ("the HEC Plan")[3], which includes measures on HEC research and development, HEC resources, and HEC system procurement over the coming 5 to 10 years. HEC is essential for science and technology development, national security, and international competitiveness. However, there is an awareness that the HEC (resources, architectures, and software tools and environments) used for government missions are not always meeting the computing needs of federal agencies.

The 108th US Congress debated at least three bills related to the HEC Plan during 2004. Of these, Congress passed the Department of Energy High-end Computing Revitalization Act of 2004 in November. Currently, the US Government strongly pushes HEC research and development, and its utilization as a strategy to increase national power.

The purpose of this article is first, to provide an outline of the HEC Plan in Section 2, and second, to discuss its most significant points in Section 3.

2 Outline of the "Federal Plan for High-end Computing"[4]

In this section, the "Federal Plan for High-End Computing " will be summarized.

The Task Force solicited input from leading applications scientists who utilize HEC to advance their research in various specialist fields. According to the survey, the estimates of additional capability needed to achieve the goals ranged from 100 to 1,000 times the current capability of today's HEC resources. Table 1 shows "Science Challenges" and "Potential Outcomes with 100 to 1,000 Times Current Capability."

Table 1 : Benefits of HEC to science and engineering

Area	Application	Science Challenge	Potential Outcome with 100 to 1,000 Times Current Capability
Physics	Astrophysics	Simulation of astrophysical environments such as stellar interiors and supernovae.	Yield understanding of the conditions leading to the origin of the heavy elements in the universe.
	High-Energy Physics	Achieve a detailed understanding of the effects of strong nuclear interactions so that the validity of the Standard Model can be tested to determine whether physics beyond the Standard Model occurs at extreme sub-nuclear distances.	Guide experiments to identify transition from quantum chromodynamics to quark-gluon plasma.
	Accelerator Physics	Accurate simulations of the performance of particle accelerators.	Optimize the design, technology, and cost of future accelerators, and use existing accelerators more effectively and efficiently.
	Nuclear Physics	Realistic simulations of the characteristics of the quark-gluon plasma.	By developing a quantitative understanding of the behavior of this new phase of nuclear matter, facilitate its experimental discovery in heavy ion collisions.
Nano-science	Catalyst Science / Nanoscale Science and Technology	Calculations of homogeneous and heterogeneous catalyst models in solution.	Reduce energy costs and emissions associated with chemicals manufacturing and processing. Meet Federally mandated NOx levels in automotive emissions.
	Nanoscale Science and Technology	Simulate the operation of nanoscale electronic devices of modest complexity.	Take miniaturization of electronic devices to a qualitatively new level enabling faster computers, drug delivery systems, and consumer and military electronics.
	Nanoscale Science and Technology	Simulate and predict mechanical and magnetic properties of simple nanostructured materials.	Enable the discovery and design of new advanced materials for a wide variety of applications potentially impacting a wide range of industries.
Aerospace	Simulation of Aerospace Vehicle in Flight	Simulate a full aerospace vehicle mission, such as a full aircraft in maneuver or an RLV in ascent or descent.	Reduce aerospace vehicle development time and improve performance, safety, and reliability.
	Full Liquid Rocket Engine Subsystems Simulation	Simulate full rocket engine subsystems during ascent including turbopump and combustion devices.	Provide capability for risk assessment during Earth-to-orbit and improve safety and reliability of space transportation systems.
	Aviation Systems Simulation	Execute high-fidelity airspace simulations and develop decision system and management tools for terminal area.	Provide capability for effectively managing national airspace and increase safety in terminal area.
Life Sciences	Structural and Systems Biology	Simulations of enzyme catalysis, protein folding, and transport of ions through cell membranes.	Provide ability to discover, design, and test pharmaceuticals for specific targets and to design and produce hydrogen and other energy feedstock more efficiently.
	Signal Transduction Pathways	Develop atomic-level computational models and simulations of complex biomolecules to explain and predict cell signal pathways and their disrupters.	Yield understanding of initiation of cancer and other diseases and their treatments on a molecular level, and the prediction of changes in the ability of microorganisms to influence natural biogeochemical cycles such as carbon cycling and global change.
National Security	Signals Intelligence	Model, simulate, and exploit foreign codes, ciphers, and complex communications systems.	Support U.S. policymakers, military commands, and combat forces with information critical to national security, force protection, and combat operations.
	Directed Energy	Advance the directed energy systems design process out of the scientific research realm into the engineering design realm.	Efficiently design next-generation directed energy offensive and defensive weapon systems. Change the design process from years to days.
	Signal & Image Processing & Automatic Target Recognition	Replace electromagnetic scattering field tests of actual targets with numerical simulations of virtual targets.	Design more stealthy aircraft, ships, and ground systems and create the ability to rapidly model new targets, enabling more rapid adaptation of fielded weapon systems' ability to target new enemy weapon systems.
	Integrated Modeling and Test of Weapon Systems	Model complex system interaction in real time with precision.	Replace many expensive, dangerous, and timeconsuming ground tests with virtual tests resulting in lower test costs and more rapid development of weapon systems.
Earth and Atmospheric Sciences	Climate Science	Resolve additional physical processes such as ocean eddies, land use patterns, and clouds in climate and weather prediction models.	Provide U.S. policymakers with leading-edge scientific data to support policy decisions. Improve understanding of climate change mechanisms and reduce uncertainty in the projections of climate change.
	Weather and Short-term Climate Prediction	Enable dynamical prediction of frequency and intensity of occurrence of hurricanes/typhoons and severe winter storms 90 days in advance.	Provide critical support to deployed naval, air, and land forces in local, regional, and global combat environments. Lives saved and economic losses avoided due to better severe weather prediction.
	Solid Earth Science	Improved statistical forecasting of earthquake hazards (fault-rupture probabilities and ground motion).	Provide prioritized retrofit strategies. Reduced loss of life and property. Damage mitigation.
	Space Science	Realistically simulate explosive events on the sun, the propagation of the energy and particles released in the event through the interplanetary medium, and their coupling to Earth' s magnetosphere, ionosphere, and thermosphere.	Provide decision makers (both civilian and military) with status and accurate predictions of space weather events on time scales of hours to days.
Energy and Environment	Subsurface Contamination Science	Simulate the fate and transport of radionuclides and organic contaminants in the subsurface.	Predict contaminant movement in soils and groundwater and provide a basis for developing innovative technologies to remediate contaminated soils and groundwater.
	Magnetic Fusion Energy	Optimize balance between self-heating of plasma and heat leakage caused by electromagnetic turbulence.	Support U.S. decisions about future international fusion collaborations. Integrated simulations of burning plasma crucial for qualifying prospects for commercial fusion.
	Combustion Science	Understand interactions between combustion and turbulent fluctuations in burning fluid.	Understand detonation dynamics (for example, engine knock) in combustion systems. Solve the "soot" problem in diesel engines.

2-1 HEC: A strategic tool for science and technology leadership

(1) The case for HEC revitalization

Recent agency studies have revealed that "current high-end computing resources, architectures, and software tools and environments do not meet current needs. Of equal concern, investigations of alternative high-end systems have largely stopped, curtailing the supply of ideas and experts needed to design and develop future generations of high-end computing systems."

The HEC Plan states that this necessitates revitalization.

(2) Goals

- Make high-end computing easier and more productive to use
- Foster the development and innovation of new generations of high-end computing systems and technologies
- Effectively manage and coordinate federal high-end computing
- Make high-end computing readily available to federal agencies that need it to fulfill their missions

The HEC Plan states that in the course of making high-end computing easier and more productive to use, the most important thing for researchers is to minimize the time to solution from new idea to results. It also states that this should be the goal of research and development in HEC systems. Figure 1 illustrates the elements of time to solution. Overall optimization requires the minimization not only of the calculations but also of each phase.

(3) Scope of the plan[*1]

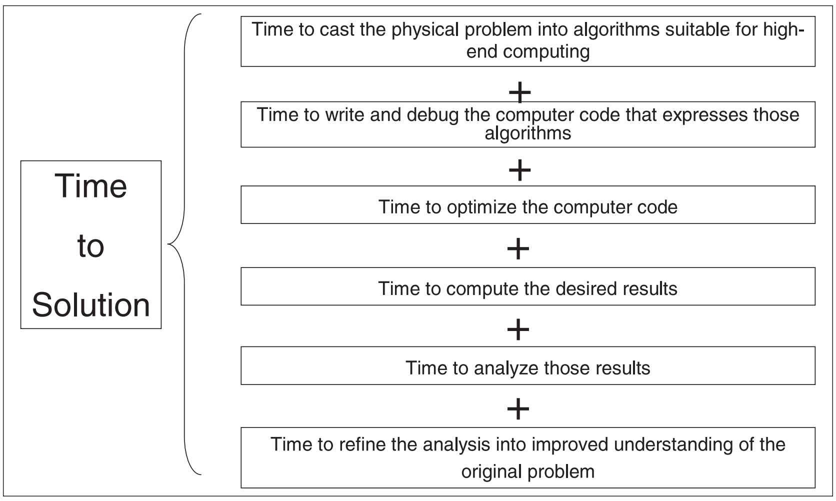
The HEC Plan includes a number of roadmaps outlining all the core technologies needed for high-end computers that might be manufactured within approximately 15 years. Key elements include:

- Core technology research and development in the hardware, software, and system technologies
- Capability, capacity, and accessibility strategies to assure that high-end computing resources are readily available to the science and engineering communities that need them
- Efficient procurement strategies that provide high-end computers that meet user requirements

Notes

*1 Visualization, networking, grid computing, general security issues, and application-specific software were considered outside the scope of this planning effort. Procurements of small-scale cluster systems also were not included in this planning activity.

Figure 1 : Time to solution



Source: Author's compilation based on reference[4]

Within the NITRD program, the annual HEC-related budget is approximately $900 million, of which the activities considered by the Task Force represent about $158 million (FY 2004). The Plan states that if these revitalization activities succeed, they will have a positive impact on the long-term activities of the entire $2.6-billion government portfolio for high-end computing.

2-2 Research and development

The HEC plan states as follows.

In the R&D area, a gap between federal requirements on computational performance and requirements for commercial systems can be seen. Compared with the business computing market and the web-based commerce market, the HEC market is not large enough to divert computer industry attention. HEC procurements are approximately $1 billion per year, while the server market by comparison is over $50 billion per year. This is why industry concentrates on the server market, and the HEC systems it provides consist of very large collections of processors designed for the smaller systems required by that market. These massive multiprocessor systems have proven exceptionally difficult to program and achieving high levels of performance for some important classes of applications has been problematic.

Recently, processor performance is continually improving, and theoretical peak performance is rapidly rising. In multiprocessor systems, however, the increasing disparity between processor speed and memory bandwidth is constraining actual performance in real operating environments. Processor speed is growing approximately 40 percent per year, while memory speed is improving approximately 7 percent annually.

The HEC Plan states that the cluster-based systems on which recent HEC investment focuses in the USA are not well suited for all applications, and different architectures would be more suitable for some high-priority government applications. The HEC Plan also describes parallel efficiency as follows: "The current HEC focus on clustering hundreds of small nodes, each with a separate OS, results in poor parallel efficiency, generally below 10% and sometimes lower than 1% of the peak on some applications."

Figure 2 shows the divergence between theoretical peak performance and sustained system performance (SSP) observed in major HEC centers.

(1) User requirements for HEC technology

The HEC Plan identifies the following primary challenges for effective use of high-end computing:

- Achieving high sustained performance on complex applications
- Building and maintaining complex software applications
- Managing dramatically increasing volumes of data, both input and output
- Integrating multiscale (space and time), multidisciplinary simulations

In addition, the HEC Plan identifies the following goals for future high-end computing systems:

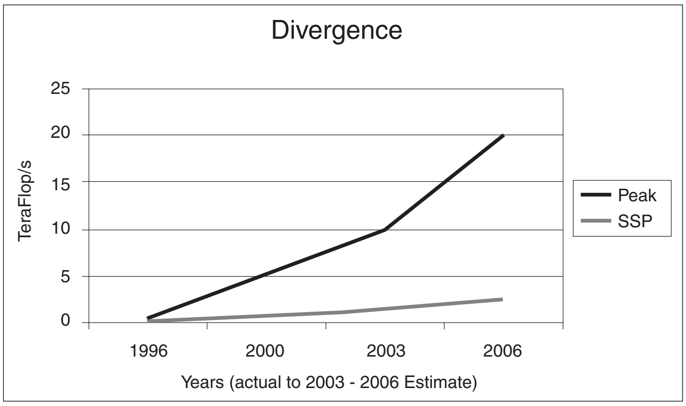
- A 100-fold increase in sustained (as opposed to peak) performance (a level of performance required to solve a number of current scientific and technological problems)
- Ultra-fast processors and new algorithms, since not all problems can be easily parallelized
- Improvements in bandwidth and latency for both memory and communications fabric, which for many applications largely determine performance
- Architectures that can meet diverse application requirements

The HEC Plan also emphasizes the lack of software tools, programming models, and operating systems. It is stated that one could expect reasonable performance on up to 1,000 processors, but that one could not expect performance from systems of 100,000 processors (projected in the 2010 timeframe) without substantial improvements.

(2) HEC R&D Strategy

In order to respond to user requirements

Figure 2 : Divergence problem between theoretical performance and sustained performance



Peak : Theoretical peak performance
SSP : Sustained system performance

in hardware, software and systems, the HEC Plan indicates (i) roadmaps, (ii) research and evaluation systems, and (iii) prioritization of HEC R&D investments for key technologies. They are outlined below.

(i) Roadmaps

The roadmaps include hardware, software, and systems. The roadmaps show two scenarios for the next decade.

First, the "current program" assumes no resource allocation changes from FY 2004.

Second, the "robust R&D program" indicates the probable scenario if new HEC system plans, execution, and system deployment are implemented in a timely manner.

Details are shown in Tables 2 through 7.

[Hardware Roadmap]

The "current program" and the "robust R&D program" are described in Table 2 and 3.

Under the "current program," without additional research effort, there will probably be little progress beyond the next five years. Such improvement would depend primarily on industry-driven commercial-off-the-shelf (COTS) technology advances and the results of existing or past research investments. Furthermore, without significant technological breakthroughs, Moore's Law will be coming to an end in the 2015 timeframe.

The "robust R&D plan" is a measure to push beyond the "current program."

[Software Roadmap]

The "current program" and the "robust R&D program" are described in Table 4 and 5.

The "current program" scenario depends on the Defense Advanced Research Projects Agency's (DARPA) High-Productivity Computing Systems (HPCS) program for the release of new architectures in the next five years. Since the DARPA program ends in 2010, future improvement through the "current program" will be based mainly on those architectures. The "robust R&D program" is a measure to push beyond that scenario.

[System Roadmap]

The "current program" and the "robust R&D program" are described in Table 6 and 7.

The "current program" scenario is dependent upon existing research activities (including HPCS) and progress after the next five years will be difficult. The "robust R&D program" is a measure to push beyond that scenario.

(ii) Research and evaluation systems

Because proper development and evaluation are necessary for future large-scale systems with 10,000 to 100,000 processors to function, the Task Force recommends the procurement of research and evaluation systems as an essential HEC R&D strategy.

The "early access" systems called as research and evaluation systems by the Task Force enable early prototype testing and provide platforms necessary for the development of new algorithms and computational techniques. In addition, such systems are essential for the evaluation of the functionality and scalability of software. During software development, testing often

Table 2 : Hardware roadmap: Current program

	Near Term (within a year)	Mid Term(within five years)	Long-Term (within ten years)
Microarchitecture	COTS-driven microarchitecture	Multi-CPU cores per chip, memory bandwidth per CPU decreases	Moore's law end?
Interconnect technologies	Interconnect technology based upon electrical interconnect and electrical switches	Interconnect technology based upon electro-optical interconnect and electrical switches	Interconnect technology driven by telecom - expect moderate advances for HEC systems
Memory	Processor/memory performance gap addressed by caches, limits performance and ease of programming	Early COTS PIM-based and streaming technologies to address processor/memory gap	Evolutionary improvements; increased use of PIMs
Power, cooling, and packaging	Thermal/packaging–chip/system technologies limited by our ability to cool via air	Evolutionary improvements do not significantly advance our ability to develop high-end systems	System performance limited by "thermal wall"?
I/O and storage	I/O driven by COTS-based needs in areas of storage and links	Petaflop-scale file systems based upon COTS technologies, RAS issues will limit usability	Depends upon 3-D storage

Table 3 : Hardware roadmap: Robust R&D plan

	Near-to Mid-Term (within five years)	Long-Term (within ten years)
Microarchitecture	Prototype microprocessors developed for HEC systems available	Innovative post-silicon technology optimized for HEC
Interconnect technologies	Interconnect technology based upon optical interconnect and electrical switches	All-optical interconnect technology for HEC
Memory	Memory systems developed for HEC needs. Accelerated introduction of PIMs	Revolutionary high-bandwidth memory at petaflop scale
Power, cooling, and packaging	Stacked 3-D memory and advanced cooling technologies address critical design limitations	Ability to address high-density packaging throughout the entire system
I/O and storage	Petaflop-scale file systems with RAS focused on HEC requirements	Revolutionary approaches to exascale "file systems"

PIM : Processor-In-Memory, RAS : Reliability, Availability, Serviceability
COTS : Commercial-Off-The-Shelf

Table 4 : Software roadmap: Current program

	Near-Term (within a year)	Mid-Term(within five years)	Long-Term (within ten years)
Operating systems (OSs)	OSs adapted from desktops or servers. Fragile and do not scale over 1,024 processors	Early introduction of OSs that scale to 10,000 processors for at most two HPCS system architectures. Clusters remain a challenge.	Little progress is expected.
Languages, compilers, and libraries	Legacy languages and libraries (for example, Fortran, C, C++, and MPI). Compiler technology inadequate for achieving scalable parallelism.	Limited production quality compilers (for example, UPC and Co-Array Fortran [CAF]) for a few systems. MPI continues to dominate. Heroic programming required for computations on over 2,048 processors.	Limited additional improvements in programmability. Production-quality compilers for UPC and CAF widely available. Mostly incremental progress with compiler optimization and MPI implementation. No revolutionary advances in languages
Software tools and development environments	Wide variety of vendor specific or research-quality tools – limited integration, difficult to use, and little portability. No integrated development environments (IDEs) available for HEC systems.	Tool capability lags HEC systems (for example, debugging 250,000-processor jobs). IDE support for small-sscale (32-processor) systems only.	Gap between tool capabilities and ability to understand large systems widens. IDE support for mid-range shared memory systems
Algorithms	Efficient parallel algorithms for some problems (for example, dense linear algebra). Others require deep expert knowledge for efficient implementation.	Improved parallel algorithms for unstructured and sparse problems	Additional progress in mapping algorithms onto advanced architectures

Table 5 : Software roadmap: Robust R&D plan

	Near-to Mid-Term (within five years)	Long-Term (within ten years)
Operating systems (OSs)	New research-quality HEC OSs that address scalability and reliability	Production-quality, faulttolerant, scalable OSs
Languages, compilers, and libraries	Optimized for ease of development on selected HEC systems. Research-quality implementations of new HEC languages, supporting multiple levels of abstraction for optimization.	High-level algorithm-aware languages and compilers for automated portability across all classes of HEC systems
Software tools and development environments	Interoperable tools with improved ease of use across a wide range of systems. First research-quality IDEs available for HEC systems.	IDEs that support seamless transition from desktop to largest HEC systems
Algorithms	New multiscale algorithms suitable for HEC systems. Initial prototypes of architecture-independent parallel computations.	Automatic parallelization of algorithms for irregular and unbalanced scientific problems. Scaling up of parallel algorithms to enable detailed realistic simulations of physical systems.

Table 6 : System roadmap: Current program

	Near-Term (within a year)	Mid-Term (within five years)	Long-Term (within ten years)
System architecture	COTS-based systems from 10 to 100 Tflops peak (1,000 to 10,000 processors) with server-class operating systems – fragile and hard to program	At most two DARPA HPCS systems capable of sustained petaflops (up to 100,000 processors or more) on selected mission applications	Evolutionary improvements only beyond HPCS systems
System modeling and performance analysis	System modeling and performance analysis tools developed but ad hoc, incomplete, difficult to use, and not integrated	Accuracy improvements in models/tools for legacy systems and applications for use by experts. Modeling of HPCS systems faces complexity challenges.	Evolutionary improvements toward ease of use and integration with system
Programming models	Legacy parallel computing models limit ease of programming. Main model is message passing. “Non-heroic” programming practice: MPI at 64 to 256 and OpenMP at 16 to 128.	Minor progress in parallel computing models. “Non-heroic” programming: MPI-2 feasible for 128 to 512 processors and DSM implementations (UPC, CAF, …) more widespread and available for 64 to 256 processors.	Incomplete implementation and acceptance of shared memory programming models (for example, UPC and CAF)
Reliability, availability, and serviceability (RAS) + Security	RAS achieved by defensive user actions (for example, checkpoint/restart) and rescheduling	Limited RAS solutions for up to 1,024-processor systems. Partial fault isolation and better profiling of user behavior to prevent inside attack.	RAS solutions for up to 10,000-processor systems. Some improvements in applications security

Table 7 : System roadmap: Robust R&D plan

	Near-to Mid-Term (within five years)	Long-Term (within ten years)
System architecture	Three or more systems capable of sustained petaflops (up to 100,000 processors or more) on wider range of applications. Programming much simpler at large scale. Emergence of adaptable self-tuning systems.	High-end systems capable of sustained 10 to 100 petaflops on majority of applications. Programmable by majority of scientists and engineers. Adaptable self-tuning systems commonplace.
System modeling and performance analysis	Accurate models/tools for HEC systems and applications. Tools and benchmarks provide better understanding of architecture/application interactions.	Models enable analysis and prediction of software behavior. Automated and intelligent performance and analysis tools and benchmarks widely available and easy to use.
Programming models	Research implementations of novel parallel computing models. “Non-heroic” programming: MPI follow-on for 1,024 processors and robust DSM implementations (UPC, CAF,…) widespread and available for 1,024 processors.	Parallel computing models that effectively and efficiently match new or planned architectures with applications. Novel parallel computation paradigms foster new architectures and new programming language features.
Reliability, availability, and serviceability (RAS) + Security	Semi-automatic ability to run through faults. Enhanced prevention of intrusion and insider attack.	Self-awareness: reliability no longer requires user assistance. Systems will have verifiable multilevel secure environments.

CAF: Co-Array Fortran, COTS: Commercial-Off-The-Shelf, DARPA: Defense Advanced Research Projects Agency,
DSM: Distributed Shared Memory, HPCS: High Productivity Computing Systems, IDE: Integrated Development Environment,
MPI: Message Passing Interface, OpenMP: Open specification for MultiProcessing, OS: Operating System,
RAS: Reliability, Availability, Serviceability, UPC: Unified Parallel C

Figure 3 : Recommended priorities

		Current Program*	Increment compared to HEC R&D Current Program				
		FY 2004 ($ in millions)	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010
Hardware	a. Basic and Applied Research	$5	Moderate	Moderate	Moderate	Moderate	Robust
	b. Advanced Development	$5	Moderate	Moderate	Moderate	Moderate	Moderate
	c. Engineering and Prototypes	$0		Modest	Modest	Moderate	Moderate
	d. Test and Evaluation	$2		Modest	Modest	Modest	Modest
Software	a. Basic and Applied Research	$33	Modest	Modest	Modest	Moderate	Moderate
	b. Advanced Development	$21	Modest	Modest	Modest	Moderate	Moderate
	c. Engineering and Prototypes	$15	Moderate	Moderate	Moderate	Moderate	Moderate
	d. Test and Evaluation	$2	Moderate	Robust	Robust	Robust	Robust
	e. Long-term Evolution and Support	$0	Moderate	Moderate	Moderate	Moderate	Moderate
Systems	a. Basic and Applied Research	$4	Modest	Modest	Modest	Moderate	Moderate
	b. Advanced Development	$40	Modest	Modest redirection	Modest redirection	Modest redirection	
	c. Engineering and Prototypes	$1	Moderate	Robust	Robust	Robust	Robust
	d. Test and Evaluation	$30	Modest redirection	Modest	Moderate	Robust	Robust
Total		$158**					

Robust funding increment　Modest funding increment
Moderate funding increment　Modest redirection

* Assumes no planning changes from FY 2004.
** This total represents the aggregate investment across all agencies in HEC as defined in the scope of the plan section of the reference[4].

Source: Author's compilation based on reference[4].

causes hardware breakdowns, interfering with application development. It is therefore necessary to separate software development testbeds from application development testbeds.

The performance information gained from extensive evaluations of research and evaluation systems is invaluable for the successful future procurement of HEC systems. If these evaluations have been able to identify failed approaches, the government will not acquire systems that do not perform as expected. In addition, such evaluations may also suggest more fruitful approaches through removal of the sources of failure.

(iii) Prioritization of HEC R&D investments

The HEC Plan examines prioritization after defining the four major stages in research and development.

(a) Basic and Applied Research: Focus on the development of fundamental concepts in high-end computing through the continuous creation of new ideas and expertise.
(b) Advanced Development: Select and refine innovative technologies and architectures for potential integration into high-end systems.
(c) Engineering and Prototypes: Perform the integration and engineering required to build HEC systems and components.
(d) Test and Evaluation: Conduct testing and evaluation of HEC software as well as the current and new generations of HEC systems at appropriate scale.

The HEC Plan also suggests that for long-term evolution and support, the government should maintain critical HEC software infrastructure over the long term.

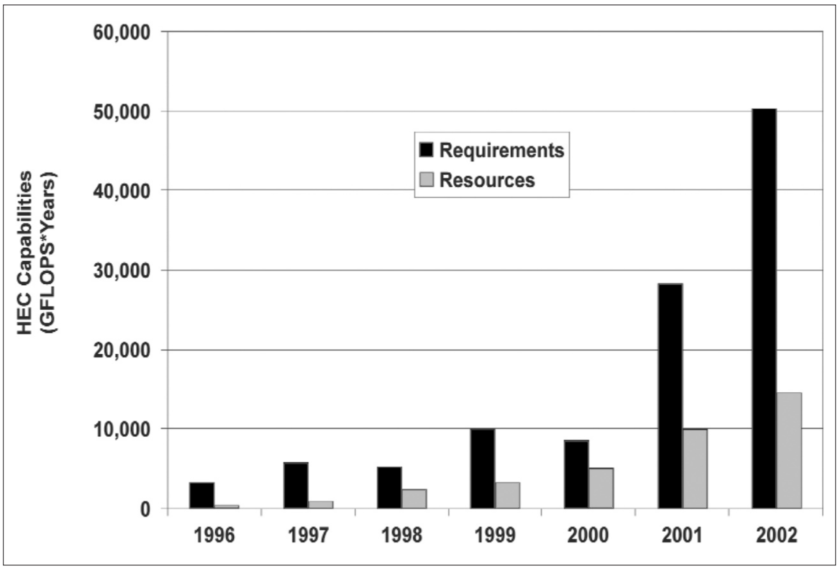
Recommendations for R&D investment for each stage are described as shown in Figure 3. The Chart depicts the prioritization of each increment compared to the "current program."

2-3 HEC resources

The Plan defines "HEC resources" as the acquisition, operation, and maintenance of HEC systems needed to carry out federal agency mission applications.

The HEC Plan indicates that since overall

Figure 4 : HEC requirements vs. available resources for the DoD High-Performance Computing Modernization Program



computing ability is not sufficient, robust investment in HEC resources is required. Some federal agencies borrow resources from other agencies because they cannot provide their users with sufficient computing capacity. The Plan also states that no civilian agency in the USA currently has access to leadership-class systems to provide true breakthrough capability for important computational problems.

(1) User requirements for HEC resources

Surveying the HEC requirements of a broad range of scientific disciplines across the federal government identified two classes of resource issues. The first is architectural availability, and the second is acquisition of HEC capacity. These issues are discussed in order below.

(i) Architectural availability

Today's HEC market is not producing products that satisfy the performance requirements of the most demanding scientific applications. Vendors provide excellent computers where commercial computing needs overlap with scientific needs. However, where scientific or defense needs do not overlap commercial IT needs, the products are insufficient.

(ii) Acquisition of HEC capacity

Federal need for HEC in science and technology is approximately triple current capacity and grows by about 80 percent annually. This trend of demand will strengthen as advanced application usage and areas of application expand (Figure 4).

(2) Addressing HEC access, availability, and leadership

The Task Force proposes separate approaches to address the three distinct problems of accessibility, availability and leadership systems in HEC resources.

(i) Accessibility

Addressing the sharing of HEC resources

- Federal agencies whose researchers currently obtain HEC resources from other agencies should examine options for providing resources to users through cooperative agreements.
- Each federal agency should assess and make arrangements to provide for its own resource needs based on mission priority.

(ii) Availability

The Task Force calls for an increase in resources needed for mission execution.

- Federal agencies should examine the value of reallocating resources to cope with increasing demand for computing resources and increasing demand for already overburdened systems.
- Assessment and adjustment of the relative balance among research and engineering modes (theory, experiment, and computation) is needed for optimal resource reallocation.

(iii) Leadership systems

The Task Force proposes the development of so-called leadership systems in order to provide US science researchers with the world-leading HEC capabilities.

The goal of such systems is to provide computing capability at least 100 times greater than that currently available on the market. A limited set of scientific applications (perhaps 10 per year) would be selected and given substantial access to such systems. Much smaller time allocations could be available for a wider set of applications (perhaps 50 per year) for pilot experiments in preparation for full-scale runs in the future. By nature, Leadership Systems could be productive for several years, but they would need regular replacement with new leadership systems based on scientific needs and technologies emerging from research and development activities. The HEC Plan states that the results of core technical HEC R&D would be utilized for HEC systems at first, but over time those technologies could be applied to servers and finally to desktops. The Plan's recommendations are as follows.

- Provide leadership systems with leading-edge computing capability for highest-priority research problems.
- Federal agencies should manage leadership systems as national resources.
- Federal agencies should operate leadership systems as an open user facilities.
- Access to the system should be governed by a peer review process.

2-4 Procurement

Procurement of HEC systems is a very complex task. It thus requires approaches that reduce the burden on both the government and vendors. Ten years ago, it was common for an HEC system to have a service life of more than five years, but now average life span is about three to four years, necessitating shorter procurement periods.

The Plan proposes three interagency pilot projects (HEC benchmarks, TCO (total cost of ownership), procurement) to improve the efficiency of Federal HEC procurement practices.

A description of each project follows.

(i) HEC benchmarking pilot project

Sustained system performance is currently the only acceptable performance criterion for measuring procurement selection decisions. Other performance indicators, such as calculated peak performance and performance on a single benchmark such as LINPACK may be useful, but they should not be used as the basis for acquisition decisions. The HEC Plan concludes that benchmark performance on actual applications is the best indicator of a system's performance in an operational environment and makes the following recommendations.

- Selected agencies with similar HEC applications will develop a single suite of benchmarks based on their applications. This benchmark suite will be used at the pilot acquisition stage.
- Participating agencies use the benchmarking results, suitably weighted for their individual applications, instead of agency-specific benchmarks.

(ii) TCO pilot project

TCO includes all the financial aspects of providing HEC services, and comprises the following four major cost areas.

- Hardware
- System software
- Space, utilities, personnel, and extra-center communications (networking)
- User productivity (including costs of application software development)

The HEC Plan makes the following recommendations for this pilot project.

- A multiagency team would evaluate all elements of TCO (e.g., acquisition and maintenance, personnel, extra-center communications, and user productivity) across several similar systems and develop best practices for determining TCO.

(iii) Collaborative multiagency HEC procurement pilot project

Applying new techniques developed from the above two projects, participating agencies will develop a common method for procurement.

They will then evaluate its effectiveness. Evaluation criteria will include improved buying power, reduced overall labor costs, total procurement time, and ability to meet the needs of the participating agencies.

3 Points of interest

Above I have outlined the "Federal Plan for High-End Computing." The HEC program has many points of interest. I will describe some of them below along with relevant technology trends.

(1) Minimizing the time to solution

The HEC Plan frequently uses the term "time to solution." This term indicates the time required for a researcher to obtain computation results, including the program development and testing periods as well as actual computation time. The Plan emphasizes "time to solution" and proposes making it the measure of the evolution of HEC. In addition, the Plan addresses time to solution is an important factor influencing costs over the whole life cycle of a HEC system, making it a baseline for all HEC activities, including HEC R&D, HEC resources, and HEC procurement.

(2) Emphasizing sustained system performance*2

Regarding sustained system performance, the Task Force has discussed it in detail from the perspective of awareness of HEC systems, optimal R&D, and optimal procurement, and the HEC Plan strongly stresses it. The roadmap suggests improvement measures.

(3) Prioritization of R&D

The Plan's recommendations for prioritization in HEC R&D investment are meaningful in that it demonstrates areas of emphasis. The FY 2004 budget related to the HEC Plan shows the relative weights of R&D areas. It is noteworthy that each total for software and for systems is greater than that for hardware. It is also noteworthy that the HEC Plan recommends many increases from the early stages, for "basic and applied research" and "advanced development" in hardware, for "engineering and prototypes", "test and evaluation" and "long-term evolution and support" in software, and for "engineering and prototypes" in systems.

(4) Resource allocation for large, challenging problems: leadership systems

The HEC Plan states that leadership system facilities must be installed in response to large, challenging research problems that require the highest performance, and that they should be made accessible to researchers both from industry and from federal agencies. It touches on the fact that currently, in the USA as well, civilian agencies do not have access to leadership-class systems. This can be seen as urging improvement. In addition, the Plan describes the spinoffs from leadership system development as a goal. The Plan seems strongly aware that although at first the results of core technical R&D activities in HEC will be limited to HEC systems with federal missions, eventually those technologies will be applied to commercial products such as servers and finally desktops.

(5) Increased access to HEC

Regarding increased access to HEC, the HEC Plan reports rapidly increasing use in the National Institutes of Health (NIH) and increased access in industrial fields such as chemical, semiconductor, and materials sectors, where obtaining necessary data through experiments is difficult, time-consuming and/or expensive.

It is noteworthy that the Plan, at the front,

Note

*2 Information related to sustained system performance: Issues concerning the sustained system performance of US HEC systems are also discussed in a report of the National Research Council (NRC)[8] written by US academic researchers. In addition, reference[9] describes Japan's Earth Simulator, which achieves high sustained system performance. See the references for details. (The content is not included in the HEC Plan, but is shown here for reference.)

Table 8 : Comprehensive approach to R&D

Activity	Purpose	Performers
Basic and Applied Research	Refill the academic pipeline with new ideas and people	Academia and government labs
Advanced Development	Develop component and subsystem technologies	Mostly industry led, partnering with academia and government labs
Engineering and Prototypes	Integration at system level and development of Serial No. 1	Industry
Test and Evaluation	Reduce risk for development, engineering, and government procurement	Government labs and HEC centers

Source: Reference[5]

describes very interesting scientific challenges and their potential outcomes in fields such as physics, nanoscience, aerospace, life sciences, national security, earth and atmospheric sciences, and energy environment. Over several pages, the Plan describes in detail the issues and HEC needs of climate and weather research, nanoscale science and technology, life sciences applications, and aerospace vehicle design and optimization. This illustrates that access to HEC will continue to increase.

(6) Procurement emphasizing TCO*3

Because TCO includes all financial aspects to provide the HEC service, the HEC Plan describes it as an element equal to benchmarks in determining system procurement. The Plan adds that time to solution, which drives costs during the HEC system life cycle, is an especially important factor.

The Plan also strongly notes user productivity as an element of TCO. In the roadmap, key issues for minimizing time to solution include ease of application software development such as important evolutions in compilers, and the programming environment with improved portability between HEC systems. Because the lifecycle of software is much longer than that of hardware, the optimized use of the huge accumulation of software assets that have been developed and maintained over many years, and optimized portability of application assets regarding functionality and performance tuned for highly practical use are important issues.

(7) Practical performance measurement*4

Since reliable benchmarks that measure sustained system performance are an important element in determining procurement, the HEC Plan describes that federal agencies with similar applications develop and share benchmarks reflecting performance in actual operational environments. The Plan also states that research on "synthetic benchmarks" is being conducted with the support of DoD and the DOE to cope with cases where actual applications cannot be used.

(8) Comprehensive approach aiming for revitalization

The HEC plan states that the revitalization should be supported for the innovative development across the four major research stages: basic and applied research, advanced development, engineering and prototypes and test and evaluation. The HEC Plan calls it a comprehensive approach and also states that this approach is vital to the establishment of a sustainable R&D process.

Although the Plan does not give specific details, the Task Force presented the purposes

Note

*3 Information on user productivity: Refer to Reference[3] describing HPCS activity in DARPA for a discussion of user productivity. (The content is not included in the HEC Plan, but is shown here for reference.)

*4 Information on benchmarks: See References[10] and[11] for current trends in benchmarks for measuring sustained system performance in real operational environments. (The content is not included in the HEC Plan, but is shown here for reference.)

and performers of the four major stages as shown in Table 8 at an international high performance computing, networking and storage conference (SC2004) on November 9, 2004. The table shows us how the approach is being promoted.

(9) Well-coordinated interagency plans from the user's point of view

The Task Force members who created the HEC Plan are listed in an appendix to it. All members belong to a user department of an HEC-related federal agency, and therefore the HEC Plan is based on a user perspective. In addition, the HEC Plan seems to have been generated by consistently considering the missions of federal agencies in HEC R&D, HEC resource and procurement.

4 Conclusions

Regarding the HEC Plan, the 108th Congress debated at least three bills (HR4516, S2176, and HR4218) that included "Revitalization of High-End Computing" in their names during 2004. Of these, HR4516 the Department of Energy High-End Computing Revitalization Act of 2004[6] ("the Revitalization Act") was approved in November*5. During the course of the debates, HEC was described as having the ability to accelerate progress in fundamental sciences, as an essential component of national security and economic competitiveness, as having a ripple effect on industry, and as requiring the support of the Federal Government. In addition, Japan's Earth Simulator was cited several times as strongly demonstrating the necessity of HEC[7]. In addition to amounts otherwise made available for HEC, the Revitalization Act is provided with authorization of appropriations of $50 million for FY2005, $55 million for FY2006, and $60 million for FY 2007, totaling $165 million over the three-year appropriation period. The Department of Energy will use these funds for HEC research, HEC system development and procurement, the establishment of a software development center, and the transfer of HEC technology to the private sector.

The Revitalization Act specifies research of multiple architectures, research on software for HEC systems in collaboration with architecture development and the establishment of a high-end software development center. The Revitalization Act also specifies sustained access to HEC systems and to leadership systems by the research community in the USA. Therefore, the HEC environment for highly prioritized processes is enforced by providing the access to leadership systems for researchers in the United States industry, institutions of higher education, national laboratories, and other federal agencies.

So far, I have presented an outline of the HEC Plan and commented on points of interest. The Task Force has concludes that current HEC systems provided by industry are not always sufficient for the required performance of application used for Federal missions. Consequently, the Task Force compiled suggestions for HEC investment, aiming for the development of science and technology through cooperation among scientists, universities, industry, and federal agencies. In the HEC Plan, Federal agencies are identified as major users of HEC systems, and therefore Federal support is essential for HEC R&D to meet their requirements. Since Japan's Earth Simulator is regarded as an excellent system by the HEC-related personnel of the US Federal

Note

*5 The status of other bills: S2176, which mandates a five-year appropriation period and an $800 million total budget, has nearly the same content as HR4516 and was debated in the Senate in March 2004. HR4218, High-End Computing Revitalization Act of 2004, is an amendment of the High-Performance Computing Act of 1991 and was received in the Senate after passing the House of Representatives in July 2004, and was referred to the Committee on Commerce, Science and Transportation. The HEC Plan covered in this article was presented in the deliberation of this bill at a hearing of the House Science Committee in May 2004. In addition, HR28 was presented in the 109th Congress in Jan. 2005.

Government, it will have a significant impact on deciding future R&D policies.

Currently, the US government is strongly promoting HEC-centric strategies in order to maintain its global leadership in science, engineering and technology, and is making every effort to maintain and succeed in technological capabilities that can generate a ripple effect through the pursuit of ultimate technologies related to HEC.

Acknowledgements

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Acronyms and full spellings

- *CAF* Co-Array Fortran
- *COTS* Commercial-Off-The-Shelf
- *DARPA* Defense Advanced Research Projects Agency
- *DOE/NNSA* Department of Energy/National Nuclear Security Administration
- *DSM* Distributed Shared Memory
- *EPA* Environmental Protection Agency
- *HEC* High-end Computing
- *HECRTF* HEC Revitalization Task Force
- *HPCC* HPC Challenge Benchmarks
- *HPCMP* High Performance Computing Modernization Program
- *HPCS* High Productivity Computing Systems
- *IDE* Integrated Development Environment
- *MPI* Message Passing Interface
- *NASA* National Aeronautics and Space Administration
- *NIH* National Institutes of Health
- *NIST* National Institute of Standards and Technology
- *NITRD* Networking and Information Technology Research and Development
- *NOAA* National Oceanic and Atmospheric Administration
- *NSA* National Security Agency
- *NSF* National Science Foundation
- *NSTC* National Science and Technology Council
- *ODDR & E* Office of the Deputy Director Research and Engineering
- *OMB* Office of Management and Budget
- *OpenMP* Open specification for MultiProcessing
- *OS* Operating System
- *OSTP* Office of Science and Technology Policy
- *PIM* Processor-In-Memory
- *RAS* Reliability, Availability, Serviceability
- *TCO* Total Cost of Ownership
- *UPC* Unified Parallel C

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5

R&D Trends of LSI Design Technology
— Bottleneck at Development of System LSIs that rule Value-Added Electronic Devices —

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1 Introduction

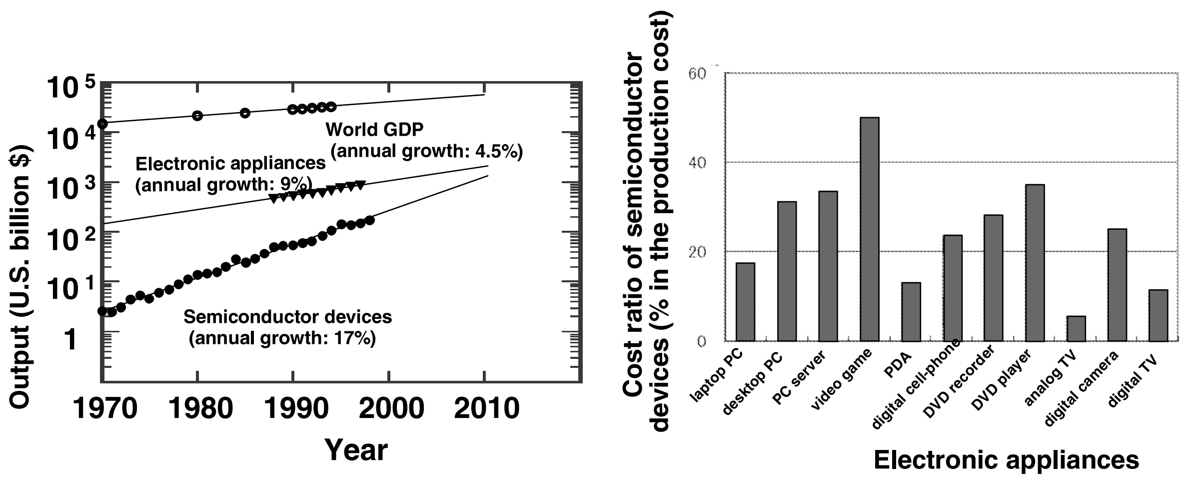
1-1 Much more value in an LSI

The progress of the semiconductor LSI technology has played a major role in the progress of advanced multi-functional electronic appliances, where such progress is represented by the LSI's increasing compactness, reduced power-consumption, and further multi-functionalities. Certain essential electronic components for appliances have been built using a couple of modules (a few centimeters in width and depth) capable of accommodating a few different kinds of LSIs. These modules are being replaced by system LSIs (a few millimeters in width and depth).

The system LSI critically affects the price and performance of the appliances. The annual output of electronic appliances and semiconductor devices is shown in Figure 1(a), together with the world GDP[1]. The GDP shows 4.5% of the mean annual growth rate, while the appliance output is shown as 9% of mean annual growth. This represents the fact that electronic appliances are increasingly consumed ahead of other purchases. The semiconductor device output shows 17% of mean annual growth, which is higher than that of appliances (9%), signifying that the importance of semiconductor devices is increasing among the components implemented in electronic appliances.

The cost ratios of semiconductor devices to the number of electronic appliances are shown in Figure 1(b)[2]. Digital technologies, when used alongside advanced signal processing, inevitably

Figure 1 : Annual output of electronic appliances and devices, and the cost ratio of semiconductors in appliances



(a) Output of electronic appliances and semiconductor devices

(b) Cost ratio of semiconductor devices in electronic appliances

Source: References[1, 2]

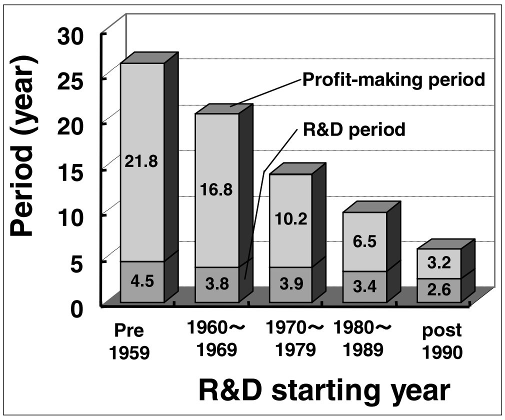
involve an increase in the semiconductor cost ratio. To be precise, this ratio sometimes reaches up to 50% in PCs and video game machines.

In future, the cost of electronic appliances will be governed by that of LSIs. The performance and cost of LSIs are essential for the successful business of electronic appliances, whereby the value of appliances is dominated by LSIs.

1-2 Encountering LSI design crisis

R&D and profit-making periods of products, services, and manufacturing (abbreviated as products hereafter) are plotted versus the R&D starting year in Figure 2. Over the last 30 to 40 years, the profit-making period has become ever-shorter compared with that of the R&D period. The ratio of both (profit-making/R&D) was about 5, but has since reverted to around 1.2, indicating a shortened product life-cycle.

Figure 2 : R&D periods and profit-making periods of products versus R&D starting years



Source: Prepared by the authors, based on reference[3]

Business success depends on technologies used to reduce the leading time (R&D period) in business circumstances involving shrinking product life-cycles. The technology for the swift development of LSIs is essential to the electronic appliance business.

However, system LSI development is facing a crisis. The productivity of silicon-semiconductor LSIs (in terms of the degree of integration) has been developed ahead of the roadmap (international technology roadmap for semiconductors (ITRS)), while the LSI design productivity has lagged behind that[4]. The number of transistors integrated in an LSI chip has increased by 58% annually (4 fold in 3 years), while the LSI design productivity per engineer has increased by as little as 21% a year, despite the introduction of design automation tools and increased computer power, as shown in Figure 3.

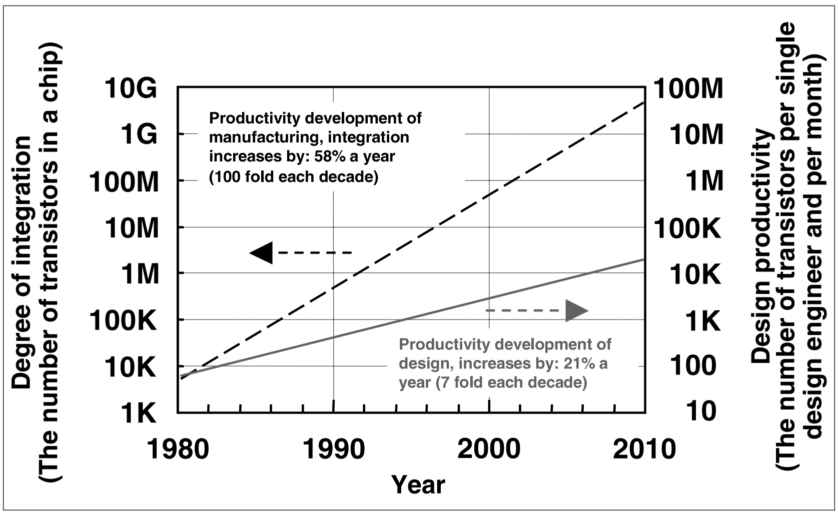
Focusing on system LSIs essential to electronic appliances' value, this feature article analyzes trends in LSI design technology and discusses present and future issues.

2 Design technology of LSIs

2-1 LSI design technology

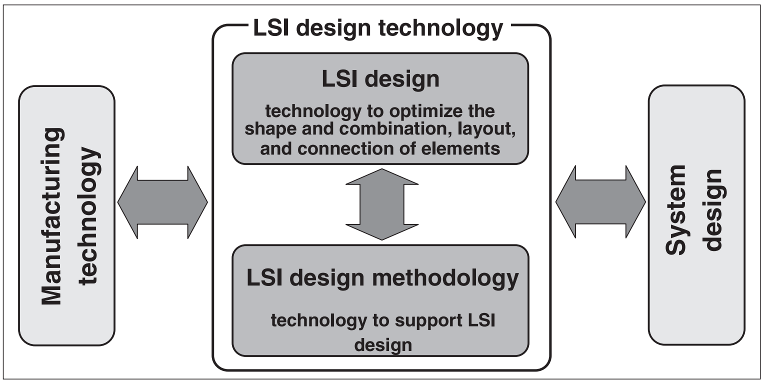
LSI design technology stands for technology used to design an LSI capable of logic operation and electronic properties that meet system requirements, optimizing the physical shape of elements, their combination, individual layout, and inter-element connection, on the basis of

Figure 3 : Maximum number of transistors in manufacturing and design



Source: ITRS

Figure 4 : LSI design technology



an available fabrication technology as shown in Figure 4.

During the optimization process, the technology can be subdivided into two (technology to design, and that to support the design), where the two technologies differ in nature and the knowledge required to use them. Their quality is evaluated using different characteristics, in many cases.

The quality of the design is, for example, evaluated by the chip performance design: processing speed, power consumption, etc. The quality of the support, meanwhile, is evaluated by the design productivity: the design period compared with the number of integrated elements, etc. When elements highly dependent on its manufacturing process are designed, the performance is optimized through a series of processes: initially, the modeling of physical phenomena and elemental characteristics; secondly, the model is replaced by a descriptive language; thirdly, elemental performance with regard to the element shape and size is computer-simulated; and finally, the performance is optimized without experimental fabrication. Accordingly, element design productivity is increased. Here, two processes play a particularly important role, namely: modeling, the means by which the description, representing the physical phenomena and element characteristics, is simplified without losing precision and reliability; and the period for designing, namely how quickly the performance is estimated with considerable precision and reliability.

Here, the technology with which LSIs are designed is called “LSI design,” while that used to support the LSI design is called “design methodology.” In this article, the latter, design methodology is discussed in detail.

2-2 Progress in design automation technology

Increasing the number of elements integrated in an LSI under Moore's law (exponential increase in the number of elements), LSIs have shown progress in design methodology to accompany the increase. The progress in electronic design automation (EDA) has been remarkable, as shown in Table 1.

The EDA technology has changed the style of description language every decade, while the number of elements in an LSI has increased 100 fold over the same period. The design methodology must have been changed drastically in order for design engineers to keep pace with the increase in elements, rather than minor improvement in the design process. The progress of the design methodology was achieved employing further abstract descriptive language, as shown in Figure 5. More upper notion, or more abstract language, has become essential with the increase in elements, owing to the limited number of logic circuits which can be simultaneously considered by design engineers.

In the course of the progress of EDA tools, a number of venture companies have been set up and selected, some of which have become well established firms providing a de facto standard for tools. However, the standards of some failed companies are still in use, such as the GDS II format (data format of a mask pattern, Calma Company, in the US).

Having developed as shown in Table 1 and Figure 5, the descriptive style of the LSI design is still based on “hierachical description level,” which was employed in the opening EDA phase.

2-3 Recent R&D trends

(1) Hardware/software co-design

After specifying the interface between hardware and software, each has been developed independently, in most cases. With an increase in system size, a variety of problems occurred, relating to ambiguity of the specification or certain other issues, shifting from hardware to software during the development process.

The hardware/software co-design is in contrast with the conventional design process, where the function and interface are defined to take account of the mutual trade-off, in the course of measuring and optimizing system performance, as shown in Figure 6(a), (c).

Sometimes, the priority of a certain function governs the choice of whether it is realized by mainly hardware or by mainly software. Here to realize LSI functions mainly by hardware means that special circuits are designed to satisfy each function of LSI. On the other hand to realize LSI functions mainly by software means that various software which works on general circuits is used to achieve LSI functions. Employing an increased number of application specific LSIs, the system achieves reduced power consumption and accelerated operation, which

Table 1 : Progress in LSI electronic design automation

Year	Description method	Description level	Remarks	Major tool vendors
'70 ~	Mask pattern	Physical shape of elements	Described using a two-dimensional layout pattern for each mask	Applicon (1969) Calma (1970) Computervision (1972)
'80 ~	Circuit diagram	Elements such as transistors	Described by element and logic gate symbols	Daisy (1980),Mentor (1981) SDA (1983, Reorganized to Cadence) Optimal Solutions Inc. (1986, Reorganized to Synopsis)
		Logic gate		
'90 ~	Text language	Register transfer	Described using text language to show data flow and a series of data processing	Syntest (1990)
		Transaction		
		Behavior	Each part of system behavior is described	CoWare (1996) TenSilica (1997)

Established years are in parentheses

Figure 5 : Progress in the descriptive style of LSI design and present hierarchical description level

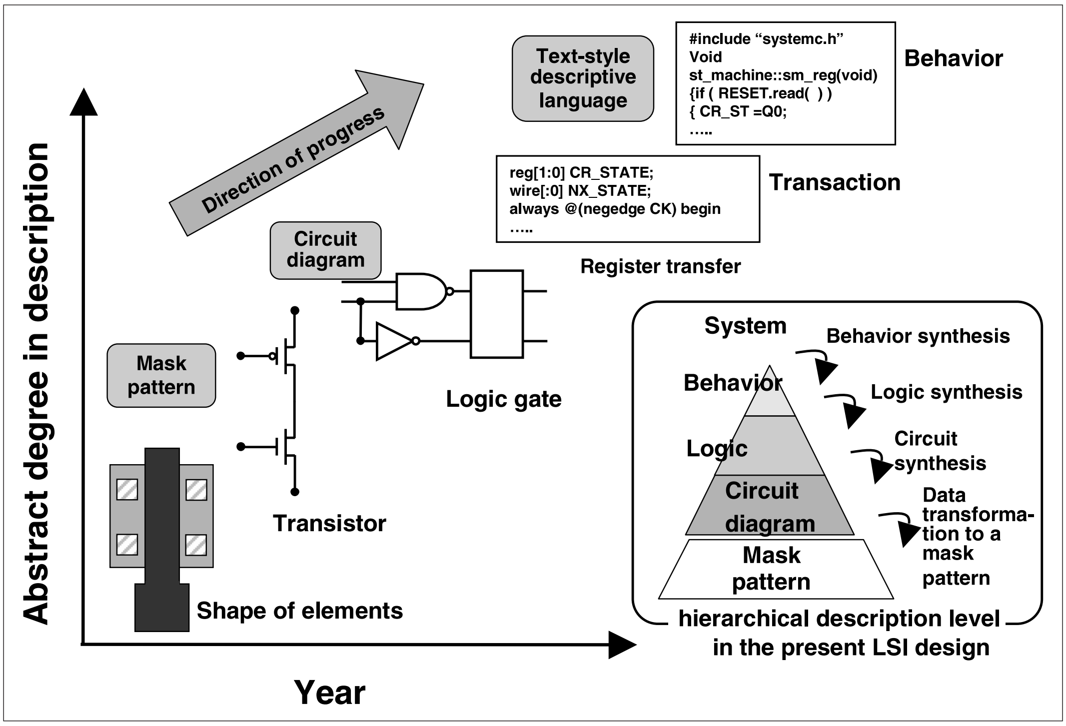
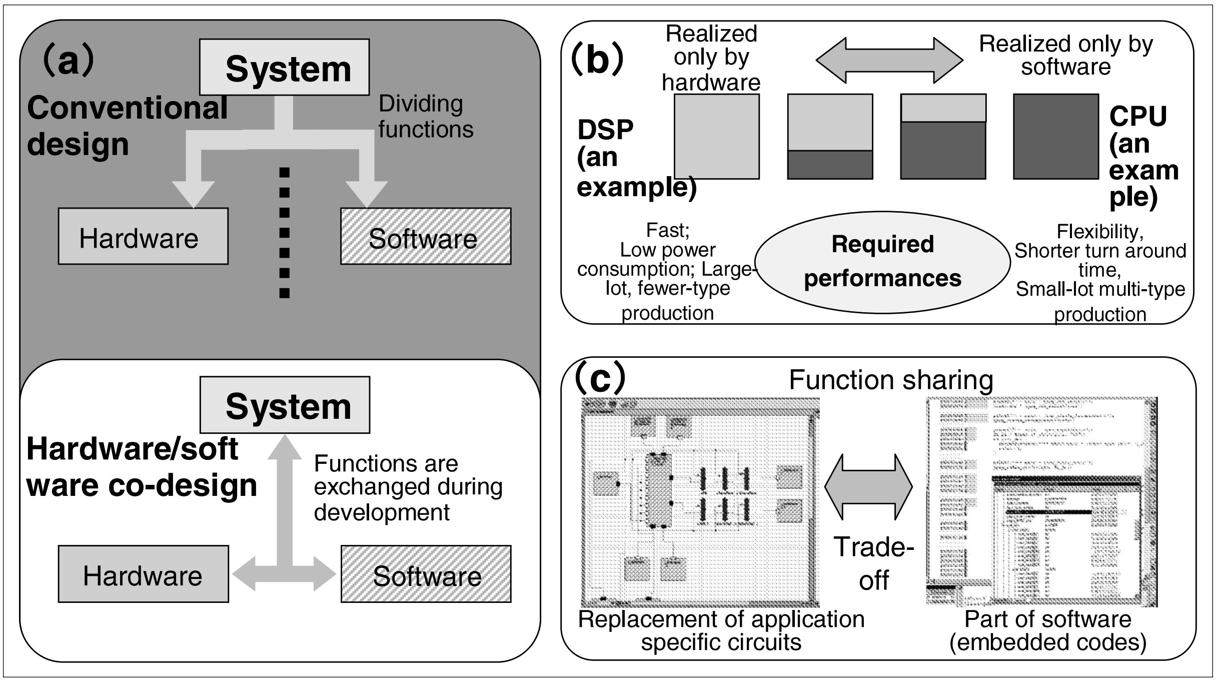


Figure 6 : Hardware/software co-design



is then used for mass production of products, due to its longer development period. Employing more software-dependent functions, the system becomes more flexible for development, and can then be used for products for a specific market, due to the shorter turn around time, as shown in Figure 6(b).

The hardware descriptive language, which has replaced symbol-based description, provides advantages during the hardware/software co-design process, whereby the development of hardware and software is smoothly linked from an initial rough-sketch of an LSI to a final system operational test. In the early 90s, LSI hardware was computer designed, and its operation was tested by a computerized logic simulation. Before the introduction of hardware/software co-design, an LSI was designed after dividing its functions into hard- and software related respectively.

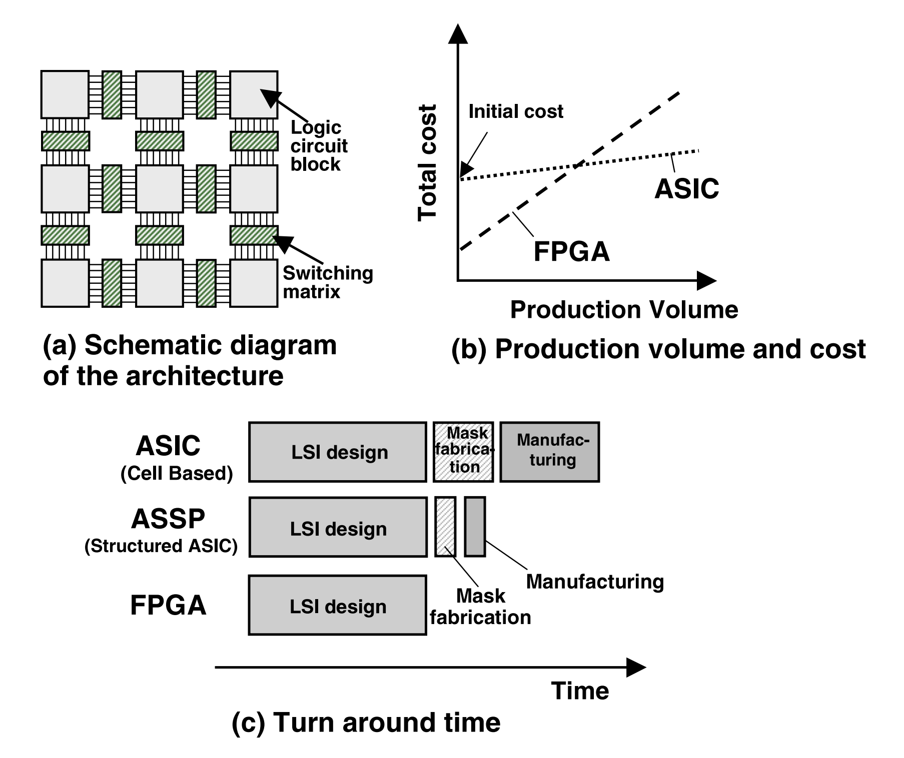
The hardware/software co-design has the advantage of a shorter turn around time, but prior to introduction, software was developed once the hardware specification was established, at a time when hardware and software could not be developed alongside each other in parallel. Given the advent of certain problems unable to be resolved through the use of software alone, hardware had to be re-designed, which considerably extended the period of time required for hardware development. However, hardware/software co-designs effectively prevented any such loss in turn around time.

(2) Shorter turn around time of LSIs

The aforementioned LSI design technology contributes, to some extent, to designing and commercializing increasingly highly-integrated LSIs in a shorter period, whereby another technology is attracting attention based on a tendency toward shorter product life-cycles. In conventional technology, LSIs are manufactured using masks prepared once designs are completed and are individually prepared for each product or customer respectively. A field programmable gate array (FPGA) and programmable logic device (PLD) contrast with the individual-mask manufacturing process, in which a customer realizes their desired functions by electrically arranging internal LSI connections, in which elements and connections are laid out in lattice form.

The FPGA is constructed by laying logic blocks and switching matrices in a lattice form, as shown in Figure 7(a). The FPGAs are manufactured using common masks, rather than those specific to a product or customer, and are used after electrically switching the internal connections through programming. The common mask reduces the initial cost to a level less than that required by an application specific integrated

Figure 7 : Shorter turn around time employing programmable LSIs



circuit (ASIC), as shown in Figure 7(b), and also shortens turn around time, contrasting with that required by individual-mask manufacturing, with a few months of manufacturing lead-time, as shown in Figure 7(c).

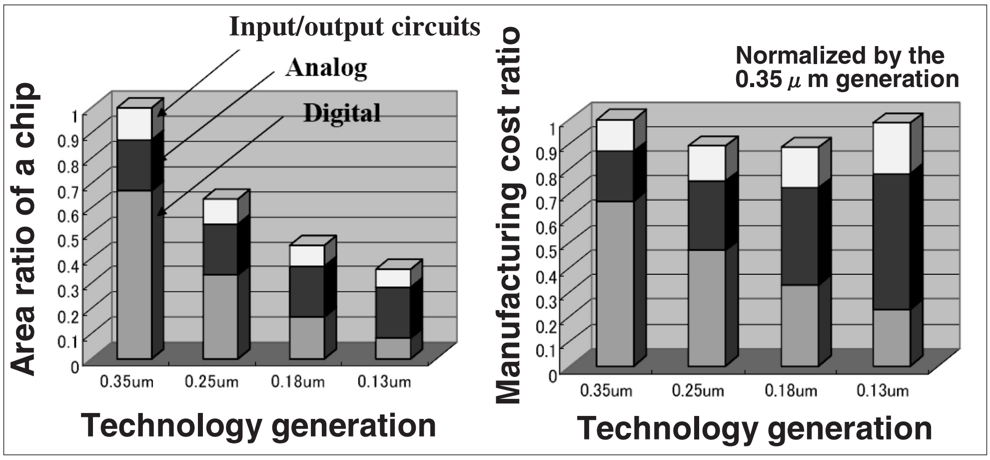
So far, the FPGA has encountered setbacks, such as the redundant use of logic circuits, reduced processing speed, and higher power consumption. The setbacks limited the use of FPGA only in test-production for function checks, etc, owing to disadvantages in integration, processing speed, power consumption, and price, in comparison with the same generation of LSIs. The FPGA was not commercially manufactured, and was replaced by LSIs for mass-production, where the FPGA-certified design was transferred to the LSI accompanied by certain reconfiguration of physical layouts, etc.

Despite the setbacks, the market requires the FPGA, under the present circumstances: The LSI manufacturing technology has seen LSI design progress ever further. This allows, in some cases, improved FPGA performance implementing the latest LSI manufacturing technology, although the FPGA remains hampered by the inclusion of redundant switching matrices. In addition, certain FPGAs are manufactured at a competitive cost in the case of small-batch manufacturing, due to the increasing cost of manufacturing LSIs: the increasing cost of mask fabrication (exceeding 100 million Yen for LSIs) and increasing risk (in terms of the development cost and period) of re-fabrication of the mask being required due to design failures. Demonstrating the remarkable progress of FPGA technology, Xilinx, Inc., U.S.A., has recently commercialized an FPGA product using a 90 nm process (power supply voltage: 1.5 V, multi-processor, large memory: a few Mb, system clock frequency: 500 MHz, equipped with clock management).

Recently, there has been considerable focus on application specific standard products (ASSPs), located midway between the ASIC and FPGA in terms of performance and cost. The lower layers of the wafer are common among certain ASSPs, while upper layers are customized for each customer. The ASSP has the advantage of basic functions being standardized, one example of which is a cellular phone ASSP standardized by a wireless telecommunication protocol. In this case, the ASSP is manufactured using IPs*1, namely, reusable circuit-design assets. An embedded processor is manufactured licensing IPs owned by ARM Ltd., UK, representing the de facto standard in this field.

ASIC is comprised of a "cell," (the smallest ASIC

Figure 8 : Area ratio of analog circuits on an LSI chip and manufacturing cost



Source: Reference[5] by courtesy of Prof. Matsuzawa, Tokyo Institute of Technology

unit) that is developed by each manufacturer. This represents a "vertically integrated product," with which Japanese companies have considerable expertise and includes the advantage of large-lot, fewer-type production. Digital home appliances are, however, standardized in most signal interfaces, making it difficult to render superior performance. Each appliance is thus only allowed superiority in peripheral functions, etc.

(3) Increasing importance of Analog-circuit design technology

With the miniaturization of digital circuits and automated design of LSIs, the importance of analog circuits is increasing. Even when the signal processing is digitized, it is impossible to eliminate analog circuits, one reason for which is the fact that a digital signal is converted to a human-sensible analog through a human interface. A deteriorated digital signal is recovered using analog-circuit technology when a digital signal is disturbed or faded during the read/write of high-density data or broadband communication. Analog technology has long been believed to require considerable knowledge and experience on the part of design engineers, from the time when discrete components were assembled into circuits. The analog circuit, which handles small-amplitude high-frequency signals in many cases, requires a large number of circuit-property indicators than the digital equivalent. Together with knowledge on materials and physical qualities of elements, the analog circuit demands on the part of design engineers for a broad range of knowledge on a system in order to totally optimize it.

The elements of a digital circuit reduce in size according to the "scaling rule," and experience enhanced performance over the course of a new generation of technological change, while analog elements include a variety of passive elements*2 and are only miniaturized to a limited extent over the course of the technological generation change: for example, there is a trade-off between the respective miniaturization and high-performance of inductors. The analog circuits start expanding surface areas in comparison with shrinking digital circuits, which has an increasing influence on the LSI manufacturing cost, as shown in Figure 8. The design period of the analog circuit is relatively longer, due to a lack of design automation tools and the design adjustment required to maximize the performance of the heavily-manufacturing-dependent analog circuit.

The design and manufacturing cost of LSIs is becoming dependent on the analog circuit, while a cellular phone, a representative product using high-frequency analog LSIs, is renewed every few months. The analog circuit will play an important role in reducing development and manufacturing costs and commercialization of competitive products, where the analog circuit may suffer from a lack of design engineers owing to the longer period of time required to educate such engineers.

(4) Future trends

The design technology is facing a crisis due to its slow progress in comparison with manufacturing, particularly in terms of productivity, as discussed in Chapter 1. Testing technologies of design and products are also inferior to actual design technology, a situation predicted to worsen as LSI development becomes more sophisticated to meet a variety of requirements. However, this is a region where an innovative technology may arise.

On the other hand, LSI design technology and manufacturing have become mutually dependent, where new methodologies such as design for manufacturing (DFM) and design for yield (DFY)[6] have been proposed. Although the LSI yield had been believed to be governed by manufacturing technology, a couple of reports claim that design technology governs the yield more than that of manufacturing following the technology generation of 90 nm.

The design technology is understood as becoming more important to bridge increasingly-sophisticated manufacturing technology and a system which will demand more various and more complicated performances. Progress in LSI and LSI applications (electronic appliances) may not be achieved without equivalent progress in LSI design technology.

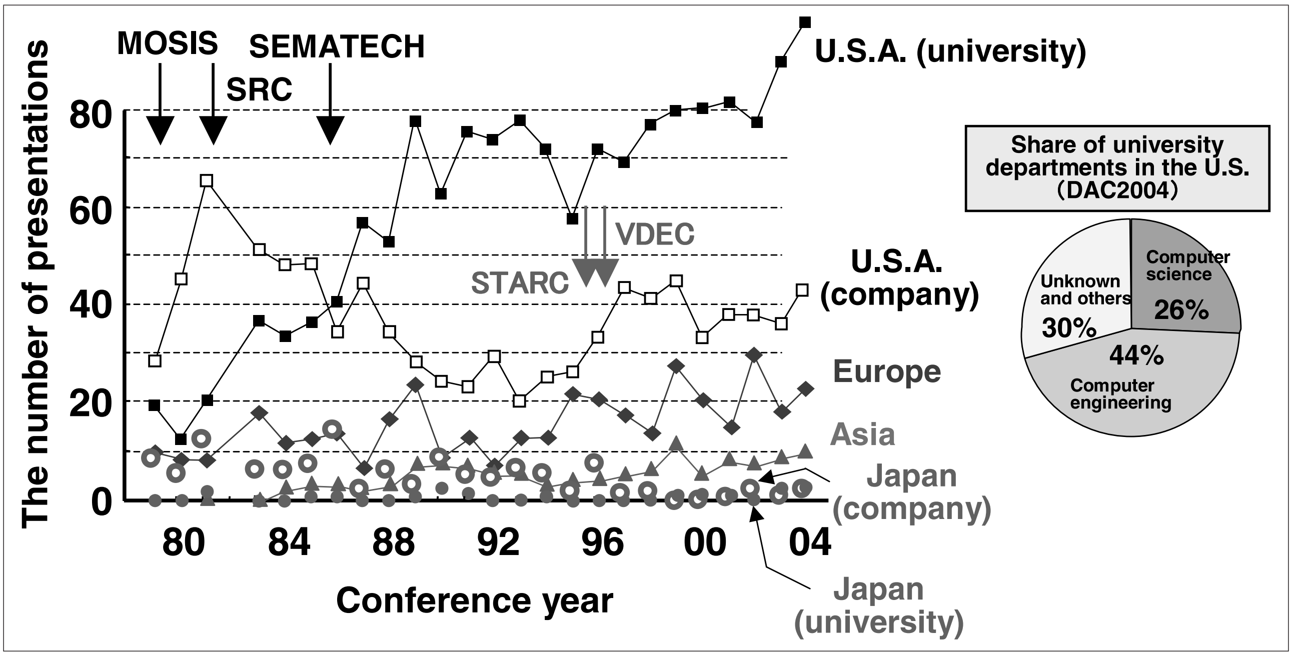
3 Present R&D status and its issues

3-1 In view of the number of presentations at conference and filed patents

Figure 9 shows trends in the number of presentations at Design Automation Conference (DAC), one of the most prestigious LSI design conference[7].

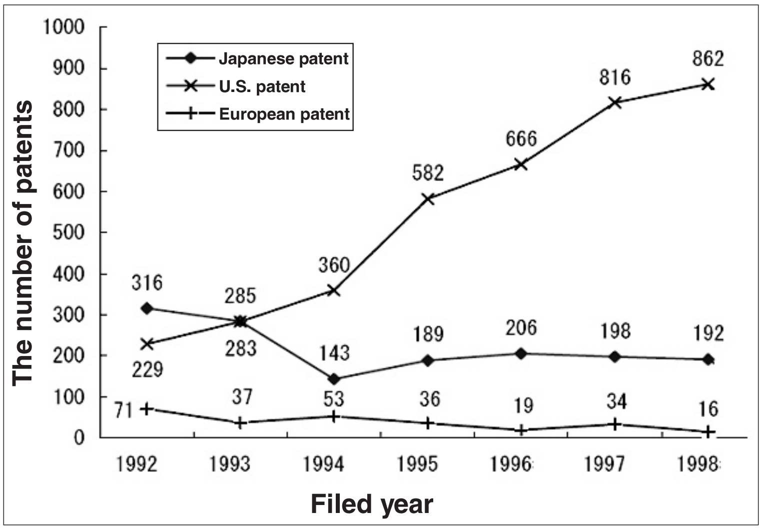
In the early 80s, U.S. companies shared most of the presentations. Once a test-production service had started at the MOSIS, U.S.A., an institution funded by the government, and the industry-university collaboration at the Semiconductor Research Corporation (SRC) got underway, presentation by U.S. universities increased greatly. Presentations from Japan, however, mainly by Japanese companies, numbered about 10 in the early 80s, comparable to that from Europe (including both companies and universities). Post 80s, however, Europe gradually increased the number of presentations, while Japan decreased its volume to 2 or 3 in the 1990s and shows no sign of advancing on this figure at present. In Japan, despite the existence of the VLSI Design and Education Center (VDEC), an LSI test-production institution comparable to the MOSIS, and the Semiconductor Technology

Figure 9 : The number of presentations at DAC by country/area and university/company



Source: The graph of "The number of presentations," courtesy of Dr. kozawa, STARC.

Figure 10 : The number of EDA patents filed in Japan, Europe, and U.S.A.



Source: Reference[8]

Academic Research Center (STARC), funded by business, which have been in operation since the mid 1990s, publications from Japanese universities, which have been scarce to date, show no signs of any increase up to now.

Dividing the number of presentations from the U.S. and Japan into companies and universities respectively, the figures are plotted on Figure 9, where presentations from Europe and Asia (excluding Japan) are mainly contributed by universities note1. As shown in the circle graph in Figure 9, 70% of the presentations at DAC 2004 were contributed by computer-related departments.

Patent numbers filed in Japan, Europe, and the U.S. are summarized in Figure 10. In the early 90s, many Japanese patents were filed mainly by Japanese companies, indicating that design technology was developed to some extent by Japanese companies at that time. However, U.S. patent filing increased far more than Japanese patents in the 90s.

To date, Japanese companies have conducted vertically-integrated semiconductor businesses, where LSI design tools and IPs were developed in house, coupled with design methodology development. Recently, however, Japanese companies have tended to replace self-developed tools and IPs with de facto standard EDA tools and IPs provided by U.S. vendors, considering the productivity of development and maintenance. The small number of presentations by Japanese companies may also reflect this trend. Japanese companies are moving toward users of tools and IPs, without research into the associated methodology.

One reason why Japanese companies are behind the recent progress in design technology is related to their success in semiconductor memory manufacturing. Memory design and manufacture in this area are not as complicated as with functional LSIs: the increase of elements in memory is accomplished without further design complication, despite an exponential increase in elements. The U.S. companies shifted their business from memory chips to functional LSIs, once the memory manufacturing business shifted from the U.S. to Japan in the late 80s. Realizing the importance of LSI design technology, U.S. companies strategically conducted their R&D on design technology, while Japanese companies may require considerable time to gain a competitive edge in this technology.

3-2 R&D promoting activities in some countries

R&D on LSI design technology is promoted in certain countries[9, 10], as shown in Table

Note

1 The share of presentation at DAC 2004. Companies in Europe, 2%; universities in Europe, 12%; companies in Asia (besides Japan), 0.8%; universities in Asia (besides Japan), 10.2%.

2. Taiwan, in particular, has been attracting attention for its promotional program in this field. Following the success of its foundry business, Taiwan is trying to renovate its industry structure from manufacturing to LSI design, assisted by government promotion. The LSI design technology, as a successfully highly-prioritized field, has been reinforced in a short period. The Si-Soft project[11], started in 2003, targets the reinforcement of design technology and involves more than 255 professors and associate professors being invited, mainly from the U.S., over 3 years, and the investment of 100 billion Yen over 4 years: of which 30% is from government and 70% from companies.

In the U.S., the federal government has funded design research in universities from the early phase of this technology, promoting

Table 2 : Research promoting activities in countries and areas

Region	Government project, etc	Major participants	Budget	Remarks
U.S.A.	FCRP backed by MOSIS, SRC, and MARCO(from 1998), etc. Design, test, and interconnection technologies in universities are reinforced.	UCB, University of Illinois, CMU, Stanford University, University of Texas, many others	SRC: budget, about 4.5 billion Yen a year; FCRP: 1 billion Yen a year.	Private companies (EDA tool vendors, Intel, IBM, etc.) develop the design technology, as well. A private organization is standardizing the interface, etc.
Europe	The organization on information and communication technologies in the European Commission prioritizes the reinforcement of semiconductor technology, with an industry-government-university collaboration under way: Alba (Scotland), IMEC (Belgium), and LETI (France).	STM, local universities, many others	IMEC: budget, 10 billion Yen a year; Alba: budget, 10 billion Yen a year (Semiconductor)	Serious in educating on design technology; Europe is competitive in analog communication ASICs for Nokia, etc.
Taiwan	The Si-Soft project is under way (from 2003, 4 years). Taiwan plans to double the number of university researchers, inviting more than 255 professors and associate professors in 3 years from overseas (mainly from the U.S.A.). More than 1,000 design engineers and researchers (Masters and PhD.) a year are planned to be produced by this increase.	National Taiwan University, National Tsuing Hua University, National Chiao-Tong University, National Cheng-Kung University	Si-Soft project: budget, 100 billion Yen for 4 years	The government reinforces industry design technology, and renovates the industrial structure.
South Korea	The Embedded System Research Center (ESRC) was established in ISRC. Research into embedded system software, SoC design technology, and real-time OS.	KAIST, Seoul National University, ISRC (ESRC)	ISRC: budget, about 1.5 billion Yen a year.	Samsung announced a focus on system LSIs henceforth.
China	Government has assigned seven areas (Shanghai, Beijing, Wuxi, Chengdu, Dalian, etc.) for their IC industry development. There is the government funded IC R&D Center (test-production, EDA, product-test service), in which universities have established a number of design-related venture companies.	Tsinghua University, Shanghai Jiao Tong University, Beijing University, Fudan University, Dalian University of Technology		China is planning to standardize its own EDA.
Japan	Reinforcing the design capability at VDEC and STARC. Promoted by the Fukuoka Pref. System LSI Designing Base Development Project (started in 2001) and the Kyushu Silicon Cluster Formation Program (Council of Silicon Innovation, Kyushu).	Kyushu University, Kyushu Institute of Technology, Fukuoka University, Waseda University, etc, STARC	VDEC: budget, about 400 million Yen a year; STARC: capital, 440 million Yen; Fukuoka IST: budget, 2,560 million Yen	In operation in the Kyushu region, etc., funded mainly by local governments.

MOSIS: Institute for the test-production of LSIs, built by the government and privatized shortly afterwards.
SRC: Semiconductor Research Corporation: Established in 1982 with the objective that the universities conduct research to meet the needs of participating companies.
FCRP: The Focus Center Research Program: A project to reinforce research into non-competitive, commonly-shared technology by U.S. universities.
IMEC: Inter-University Microelectronics Center: Started in 1984 as a non-profit organization, currently employing over 1,000 researchers.
ISRC: Inter-university Semiconductor Research Center: Established in 1985 with the objective of promoting industry-government-university collaboration.
VDEC: VLSI Design and Education Center: Design education center for large-scale systems. An institute to support universities for their education on LSI design and test-production.
STARC: Semiconductor Technology Academic Research Center: Institute to support industry-university collaboration funded by companies.

Source: Prepared by the authors, based on references[9, 10] the establishment of venture companies, some of which have influential R&D power in this field. Besides venture companies, Intel, IBM, etc. have been developing EDA tools and design methodology to develop state-of-the-art LSIs.

In Europe, LSI design technology has been reinforced by industry-university collaboration, such as that in the Inter-university of the MicroElectronics Center (IMEC) from the early phase of technology under the initiative of the European Commission. STMicroelectronics, IMEC, etc. show their strength in high-frequency analog LSIs for wireless communication, having Nokia (a world-beating cellular phone manufacturer) as a customer.

In South Korea, a government-funded design-technology development project was started in February 2005 and is focusing on embedded systems. This project targets the reinforcement of technology for embedded software and systems.

Together with reinforcing LSI design technology, China is promoting R&D in LSI design methodology, backed by its huge market. Using the EDA tools currently provided by U.S. companies, China is attempting to develop its own proprietary EDA tools to replace the U.S. tools.

In Japan, VDEC (government project) and STARC (industry-university collaboration) have been in operation for about 10 years, although their budgets are uncompetitive. Recently, a project to develop the LSI design technology got underway in Fukuoka prefecture, promoted by local government. However, except for projects funded by local governments and companies, there is no project well funded by national government.

Following the success of the Semiconductor Manufacturing Technology (SEMATECH)*3, common interfaces are proposed to effectively exploit design environments and IPs, which are monopolized and solely provided by the U.S. They are, for example, the Virtual Socket Interface Alliance (VSIA, established in 1996) and the Structure for Packaging, Integrating, and Re-using IP within Tool-flows (SPIRIT, established in 2003).

SEMATECH standardized interfaces are used within semiconductor manufacturing equipment as a form of non-competitive commonly-shared technology, which has enabled the flexible combination of equipment within a manufacturing factory. This has promoted the use of standardized, de facto equipment for specialized manufacturers.

4 To strengthen competitive technologies

4-1 Why LSI design methodology ?

The EDA tool industry is one of the smallest segments in the semiconductor business, sharing about 400 billion Yen (2% of the semiconductor market). The productivity of LSI design is dependent on the performance of such EDA tools, which therefore play an important role in overall industry progress.

Semiconductor manufacturing technology in Japan was believed to have a cutting edge, particularly in terms of DRAM manufacturing. When the interfaces between manufacturing equipment were standardized by SEMATECH, this opened the way for specialized manufacturing, opening the door to the innovative manufacture of LSIs and allowing any company in possession of de facto equipment to do so. The technology materialized in the form of equipment, where Japanese companies, with competitiveness in the shape of combined technologies, lost their competitiveness. Japanese companies did not have competitiveness in terms of equipment, while other equipment vendors provide their standardized products to a global market, ensuring a uniform level of quality in manufacturing technology worldwide. Under such circumstances, the LSI manufacturing companies, unable to develop their technical advantages, face difficulties in establishing barriers to entry.

The LSI design has been developed in the same way as DRAM manufacturing technology, where the enhancement of design productivity has allowed the introduction of IPs in the form of IP-based design or platform design*4, to become increasingly commercially available. With progress in interface standardization by institutes and companies discussed in

Chapter 3, the LSI design is specialized in individual fields, dividing providers and users of the design tools. Every design engineer can complete their job with quality, provided the engineers have highly-automated tools and commercially-available IPs, meaning differences in engineer quality and certain improvements to tools do not affect the final product. However, the personnel cost may govern the competitiveness of the LSI design.

The imported EDA tools and IPs may jeopardize national industrial security: thus their export regulation puts a stop to the LSI design, even when the LSI manufacturing industry competes effectively on a global scale. In addition to industrial competitiveness, certain key components used inside the country should avoid excessive dependence on imported design tools. Considering this risk, China is attempting to develop its own design methodology and form of EDA technology, possibly also providing its own standard of tools.

A value-added LSI design is substantially governed by LSI design methodology, used to develop commercial IPs and common design tools. Without knowledge and expertise concerning this methodology, the limits and issues of the present methodology cannot be understood, and people remain incapable of coping with newly-emerging problems. Competitive LSI design technology is recognized as technology used to produce and move to the next-generation design methodology.

4-2 Action in scope

The LSI design technology of Japan (mainly Japanese companies) was more competitive than the present, as discussed in previous chapters. The competitiveness in the R&D of Japanese companies has been lost, while that of Japanese universities shows no progression. Recently, countries and certain regions in Asia, other than Japan, have been promoting development of LSI design technology to achieve reinforcement in a short period of time.

Considering current circumstances, actions are proposed to a certain extent to reinforce the competitiveness of LSI design technology in Japan.

It is vital to retain a number of engineers and researchers, and properly educate them, as innovative design technology develops; incorporating new ideas and fresh capability to materialize the latter, fully dependent on the ability of engineers and researchers. Researchers in silicon LSI technology are extremely lacking in Japanese universities, in comparison with other countries [note2]. Certain tertiary research programs also failed to keep pace with the change in the semiconductor industry structure. Research into III-V column compound semiconductors, such as GaAs, represents 25% of the programs in universities in Japan, though the share for compound semiconductors is as small as 1 to 2% of semiconductor sales[12], representing a smaller number of Si-related researchers in Japanese universities than that overseas. The inclusion of some industry and overseas researchers should be considered in Japanese universities, to compensate for this mismatch.

In the long run, education on design technology should be reinforced in Japanese universities. The contribution by computer-related departments in universities is remarkable in the U.S. (Figure 9), Europe, and Asian countries apart from Japan, meaning certain measures to reinforce related areas of education in Japanese universities are highly anticipated[12, 13].

When a new LSI is designed, the development of a new methodology is also often necessary.

Together with each government-funded program for design methodology used to develop key LSIs, one of the actions involves conducting a government project, for example, focusing on security-related LSI technology as one of the basic technologies of the ubiquitous network.

This new LSI technology is related to that used to establish secure environments in the fields of electronic currency, identity recognition,

Note

2 This field in Japanese universities is comprised of 50 professors and vice professors. The Si-Soft project in Taiwan is planning to, at least, double the number of researchers (at 200 before the project) in universities in three years

and encryption. The new-LSI development will contribute to reinforcing Japan-original LSI design technology, even if the LSI is not highly integrated and may not share a large market in the semiconductor business. LSI design relating to national security should not be dependent on the "black-box" imported EDA tools and IPs. In addition, a synergistical technical effect is expected when the new LSI design methodology is successfully developed.

Well-experienced engineers, who were in charge of the development of EDA technology in Japanese companies, still have the capability to work. They may contribute toward reinforcing EDA technology in Japan, collaborating with younger engineers and transferring their expertise. If the present chance is lost, the engineers teaching LSI design technology may become too senior and be lost, thus prompting an influx of overseas design engineers, together with EDA tools. It is the last chance for their expertise to be transferred to and maximized in the younger generation.

LSI design technology will face future issues, which may arise in analog circuit design, and design and product testing. Besides those, a variety of issues may arise in the increasingly-sophisticated LSIs. In the field of consumer electronic appliances, the most advanced and sophisticated LSIs are, however, commercialized in Japan prior to other countries and areas. Japan has a market with the advantage of accepting advanced and innovative systems and LSI design. The highly-valued requirements for LSIs should not be presented only to foreign EDA tool vendors from LSI manufacturers in Japan, which are encouraged to share technical issues with universities through conferences, exhibitions, and industry-university communication. Sufficient technical capability to resolve current issues is demanded on the part of universities.

5 Conclusions

The value of electronic appliances is becoming governed by system LSIs, where shortening appliance life cycles are rendering technology to design sophisticated LSIs in a short period vital. LSI development is more heavily dependent on design technology rather than manufacturing, and is facing a bottle-neck in such design technology.

LSI design methodology has shown progress each decade, abstracting the design description method: in the 70s, the layout pattern of elements; in the 80s, circuit diagrams using symbols; and in the 90s, text-style language. The design technology has progressed alongside software technology development.

Design technology in Japan, however, which was behind the progress of the highly abstracted description, has not shown equivalent progress, since the description has become more highly abstract. The presentation of design research by companies, universities, and institutions in Japan, has actually gone down at DAC, a prestigious conference in this field, where accepted presentations from Japan currently represent 2% of the whole.

Universities share 70% of DAC presentations, and play an important role in developing design technology. U.S. universities began to increase the number of presentations accepted at DAC once the LSI test-production service and industry-academy collaboration got underway. Taiwan, meanwhile, successful in semiconductor manufacturing, has been rapidly reinforcing their LSI design technology, under government leadership. With other regions and countries also reinforcing such technology, Japan is being left behind.

More researchers in this field, where a lack of numbers causes R&D to deteriorate, are necessary in Japan. In the short run, researchers may be employed from industry or foreign countries, but in the longer term, the university education related to computer science or engineering should be reinforced to produce engineers and researchers capable of developing design technology.

A new LSI design methodology could then be developed, powered by the competitiveness of the design technology, and should progress through the development of nationally essential LSIs, such as those security-related.

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Glossary

*1 IP
Stands for "intellectual property," and, in the field of semiconductors, represents a design asset related to circuits or devices, distributed for re-use.

*2 A passive element
An element incapable of amplifying input signal power. Its property is, in many cases, governed by its physical shape or the material used.

*3 SEMATECH
Stands for "SEmiconductor MAnufacturing TECHnology," and is a consortium co-funded by the Department of Defense, U.S.A., and four private semiconductor manufacturers, in which the semiconductor manufacturing technology is studied. This was established to recover the U.S. semiconductor industry that had lost its way in the 80s.

*4 IP-based design
platform design. A method used to design system LSIs, where virtual components (VCs) and virtual sockets (VSs) are used, as a print circuit board is designed and developed: one IP (design asset , such as functional modules) makes up a VC, and different kinds of IPs are combined using VSs. Standardized interfaces between IPs facilitate their commercial use.

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(Original Japanese version: published in March 2005)

6

Science and Technology Trends in Fire Protection and Disaster Management
— A Consideration of Characteristics and Directions in Science and Technology for Safety and Peace of Mind —

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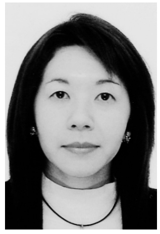

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1 Introduction

The White Paper on Fire and Disaster Management compiled annually by the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications brings together information on a truly wide variety of disasters and accidents, including fires, accidents at hazardous materials facilities and complexes, windstorms and floods, wildfires, earthquakes, and accidents related to gases, toxins, deleterious substances, and nuclear power. According to statistics in the White Paper on Fire and Disaster Management, the number of fires in Japan has been increasing since 1998, and over 2,000 people have died in fires since 1997[1].

The 2003 White Paper on Fire and Disaster Management includes an urgent report on "The increase in corporate accidents and responses thereto." As can be seen in Table 1, 2003 saw the frequent occurrence of fires, explosions, and accidents at industrial facilities around Japan. Although it is not included in Table 1, many readers will recall the April 11, 2003, explosion at a fireworks factory in Kagoshima Prefecture that killed 10 and injured 4. On the other hand, 2004 saw damage from numerous natural disasters, such as several typhoons, especially No. 23, as well as landslides caused by the Niigata-Chuetsu Earthquake. Many industrial disasters occurred in FY 2003, while many natural disasters occurred in FY 2004. After the landslides caused by the Niigata-Chuetsu Earthquake, increasing the safety of fire protection and the disaster management response to landslides became an issue. In December, as if to punctuate this year of natural disasters, a major earthquake in the ocean off Sumatra brought tsunamis causing damage of historical proportions to coastal areas all around the Indian Ocean.

Regarding policy on the allocation of resources such as budgets and personnel for science and technology in FY 2005[2] (Council for Science and Technology Policy, May 26, 2004), "strategic and comprehensive promotion of science and technology for new efforts on national and social problems" was established as a new area of strategic emphasis. The comprehensive and cross-sectional promotion of science and technology to build a safe society that provides peace of mind is one example of this policy. In The Japanese and the Jews, Isaiah Ben-Dasan wrote that the Japanese are a people who believe that safety and water are free. While Japan has taken its safety and peace of mind for granted, there is now a real sense that it is time to emphasize science and technology policy to build a society that is safe and provides peace of mind. To build such a society, it is essential that we understand the causes of accidents and disasters and that we fully discuss prevention and

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Table 1 : Major industrial accidents in 2003

	Date	Deaths and injuries	Description
Fire at Idemistu Kosan's Hokkaido oil refinery	26-Sep	None	Immediately after the 2003 Tokachi earthquake, a fire broke out at an oil storage tank (about 33,000 kiloliters) and the attached pipes. The fire burned for about 7 hours.
	28-Sep	None	About 54 hours after the earthquake, a fire broke out in front of a naphtha storage tank (about 33,000 kiloliters). It burned for about 44 hours.
Fire at Bridgestone's Tochigi factory	8-Sep	None	A fire broke out near a refining mixer at a Banbury factory for manufacturing rubber panels for tires, and the entire factory (40,885 m^2) burned with the loss of about 165,000 tires. Along with two days of firefighting, the fire required the evacuation of 5,032 people from 1,708 households.
Fire at Nippon Steel's Nagoya works	3-Sep	15 injured	A gas holder (about 50 m high and 35 m in diameter) inside the plant holding roughly 40,000 m3 of gas for fuel exploded and burned. Workers inside the plant were injured, and windows were broken in nearby homes.
Fire at ExxonMobil's Nagoya oil tanks	29-Aug	6 dead 1 injured	A fire broke out near a gasoline tank in a storage facility. The tank was undergoing renovation, so the gasoline had been drained. The fire broke out while waste oil at the bottom of the tank was being transferred to trucks.
Fire at Mie Prefecture refuse-derived fuel (RDF) electric power generation plant	14-Aug	2 dead 1 injured	On August 14, a fire broke out, injuring 4 workers. The Fire Department conducted firefighting and cooling work. On August 19 at 2:17 p.m., an RDF tank exploded, and two firefighters working on its roof were thrown off. The roof flew about 200 meters, damaging the building that housed the power plant's control room.
Fire at Nippon Steel's Yawata works	11-Jul	1 dead 2 injured	A vat of molten metal (about 150 tons) with a truck attached was being lowered by crane onto a scale when the vat tipped over, spilling the molten metal and burning the plant's walls.

Source: 2003 White Paper on Fire and Disaster Management

response. Science and technology is necessary for this. In the evaluation of science and technology in recent years, increasing emphasis is being placed on the extent to which results are being reflected in people's everyday lives. Science and technology to build a safe society that provides peace of mind cover a wide array of research areas, from academic research on the mechanisms that generate natural disasters to practical research directly tied to mitigating damage when disasters occur. Even within the field of science and technology, to build a safe society that provides peace of mind, scientific and technical issues related to fire protection and disaster management are the areas closest to people's daily lives because they protect lives and property from damage due to disasters. From this perspective, this article analyzes current conditions and the near-future outlook for fire protection and disaster management science and technology, a practical side of science and technology for safety and peace of mind, and offers suggestions for the direction of this science and technology based on its characteristics.

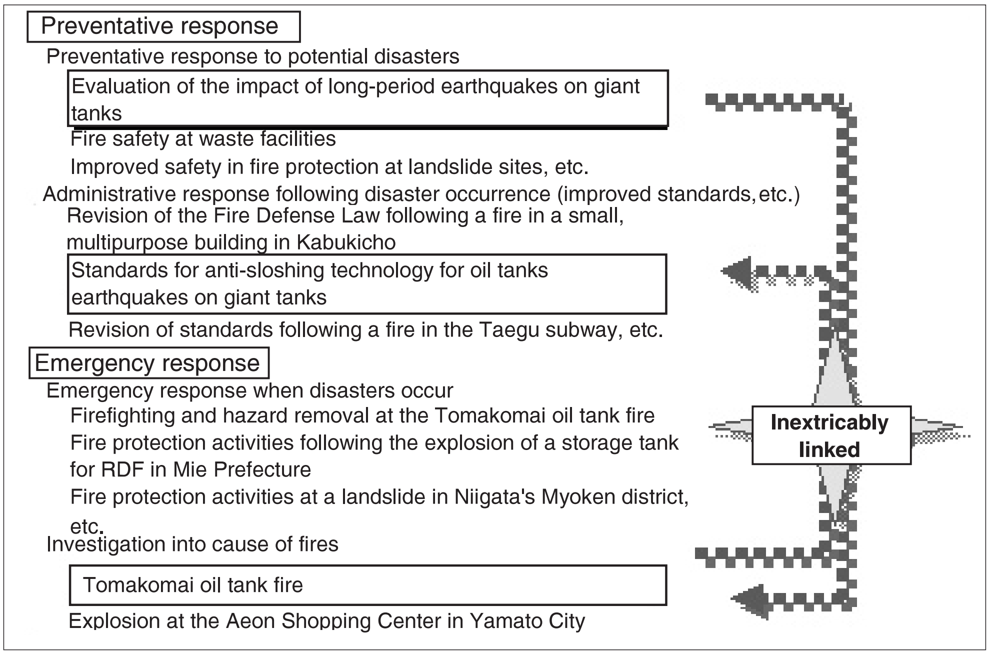
2 Current conditions in fire protection and disaster management science and technology

2-1 Fire protection and disaster management prevention and response

Fire protection separated from the police in 1948. During the half century since fire protection was undertaken by local governments, fire protection and disaster management began with firefighting activities and response to fires after they broke out, later expanding to include areas such as fire prevention, response to hazardous materials accidents, first aid and rescue activities, response to natural disasters such as earthquakes, response to nuclear power accidents, and so on.

Figure 1 depicts the current approach to prevention and emergency response in fire protection and disaster management. Preventative responses to potential disasters include the evaluation of the effect of long-period earthquakes on giant tanks, fire safety at waste facilities, and improved safety in fire

Figure 1 : Interrelationship between fire and disaster management and prevention



protection activities at landslide sites. Examples of administrative responses (improvement of standards, etc.) after disasters occurred include revision of the Fire Defense Law following a fire in a small, multipurpose building in Tokyo's Kabukicho, sloshing-prevention technology for petroleum tanks, and improved standards following a fire in the Taegu, South Korea, subway. These examples demonstrate that fires both inside and outside Japan are considered in such efforts.

Emergency responses included firefighting and hazard removal at the Tomakomai oil tank fire, fire protection activities following the explosion of a storage tank for refuse-derived fuel (RDF) in Mie Prefecture, and fire protection activities at a landslide in Niigata's Myoken district. Cases requiring investigation into the cause of fire included the Tomakomai oil tank fire and an explosion at the Aeon Shopping Center in Yamato City.

2-2 Overview of the Strategic Plan for the Advancement of Fire Protection and Disaster Management Science and Technology

As the areas to which fire protection responds have expanded, the relationship between fire protection and disaster management and science and technology has changed in the following two respects: (1) the appearance of new disaster types as science and technology develop and (2) improvement of fire protection activities through science and technology. Figure 2 shows the research fields of the National Research Institute of Fire and Disaster (NRIFD) and organizations (not including universities) conducting related research, while Figure 3 shows the course of research undertaken by the NRIFD from the second half of the 1980s into the first half of the 1990s. As can be seen in the charts, themes based in the field are essential to NRIFD's research, and they form NRIFD's mission. In November 2001, the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications set and published the Strategic Plan for the Advancement of Fire Protection and Disaster Management Science and Technology (hereinafter "the Strategic Plan")[3], bearing in mind the forward-looking approach of the NRIFD and incorporating the discussions of an advisory group of outside experts on fire protection and disaster management science and technology chaired by Yoichi Uehara, Professor Emeritus of Yokohama National University. This is the first strategic plan to be set since the start of fire protection by local governments in 1948. Against the background of changes in NRIFD's research fields as shown in Figure 3, it is generally intended to be applied by about FY 2005. The 1995 Great Hanshin-Awaji Earthquake (Kobe Earthquake), which was an urban-epicenter

Figure 2 : National Research Institute of Fire and Disaster research fields and relationships with other organizations

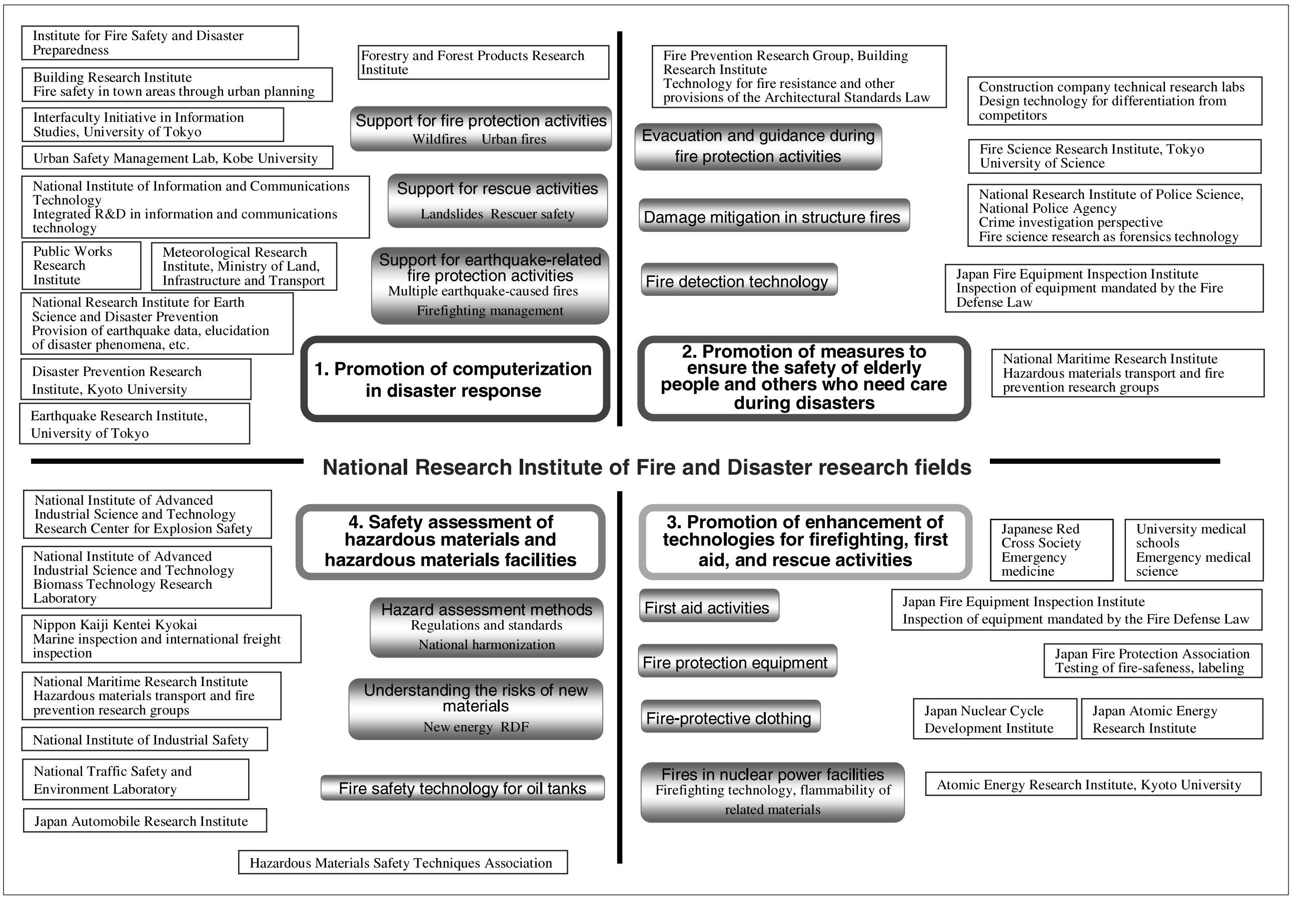
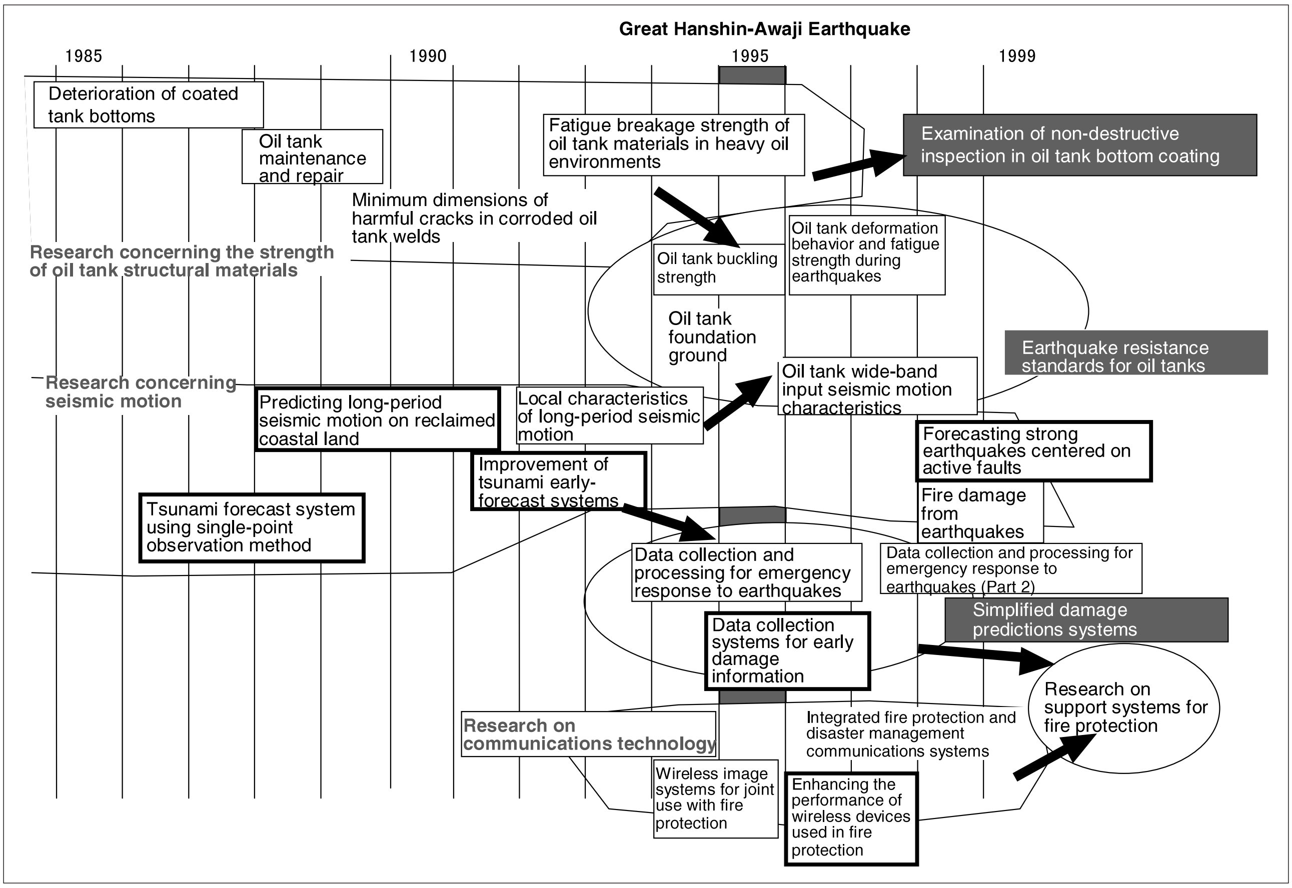


Figure 3 : Interrelationships among research topics in the National Research Institute of Fire and Disaster's research fields



earthquake, raised the issue of information blanks that may occur immediately following a large, widespread disaster. The Strategic Plan incorporates issues such as the problem of exposure of rescue personnel to radiation during criticality accidents, as occurred at the uranium fuel processing facility in Tokaimura, Ibaraki Prefecture, in 1999, and the hazard potential of new substances, as demonstrated by a hydroxylamine explosion at a chemical plant in Gunma Prefecture in 2000.

Fire protection and disaster management science and technology should form a proactive PDCA cycle*1 that includes prior response, post response, and analysis of causes. Figure 4 shows the safety cycle for fire protection and disaster management science and technology.

Expectations are high for the use of new technologies such as information technology, sensor technology, and new materials as science and technology for disaster prevention and resistance. The Strategic Plan organizes topics related to fire protection and disaster management science and technology into the following nine main areas.

(1) Enhancement of disaster information communications systems
(2) Promotion of household fire prevention measures
(3) Improvement of disaster prevention capability
(4) Enhancement of fire protection support facilities, fire protection equipment, and so on
(5) Strengthening of special disaster prevention policies
(6) Improvement of security measures at hazardous materials facilities
(7) Enhancement of first aid and rescue work

Figure 4 : Relationship between prevention and emergency response in fire protection and disaster management

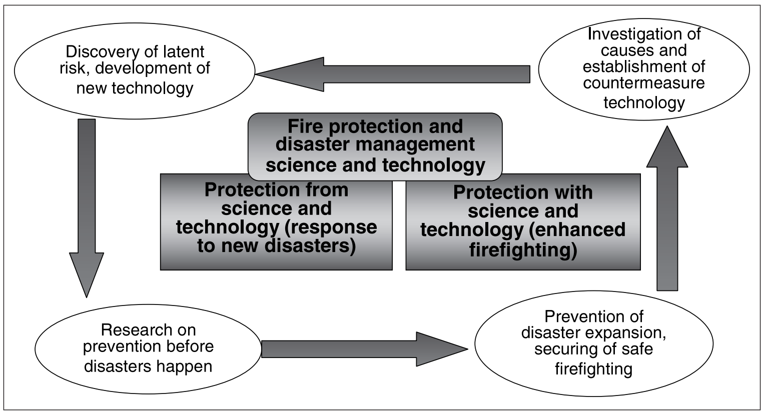
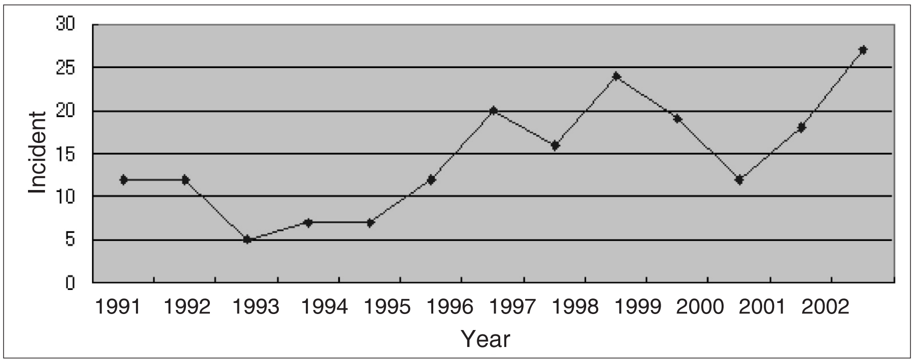


Table 2 : Priority fields in fire protection and disaster management R&D

(1) Promotion of computerization in disaster response	To promote computerization in disaster response, research and development of equipment for understanding and analyzing disasters, for simulations to assess and predict disasters, for transmission of information during disasters, and for use by firefighters and other line personnel, systems to integrate such devices, and enhancements.
(2) Ensuring the safety of elderly people and others especially vulnerable to disasters	Development of devices to support evacuation and other measures for elderly people, infants, people with disabilities, and others who require care during a disaster, devices to transmit information, devices for evacuation, and research and development of methods for evaluating such devices and setting their technical standards.
(3) Enhancement of technologies for firefighting, first aid, and rescue	To enhance technology for firefighting, first aid, and rescue, research and development of fire and rescue robots, support systems for fire and rescue activities deep underground, enhanced first aid activities, firefighting methods for materials that are difficult to put out, and equipment and facilities for fire and rescue.
(4) Safety assessment of hazardous materials and hazardous materials facilities	To ensure the security of hazardous waste facilities, research and development on risk assessment of new materials, incident analysis methods for effective accident prevention, methods to predict the occurrence and expansion of hazardous materials accidents, and methods to assess safety.
(5) Promotion of environmental protection	Research and development on firefighting technology that contributes to the social issue of protecting the environment by having a small environmental impact and on technology to prevent, detect, and respond to hazardous materials leaks.

Figure 5 : Leaks due to corrosion and other deterioration at outdoor oil storage tanks



(8) Concern for the environment
(9) Response to internationalization

Based on these areas, the Strategic Plan proposes prioritization of fire protection and disaster management research and development in the five fields shown in Table 2.

3 Concerns related to safety and peace of mind in the near future

3-1 Fire protection and disaster management in an aging society

Currently, the death rate per 100,000 persons from household fires is 27.4 times greater for those aged 81 and above than for those between 21 and 25. As society ages, increased harm to elderly people is a concern.

3-2 Contradictions between environmental issues and a safe society that provides peace of mind

In the past, chlorine-based chemicals were used as fire retardants to make products difficult to burn, but because they generate toxic materials, they were replaced with bromine-based chemicals. However, there is also concern regarding the environmental and health impacts of bromine. In addition, they are also causative agents for the generation of dioxins during incineration. It is therefore problematic to use bromine-based fire retardants in computers and other products, but non-use can increase fire risk in homes and offices. Furthermore, Japan's refuse-derived fuel (RDF) facilities, which were introduced as an environmental measure, have been plagued by malfunctions, including explosions, becoming a safety problem in their own right.

3-3 Disasters due to arson and other crimes and due to terrorism

Fires caused by or suspected of being caused by arson account for 22.9 percent of all fires (14,553 cases in 2002) and continue to increase. The September 1, 2001, fire in a small multipurpose building in Tokyo's Kabukicho that killed 44 is believed to have been caused by arson. The fire in the subway in Taegu, South Korea, was caused by arson with gasoline, requiring a rethinking of the conditions hypothesized for fire and evacuation measures in subways.

3-4 Accidents accompanying aging infrastructure

As exemplified by the accident at the Mihama nuclear power plant caused when a corroded pipe burst and released steam, deterioration of major facilities over time is causing concern. In particular, fires and leaks at hazardous materials facilities, which had been slowly declining since about 1980, began to increase in 1994. Figure 5 shows the trend in fires and leaks at outdoor storage tanks, while Figure 6 shows that in hazardous materials facilities. In 2002, there were 170 fires and 331 leaks, totaling 501 incidents. Corrosion was the most common cause, accounting for 35.1 percent of the cases.

3-5 Large earthquakes and other natural disasters

On September 26, 2003, a magnitude-8 earthquake struck the sea off Tokachi in Hokkaido. The earthquake caused a fire at some petroleum tanks in Tomakomai City, which burned for 44 hours. In the end, firefighting was impossible, and the fire was allowed to burn itself out. An earthquake of this scale was expected to occur only every 100 to 200 years, but this time, it happened after only 50, so the period of recurrence is being reexamined. Preventative measures are particularly necessary for oil tanks in the earthquake-prone areas shown in Figure 7.

4 Outlook for priority fields in the near future

Based on the above concerns, priority research fields such as the following should be promoted.

4-1 Response to an aging society

To reduce damage caused by household fires, it is important to widely disseminate the use of fire detectors. The NRIFD is conducting research on applied technology to utilize common household appliances such as air conditioners to detect fires. Prototype air conditioners equipped with smoke detectors that not only flash lights and give audio alarms, but also use wireless technology to break into television screens and display warnings as well as utilize the telephone to call

Figure 6 : Fires and leaks at hazardous materials facilities

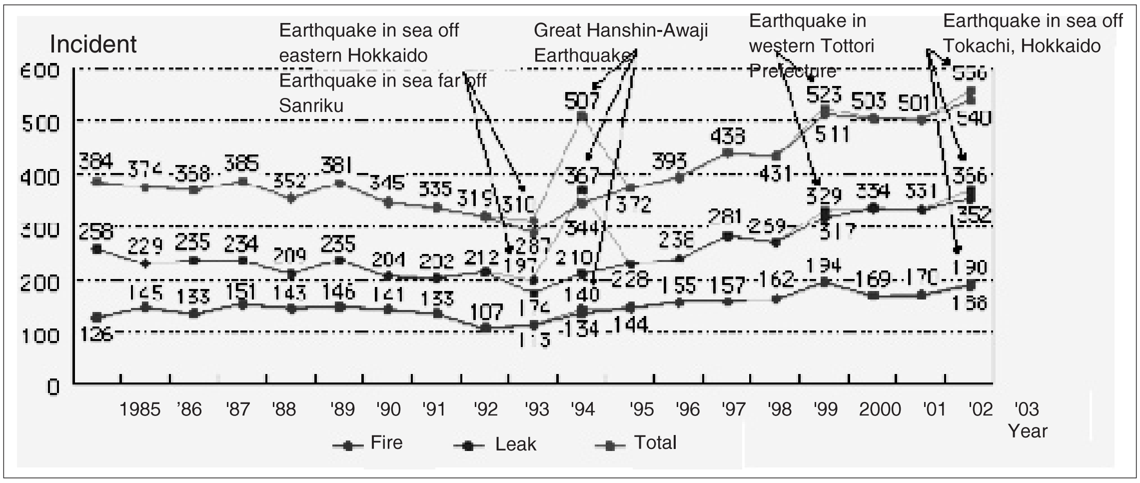
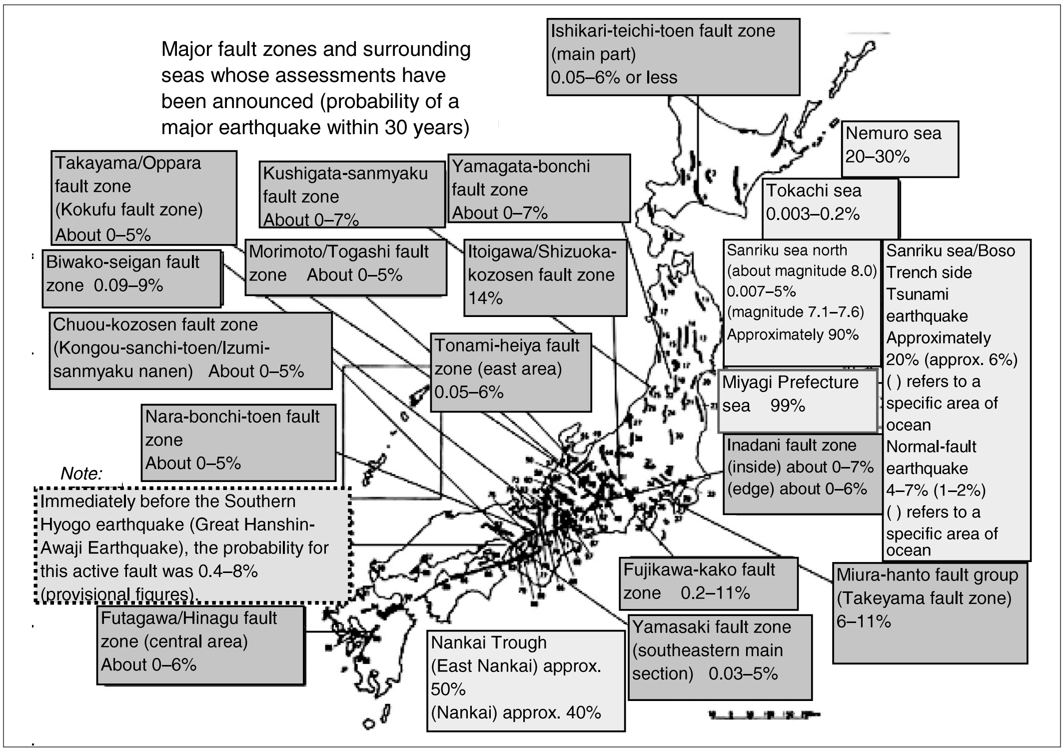


Figure 7 : Earthquakes feared likely to occur in the vicinity of Japan[4]



Source: Headquarters for Earthquake Research Promotion, Ministry of Education, Culture, Sports, Science and Technology (2004) for outside emergency assistance. In addition, technology is being developed for people such as the elderly or those with disabilities who have hearing difficulties. Scent is one method, but it requires basic data on what type of smell should be released in what quantity in order to be recognized as a fire alarm. Other methods being researched include the shaking of bedding or pillows for fires that occur while people are sleeping, as well as flashing lights. Furthermore, research on communications networks to automatically inform outside entities in the event of a fire must be pursued. This kind of technical development is expected to result in decreased damage[5].

4-2 Environmentally-friendly fire retardation and innovations in firefighting technology

(1) Towards forbidding the use of ozone-layer-damaging materials

Along with the prohibition of the production of halon, which damages the ozone layer, new types of extinguishants and firefighting technologies are being developed. Among these extinguishants, some have been reported to actually ignite materials under certain conditions, or to promote the generation of hydrogen fluoride or other substances harmful to humans as discharge from burning. To use extinguishants safely, advanced quantitative simulations are needed to clarify their ignition and quenching phenomena and the processes by which they generate discharges.

One candidate to replace halon in firefighting equipment is water mist. This refers to firefighting equipment that uses water, but in a way that pays more attention to the distribution of the sprayed water droplets than do conventional sprinklers or misters. Water mist can achieve the same fire suppression effect as conventional sprinklers, while using only a fraction of the water, enabling water damage such as flooded rooms or property that are unusable after becoming soaked to be minimized. Because the principles of water mist firefighting have not all yet been clearly established, it is necessary to divide fires into several stages, define the optimal conditions for water mist firefighting at each stage, and clarify usage policy. In addition to use in ceilings and so on as fixed fire suppression equipment, use in fire hoses by fire crews is also being studied[6].

(2) Innovations in firefighting technology in the energy sector

In December 1995, a sodium leak and fire occurred in the secondary cooling system pipe room at the Monju fast breeder reactor. Since the accident, the combustion behavior of sodium has been carefully observed and research into firefighting conditions is progressing. Sodium cannot burn in extremely low concentrations of oxygen, but will reignite under certain temperature conditions and displays specific oxidation reactions under low-oxygen conditions. In other words, even after a sodium fire appears to be out, if certain temperature and gas saturation conditions are met, it may reignite. To suppress sodium-leak fires with certainty, clarification of the mechanism of stabilization of the remaining sodium and of re-ignition of the combustion residue at environmental temperatures, and exploration of extinguishants not made from inert gases, are needed.

Lithium is a metal that requires further attention from the perspective of combustion. Because lithium-ion batteries offer advantages such as high energy density and reusability, they are widely utilized in mobile telephones, computers, video cameras, and so on. Because lithium reacts with water, the use of gas and powder extinguishants may be considered when there is a fire. Along with research to understand the degree to which rare-gas and powder fire suppression is effective, research on fighting lithium fires concerning whether lithium has specific combustion behavior as sodium does, and other aspects of lithium's burn characteristics, is needed.

Research into new forms of energy offering advantages in cost, performance, environmental responsiveness, and so on is progressing. As conditions for the spread of such new energies, evaluation of their safety from the perspectives of fire prevention and disaster management is essential. For example, the fuel-cell automobiles now being tested generally utilize hydrogen, which will require safety measures for parking garages and tunnels. There is a very real danger that the same firefighting methods that have been used until now with gasoline vehicles may not have the same fire suppression effect. It is therefore essential that appropriate firefighting and prevention technologies be developed[7].

(3) Innovations in fire protection and disaster management technology for waste processing facilities

Through efforts to separate waste by type in recent years, waste processing facilities are collecting massive amounts of refuse that is not for incineration. Plastics are categorized as non-burnable waste, but some of them generate large amounts of heat. In addition, flammable materials such as batteries, aerosol cans, and gas cylinders are also sometimes mixed in with non-burnable garbage. At waste processing facilities, sparks from impact or friction during crushing or other processing, as well as chemical reactions, can cause ignition leading to fires. Therefore, first an examination of conditions at waste processing facilities is needed, followed by research on fire prevention and firefighting systems that respond to the characteristics of such fires.

4-3 Innovations in technology in response to the declining safety and increasing vulnerability of large, complex structures as public safety declines

Large, complex structures are designed and constructed to ensure safety against ordinary causes and types of fire. In the event of fire started by arson or terrorism, however, the spread of gasoline and so on can cause the size and spread of fire to be greater than expected, and large, complex structures such as underground facilities are vulnerable because evacuation and firefighting activities are difficult.

To respond to this situation, research to clarify the environments that fire crews and citizens will encounter is needed. At the same time, exposure of the potential dangers of large fires that would make firefighting and evacuation difficult, and technical innovation leading to the development of evacuation guidance systems and of protective clothing to reduce injuries from firefighting and evacuation are necessary.

4-4 Innovations in technology for inspection and maintenance of aging social infrastructure

Through rust, metal fatigue, cracking, and so on, oil tanks deteriorate over time. Moreover, they are located near the ocean and face repeated heavy loads as they are filled and emptied. The damage that oil tanks incur under these harsh conditions can lead to catastrophes such as leaks, fires, and pollution. Most damage is caused by aging or by earthquakes. The corrosion environment is complex, and even earthquake damage depends on the strength of the earthquake, the type of seismic waves, the foundation ground, tank structure and content volume, and so on. Safety assessment must therefore be conducted considering tank conditions, and it is important to take aging and earthquake resistance into account at the same time. Along with assessing the health of tank bottoms through acoustic emission (AE), it is necessary to establish safety evaluation methods such as computer simulation to analyze oil tank conditions considering expected earthquake strength.

4-5 Preparation for major earthquakes and other natural disasters, elucidation of the impact of long-period seismic motion, and disaster prevention data systems

Research on robots to rescue earthquake victims is advancing. Research is progressing on combining multiple self-propelled, compact, lightweight robots to form protective walls against radiation or to gather around a victim, change his/her position for easier transport, and pull him/her to safety. Compact robots developed by the NRIFD weigh about 5 kg each, are radio-controlled, and move in groups of multiple units. Leader robots are operated by fire crewmembers, but other compact robots follow the light emitted by the leader and move independently. The compact robots are divided into protective wall groups and dragging groups. Each individual joins the link in its own role and carries out its own function. In addition, research on robots that climb up and down apartment buildings by following along their verandas is also underway. Robots that can detect people buried under rubble will be another ongoing research theme.

Earthquake damage to storage tanks is a complex phenomenon that depends on the interplay among factors such as seismic motion characteristics, tank structure, the type of ground the tank stands on, the properties of the material stored, and so on. It is therefore necessary to utilize various analytic methods in elucidating through computer simulation of multiple types of seismic wave the mechanism of damage from buckling caused by tank floors rising due to seismic motion, and to develop safety evaluation systems for smaller tanks. Research thus far has demonstrated that if seismic waves can be predicted, tank strength can be evaluated. In addition, precise computer simulations that can predict damage in advance are needed to ensure safety. Oil tanks, which are large structures, may resonate with long-period seismic motion during earthquakes, causing sloshing (movement of the liquid within the tank). Research on improving the accuracy of sloshing prediction based on the concept of "seismotectonics zoning" is therefore underway. For short-period seismic motion as well, research on methods to accurately predict short-period seismic motion by utilizing ground boring data is being conducted[8, 9].

In addition, for example, it is difficult to prevent expansion once an accident at a nuclear reactor occurs. The tsunamis caused by the earthquake off Sumatra caused massive damage and took as many as 220,000 lives. In the case of structure fires as well, firefighters cannot arrive until about five minutes have passed, so primary damage from explosions and so on cannot be mitigated. The larger the disaster, the more important and effective is a preventative rather than a subsequent response. In other words, to ensure safety and peace of mind for the public, prevention as well as response is essential, and in true emergencies, both are needed.

5 Proposals

Based on the above analysis of the current state and future outlook of trends in "fire protection and disaster management science and technology," in this section, we offer proposals for science and technology to build a safe society that provides peace of mind.

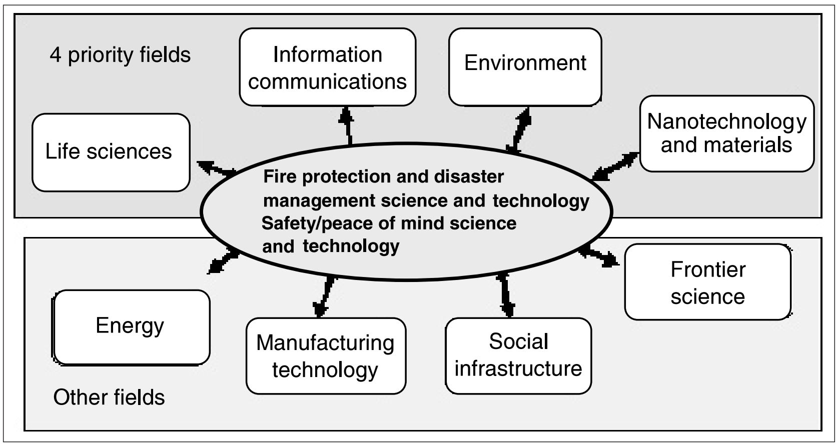
5-1 Make outputs to outcomes

To apply the fruits of fire protection and disaster management science and technology towards achieving a safe society that provides peace of mind, the public must understand these fruits and utilize them. Users of fire protection and disaster management science and technology include not only those who work in fire protection, but the general public as well. The utilization of science and technology to prevent accidents before they happen is a matter of course, but at the same time, people must be educated so that they can properly understand, manage, and use them. Various budgets are allocated for research directly linked to technology, but funds should be allocated for preventative education and so on in the same way. Like pure scientific research, the results may not be tangible, but this education is essential in constructing a safe society that provides peace of mind. One can easily imagine that when an earthquake occurs, damage will vary widely by location. Therefore, providing all residents in a given area with disaster drills through virtual reality and other simulations can be effective from the perspective of damage mitigation[10]. In the event of an actual disaster, what percentage of people could handle fire extinguishers? According to a survey by the Tokyo Fire Department in FY 2000, the use of fire extinguishers was necessary in 1,199 of 1,921 fires, but they were actually used in only 624 cases. Because fire extinguishers were available and needed but not used in almost half the cases, regular training and practice in actual use is needed not only in schools but in workplaces and for all residents.

5-2 Effective interdisciplinary research

If we look at the fire protection and disaster management science and technology fields that should be promoted, in terms of the "four priority research fields" and "four other fields" found in the second Science and Technology

Figure 8 : Relationship of fire protection and disaster management science and technology to the priority fields of the second Science and Technology Basic Plan



Basic Plan, we can see that fire protection and disaster management science and technology is an interdisciplinary field.

For example, to achieve "the building of a society that provides elderly people with safety and peace of mind regarding fires and other disasters," the union and fusion of research results in the fields of "information communication technology," "energy," "manufacturing technology," and "social infrastructure" are essential. The four other priority research fields for fire protection and disaster management science and technology also require the union and fusion of research results from multiple fields. As can be seen in Figure 8, science and technology related to fire protection and disaster management is an interdisciplinary research field spanning all the priority areas of the second Science and Technology Basic Plan.

Researchers who conduct this interdisciplinary research in science and technology for fire protection and disaster management need the ability to flexibly change research themes and to be aware of unusual phenomena that have yet to occur. The former is needed because fire protection and disaster management science and technology are interdisciplinary fields. The latter is necessary because researchers must uncover research themes to prevent accidents before they happen. To prevent accidents, it is just as important to be aware of potential causes (including causes that check accident damage) as it is to learn from past events.

Currently, the evaluation of researchers by their results is increasingly widespread and becoming more important. In most such researcher evaluations, changing research fields may not be advantageous because it can cause a temporary drop in publications and presentations. To foster interdisciplinary researchers, it is therefore desirable to devise evaluation methods that integrate contributions over time into building a safe society that provides peace of mind.

5-3 Using openness to expand the market for utilization of results

Within science and technology for safety and peace of mind, fire protection and disaster management science and technology have the characteristic of being a practical discipline that makes a clear contribution to society. This contribution is made from both the aspect of prevention through regulatory systems and the aspect of fire protection response after disasters occur. In contrast with research on terrorism and emergencies and information security, which also aims to contribute to safety and peace of mind, research in science and technology for fire protection and disaster management is quite different in its characteristic openness.

Numerous national research organs, such as the National Institute of Information and Communications Technology, the National Research Institute for Earth Science and Disaster Prevention, the Public Works Research Institute, and the National Institute of Public Safety, as well as universities, have utilized this openness for research in fire protection and disaster management from a variety of perspectives and through various links among themselves. In the future as well, research in fields such as nanotechnology and information technology that will probably be given priority in the next Science and Technology Basic Plan, and their strengthened promotion, will be vital to the progress of fire protection and disaster management science and technology. It is necessary not that priority fields be set, but rather that the existence of interdisciplinary research and development fields such as science and technology for safety and peace of mind be recognized.

There are issues involved with implementing fire protection science and technology and contributing the results to society. The market scale is small, so there is little motivation to develop equipment in accordance with the frontline needs of fire protection, and it is difficult to adopt the most advanced results of research in science and technology to combat disasters. The key to overcoming the small market scale is the utilization of openness in science and technology for fire protection and disaster management.

In other words, in principle, research results both for prevention and for countermeasures in science and technology for fire protection and disaster management should be open. An effective and efficient research system with full-fledged cooperation among industry, academia, and government, as well as intra-governmental cooperation, is needed. Such cooperative systems could enable the fruits of fire protection and disaster management science and technology to enter the general market, expanding the target market for research and development.

5-4 *Adding strategy to fire protection and disaster management science and technology*

Using the example of fire protection and disaster management robots, we offer suggestions on strategy for fire protection and disaster management science and technology.

Some believe that because practical robots for everyday-life environments do not yet exist, robots for the more difficult environment of fire protection activities cannot be manufactured. However, by limiting the environments they encounter and how they respond, fire protection and disaster management robots can be sufficiently developed from existing research and development. Indeed, by adding conditions such as:

- Limiting the kinds of disaster for which they will be used,
- Limiting their possible activities,
- Limiting their operating time, and
- Providing human operators (remote control rather than full automation)

The practicality of introducing fire protection and disaster management robots is quite high. To break through the current situation in which such robots "move too slowly to be used on-site," "are not durable," "do not behave dependably," and so on, manufacturers and robot scientists must find the idea of realizing fire protection robots attractive enough to create systems for full-fledged work on them.

To make fire protection robots attractive to the market, these processes must be added to intra-governmental cooperation:

- Preparation of a practical environment through the creation of a fire protection equipment standardization and distribution plan (Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications)
- Formation of the initial market for commercialization (fire protection procurement; Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications and local governments) and industry creation and fostering (Ministry of Internal Affairs and Communications, Ministry of Economy, Trade and Industry)

A vision and systems can be constructed to take the next steps to enable even local fire departments to adopt robot technology within 10 years based on the fruits of robot research and development achieved through industry-academi a-government cooperation, and to link them with the market for general-care robots.

Period 1: Achieve performance and price-enabling adoption by national rescue teams.
Period 2: Achieve performance and price-enabling independent adoption by major fire departments.
Period 3: Achieve performance and price-enabling adoption by all fire departments.

The environmental resistance and performance required for frontline fire protection activities is equivalent to or greater than that required by military technology. While the scientific and technical issues to be solved are advanced, the cost effectiveness required is closer to that of the civil sector.

It is simple to open up the results of fire protection and disaster management science and technology. Compared with the United States of America, the world's policeman that leads in science and technology through its military technology, Japan may be able lead the world in fire protection through breakthroughs in the science and technology of disaster prevention and mitigation, contributing to the global community.

To effectively utilize fire protection and disaster management science and technology and contribute its achievements to society, such visions and systems are vital.

Glossary

*1 PDCA cycle
The cycle comprising Plan, Do, Check, Act.

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7

Effectiveness of the Quasi-Zenith Satellite System in Ubiquitous Positioning

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1 Introduction

Recently, a variety of research is underway targeted at "ubiquitous positioning" in many countries including U.S.A., U.K., France and Australia. In Japan, for instance, a study on the application of ubiquitous positioning to the distribution of goods has been carried out by University of Tokyo. "Ubiquitous" means "existing at any place, at any time" or "omnipresent." In a future information society, methods for measuring precisely where you are will be as important and matter-of-course as ubiquitous hardware devices such as wearable computers and IC tags. This trend is heralded by the fact that millions of mobile phone users have signed up for positional information services. Although the positional accuracy currently available from mobile phone services is still low, even sometimes giving wrong information, the mainstream will shift to utilization of the Global Positioning System (GPS) for much higher accuracy. You can calculate your exact position using time signals from more than four GPS satellites simultaneously. GPS has already established itself as one of the key components of nation-level infrastructure and has been used in a variety of social activities.

In ordinary life, time is expressed in terms of hours, minutes and seconds. In ubiquitous positioning, your location is expressed in terms of degrees, minutes and seconds to the precision of one tenth second in both longitude and latitude[*1]. Linking positional information with other sources of information will also be a commonplace application; geographical information systems will show you the local area map, and other systems will provide interesting related information.

The Ministry of Internal Affairs and Communications (MIAC) has launched a research project, scheduled to be completed by April of 2007, to build a high-performance infrastructure, providing police, fire fighting agencies and maritime safety agencies with enhanced emergency calls capabilities for improved safety and freedom from care. Swift localization of the transmitter has been a longstanding challenge in mobile phone emergency calls. Mobile terminals with automatic positional information transmission capability using GPS will enable police to reach the spot much more quickly.

However, GPS positioning is often unavailable in areas without a clear skyline, such as mountainous terrain and densely populated areas, because sufficient GPS satellites are not in sight. This has been often pointed out as major blind side in GPS utilization.

The Quasi-Zenith Satellite System (QZSS), which will be complementary and augmentative with GPS, will be the most effective in solving this problem. System development will be carried out through cooperative effort between the public sector and governmental organizations, including the MIAC, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure and Transportation (MLIT), Japan's original satellites system will also provide substantial impetus and business opportunities to the aerospace industry.

This articles gives an overall picture of many aspects paving the way to ubiquitous positioning, including the status of the U.S. GPS satellite system and its inherent blind side, an overview of the emergency calls enhancement project initiated by the MIAC, the architecture and role of the Quasi-Zenith Satellite System, and research trends in enhanced positioning technology undertaken by ministries and research organizations. Quasi-Zenith Satellites can be multipurpose entities: they can be used, depending on the instruments they carry, for communications, broadcasting and monitoring as well as their original purpose of positioning. However, it is apparent that priority lies in positioning (complementation and augmentation of the existing GPS system) over other missions such as communications and broadcasting. I therefore propose that the role of the first QZSS system concentrate on complementing and augmenting the GPS system. I also propose establishing a governmental organization that presides over the entire project for the early implementation of a ubiquitous positioning system using the Quasi-Zenith Satellites.

2 GPS satellites system

2-1 Trends in GPS satellite development

The term GPS satellite (or navigation satellite) generally refers to the 24 NAVSTAR satellites operated by the U.S. Air Force (currently, five backup satellites have been added to a total of 29). As shown in Figure 1, the basic design of the system allocates 4 satellites in each of the 6 orbital planes. In addition, several backup satellites orbit the earth in preparation for malfunction or failure. Each satellite circles the earth in approx. 12 hours at an altitude of 20,200 km, roughly at midpoint between LEO (low-earth-orbit) and geosynchronous orbit. With its orbital inclination angle of 55° and high altitude, the system is able to cover almost all the earth's surface except a part of the polar regions. The Department of Defense (DoD) started investigation into satellite-aided positioning systems in the 1960s. After several stages of cut and try technical development, DoD launched the first NAVSTAR satellite in 1978.

As shown in Table 1, the NAVSTAR constellation started steady operation in 1990 (Block 2 and 2A) after completion of the validation phase (Block 1). Due to the life of these satellites, they are in a process that started in 1997 of being replaced by new satellites (Block 2R), and Block 2RM (the additional M stands for "Modernized") satellites with enhanced performance and an additional time signal for private sector use are scheduled to be launched shortly. Block 2F satellites with a newly added third time signal for private sector use are being constructed; the first one in this series is scheduled for launch in 2006. Furthermore, conceptual development for next-next generation satellites, or Block 3, is currently independently underway by

Figure 1 : NAVSTAR satellites and six orbital planes [1]

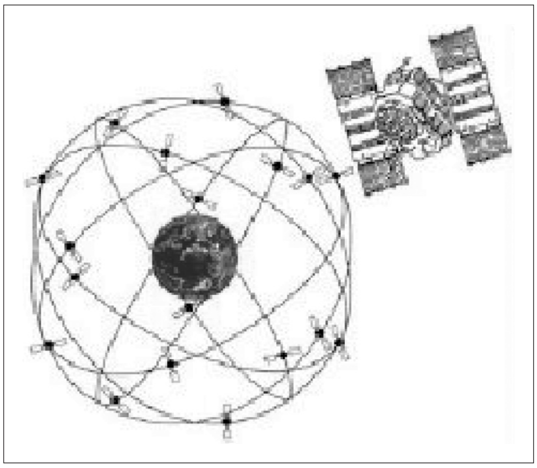


Table 1 : Global Positioning satellites launched by U.S.A.

Block	Manufacturer	Launched	Number	Orbital inclination	Weight (kg)	Design life	Power
1	Rockwell International	1978-1985	11	63°	759	5 years	0.41kW
2		1989-1990	9	55°	1,660	7.5 years	0.71kW
2A		1990-1997	19	55°	1,816	7.5 years	0.71kW
2R	Lockheed Martin	1997-2006	2R 12 2RM 7	55°	2,032	10 years	1.14kW
2F	Boeing	2006-2012	33	55°	2,160	15 years	2.44kW
3	Lockheed Martin/Boeing	Undecided (201?-)	Undecided	Undecided	Undecided	Undecided	Undecided

Lockheed-Martin and Boeing. DoD will soon decide the main contractor for development and manufacturing Block 3 satellites between these two manufacturers.

2-2 Functional aspects of GPS satellites

The current workhorses of the NAVSTAR constellation, Block 2A and 2R, carry two types of atomic clocks and constantly broadcast the precise time base signals according to their own clock and orbital elements once every second. They are capable of sending time base signals practically to a precision of 10^{-9} to ground GPS receivers.

A technical specification common to all blocks is the frequency of the transmitted signal. Current GPS satellites use two frequencies: L1 centered at 1575.42 MHz and L2 at 1227.6 MHz. These frequencies should not be changed even in the future, as this is prerequisite for the continuous use of ground receivers. Note, however, a plan to add a new frequency (L5: centered at 1176 MHz) that will be open for private sector use (proposed for use as a civilian safety-of-life signal) is underway for implementation in Block 2F satellites. This proposal has been approved by the International Telecommunication Union - Radio Communication Sector (ITU-R).

2-3 Non-U.S. positioning satellites

Russia has deployed the Global Navigation Satellite System (GLONASS) using its proprietary positioning satellites. Due to the dwindling number of normally operating satellites, Russia plans to launch about 10 replenishment satellites starting in 2005. Although it has limited usefulness due to the sparsely populated constellation, the signal from GLONASS is available in Japan. Instruments capable of receiving both GPS and GLONASS signals are also on the market.

European countries currently depend on GPS satellites of U.S.A. for their positioning needs. However, the European Union (EU) and the European Space Agency (ESA) are now jointly pursuing the Galileo project aimed at possessing their own Global Navigation Satellite System (GNSS). The Galileo positioning system promises global utility, and non-European countries such as China, India, Israel and Brazil have decided to become partners in the project. It is planned that a constellation of 30 positioning satellites, GNSS, be launched within a few years. When the project enters the deployment phase, 8 satellites will be launched at a time using an Ariane V launch vehicle.

China has launched three "Beidou" geostationary positioning satellites of its own, and they are mainly used for traffic control and car-theft monitoring. India is also planning to launch a GPS augmentation satellite, "Gagan (sky)." The geostationary satellite is positioned at a high angle of elevation near the zenith over India's southern high-tech industrial area including Bangalore. These regions will enjoy full geographical advantage for ubiquitous positioning by having a GPS complementation satellite just above them.

2-4 GPS complementary and GPS augmentative

In locations without major obstructions, the position of the receiver can be easily and accurately determined using GPS signals. This is essentially the case with the U.S. forces: the main areas in which they use the NAVSTAR are in open sky and sea, enabling them to exploit the full potential of the system. In civil use, however, there is a possibility of the signal path being obstructed by the jungle of high-rise buildings in densely populated area or canyons in mountainous terrain, meaning the required number of signals for accurate localization cannot be received. "Availability" is the term used to represent the probability that you can use GPS services properly in a particular place. Many urban areas in Japan have availability somewhere between 30 to 40%. A survey conducted in the West Shinjuku area (Shibasaki Laboratory, University of Tokyo)[2] revealed that a large proportion of residential areas with narrow roads and dense residential areas have limited availability in addition to downtown with its high-rise buildings.

Positioning errors are also an important factor to be considered. In civilian applications of GPS positioning, errors greater than 10 meters may arise due to such factors including: propagation delay in the ionosphere, time base signal error, positional information error of the satellite, delay due to water vapor in the troposphere, and multipath signals on the ground. The main source of error is delay in the ionosphere. However, this error can be compensated for using the frequency difference between L1 and L2. Error compensation using two frequencies will be available for civilian applications when Block 2RM of GPS satellites is launched.

Low availability and measurement errors have been pointed out as drawbacks in the use of GPS, and the U.S. itself has admitted the need for systems to complement and augment GPS satellites.

"Complementary" and "augmentative" systems have distinct meanings that must be clearly defined.

"GPS complementary" is to allocate a satellite (corresponding to one GPS satellite) at the near-zenith position at all times. A near-zenith satellite transmitting the L-band time based signal and positional information can be actually implemented.

"GPS augmentative" would be to improve GPS accuracy, where, for example, a network of fixed ground-based reference stations analyzes errors in the signals received from GPS satellites and produces corrective information as well as integrity information for improved accuracy; this information is distributed to other receiver stations via various communication links. This method is called Differential GPS (DGPS).

Methods for distributing GPS augmentative information to end users have already been implemented on a chargeable basis using ground-base FM broadcasting, or by mobile phones. However, these services remain inaccessible to some regions. If we have a near-zenith satellite in place, even regions that cannot be reached from ground-base stations can access GPS augmentative information by relaying the S-band signal. GPS augmentative information may differ from one locality to another; it is a subject of future discussion as to how many meshes are required to cover the whole of Japan for consistent augmentative information processing.

3 DOP number that determines GPS accuracy and minimizing atomic clock

3-1 DOP number

To accurately determine 3-dimensional coordinates, you have to receive signals from four or more of the satellites. It is desirable that the four satellites be spatially arranged so that the Dilution of Precision (DOP) number is as near to 1 as possible.

DOP is the index number that describes the geometric quality of a GPS satellite configuration in the sky. Ideally, one satellite at the zenith and other three satellites, shifted 120° from each other, constitutes a regular triangular pyramid. This ideal configuration is represented by a DOP number of 1, and it increases as the shape of the pyramid deviates from the ideal configuration. The number is calculated by comparing the actual volume of the triangular pyramid with that of the ideal configuration. GPS receivers with accuracy-setting capability can use a DOP number for setting their own accuracy level. Although a DOP number of 1 is desirable, it is very rare that a GPS satellite is actually close enough to the zenith at any one time. In this respect, a Quasi-Zenith Satellite in place can be an effective complementary method to the GPS system, so that the DOP number can attain value near 1.

3-2 Minimizing atomic clock

The GPS satellite is an ultra-high precision atomic clock orbiting the earth. Block 2 and subsequent NAVSTAR satellites carry two types of atomic clock: the cesium clock and the rubidium clock.

Atomic clock components used to be very large. Recently, however, with the development of portable atomic clocks[3], they have become small enough to fit in individual aircraft and vehicles of U.S. forces. These machines had to receive time base signals from positioning satellites to obtain exact time information, but satellite signals have often had to be replaced by the portable atomic clock.

The U.S. Defense Advanced Research Project

Agency (DARPA) has been undertaking research into fabricating ultra-small atomic clock chips of less than 1 cm^3. If grain-sized atomic clock chips become a reality, they will surely be integrated into ordinary hand-held devices. Such a device could be used for positioning applications on a par with GPS satellites, making exact positioning possible even if the signal from one of the GPS satellites is obstructed.

4 Trends in GPS satellite application in Japan

4-1 Framework for GPS satellite application

Japan, as well as other countries, shares in the bounty of GPS, which is owned and operated by the U.S. It has already become an essential component of our social infrastructure, and many of our activities could not take place without it. Can we completely rely on the infrastructure provided by another country?

In a Japan-U.S. joint communiqué issued in September 1988, U.S. President Clinton and Japanese Prime Minister Obuchi declared that U.S. would continue to provide GPS services free of charge to the whole world, and Japan would cooperate in enhancing GPS application technology. In October of the same year, the U.S. House Representative and Senate both passed a bill that prevented the President from changing this open GPS policy without the approval of congress. These developments have enabled Japan to use GPS information without anxiety, at least for the foreseeable future, and manufacturing and sales of car navigation systems in Japan took a sudden upward jump[4].

Although there is certain assurance for the continuous, unobstructed use of GSP, there is still some insecurity that access to the GPS system might one day terminate or precision will degrade in line with U.S. policy change. One solution would be for Japan to launch its own constellation of GPS satellites using proprietary Japanese technology.

4-2 Typical application of GPS

The main use of GPS lies in acquiring positional information with a variety of applications including car navigation, Geographical Information Systems (GIS), geographical markers, cadastral surveys, and crustal movement monitoring. There are many other applications: meteorological observation using the delay in electromagnetic waves, anemometric observation at sea using reflected electromagnetic waves, and reference clocks that solely use time base information. In exploiting Quasi-Zenith Satellite resources, the most advantageous application would be enhancing emergency calls, especially the automatic notification of a transmitter's location.

4-3 Enhanced emergency call

With the amazing prevalence of mobile phones in recent years, more than half of police notifications are transmitted using mobile phones.

When an emergency call is sent from a fixed-line phone, the sender can be easily located using the telephone directory database. For mobile phones, however, few good methods are available to pinpoint transmitter location with sufficient precision. In August 2003, IT Strategy Headquarters stated that localization and positional information notification of the transmitter used for emergency calls must be positioned among the most important and urgent agenda items in the e-Japan Priority Policy Program.

The U.S. government has made it mandatory, since 1999, that mobile phone carriers equip their devices with automatic positional information notification capability when the subscriber makes a emergency call (#911), which is called Enhanced 911 (E911). The EU has also decided to introduce E112 in 2002. Implementing this emergency mechanism, however, has not made much headway. In U.K. and Germany, legislation review is underway to make this mechanism mandatory.

In Japan, the decision made by the IT Strategy Headquarters is equivalent to introducing a Japanese version of E110 (police), E119 (fire fighting) and E118 (maritime safety).

Following the IT Strategy Headquarters' decision, the Minister for Internal Affairs and Communications, Mr. Taro Aso, submitted this subject to the Information and Communications

Policy Site (chaired by Mr. Yoshihisa Akiyama) for deliberation ("Enhancement of Emergency calls in Telecommunication Policy"). The committee returned some of the deliberation results as "Technical provisions required for subscriber localization in emergency calls" (June 30, 2004)[5].

The report (partial) is mainly based on discussion in the Enhancement of Emergency Calls Committee (a subdivision of the Information and Communications Policy Site: chaired by Prof. Norihisa Doi, Chuo University), whose constituent members are mainly mobile phone carriers such as NTT DoCoMo, KDDI, and Vodafone.

This partial report discussed the status of emergency calls from mobile phones and the need for positional information notification, technical conditions related to positional information notification, the time schedule, items to be implemented and future assignments.

The schedule for implementation is as follows. Handling of positional information in emergency calls will start in April 2007. After this, on-board positional information notification capability will be compulsory for all new and updated mobile phones. The projected prevalence of mobile phones with this function will be 50% by 2009, and 90% by 2011.

4-4 Effect of enhanced emergency calls

With the rapid increase in emergency calls from mobile phones, the quick localization of the transmitter is sometimes difficult. In fact, the average time required to reach the spot has become longer by 1.5 minutes (32%) in these ten years in Japanese major cities (ordinance-designated cities). The deterioration is especially visible in these two or three years. However, note that the overall time from the occurrence of accident/incident to notification to the police or related agency must be shorter because callers without mobile phones must have found a fixed-line telephone in the first place, which may have taken a considerable time. With the prevalence of mobile phones, it has become common that multiple emergency calls reach the authorities simultaneously, making the situation more confusing; there may be calls from multiple witnesses of a single incident or independent witnesses of multiple incidents. Enhancing the emergency call capability of mobile phones (for example, E110) is expected to reduce the total time and aid proper judgment for emergency action.

If a large-scale disaster occurs, communication using fixed-line phones may be severely restricted. However, emergency response mechanisms are already in place to give highest priority to emergency calls and maintain the flow of communication.

4-5 Accuracy of positional information communication

According to the partial report, the required accuracy of positional information is as follows: positional accuracy should be within a radius of 15 m (best-case scenario), and the information is represented by a latitude and longitude value (in 0.1 sec unit) and altitude (in 1-m units). The basic method of obtaining positional information is to use GPS signals from four or more GPS satellites; in this case, the practical accuracy of the data is somewhere between several meters to several tens of meters. When there is not a sufficient number of GPS signals available, for example, in densely populated urban areas or inside buildings, a synchronization signal from a base station will be used instead, in which case positional accuracy will deteriorate considerably from tens of meters to hundreds of meters. Even this synchronization signal may be unavailable in areas such as underground cities and indoors, where cell-based positioning will be used. In cell-based positioning, cell IDs that were obtained from mobile terminals are stored in a positioning server's database, and the relevant positional information is searched from this database. The positional accuracy of the cell-based method depends on the density of the base station network; typical values are several hundreds of meters in urban areas and about ten thousand meters in regional areas.

In an open-sky environment, positioning using GPS signals has clear advantages. However, this does not apply in the majority of urban areas, even in low-rise shopping areas and residential areas. Full-fledged enhancement in emergency calls, as we expect it to be, may not be realized if we completely depend on information provided by U.S. GPS satellites because of their low availability.

To mitigate these problems, the Japan Aerospace Exploration Agency (JAXA: an independent administrative entity) is planning to launch a geostationary Engineering Test Satellite VIII (ETS-8) equipped with time signal transmission capability around 2006. It will be used to validate high-precision positioning. Although, with its low elevation angle of 45°, it will have limited capability to complement GPS, the satellite is expected to play an important role in enhanced emergency calls (E110, E119, and E118) development.

5 Mechanism and roles of Quasi-Zenith Satellites

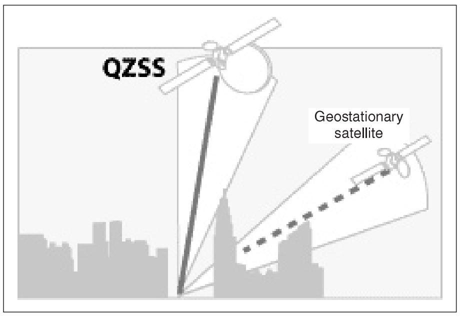
5-1 What is a Quasi-Zenith Satellite System?

The Quasi-Zenith Satellite System (QZSS) is a constellation of three satellites that orbit the earth in synchronously with the rotation of the earth (23 hours 56 minutes) on different orbital planes, with at least one satellite positioned near the zenith over the country at all times, in low to middle latitude on the same line of longitude. The geostationary satellite, on the other hand, is positioned over the equator at all times, orbiting every 23 hours and 56 minutes, and its position is controlled from ground stations so that is does not deviate from the fixed angle. Viewed from the middle latitude regions, the geostationary satellite is often invisible from the ground obstructed by buildings and mountains due to its low elevation angle (around 45 degrees at most). The three Quasi-Zenith Satellites round the earth reciprocating the northern and southern hemisphere with their orbits cutting a figure of 8 when projected onto the earth's surface. The trajectory takes various orbital inclination and eccentricity values, but is always centered on a certain longitude.

5-2 Practical example of QZSS and research history in Japan

In the United States, Sirius Satellite Radio launched three Sirius satellites for radio

Figure 2 : Comparison of Quasi-Zenith satellites and Geostationary satellites



Source: JAXA home page [6]

broadcasting covering the entire American continent. The number of subscribers has just recently exceeded 700,000, with a subscription fee below $10 a month. The company forecasts that the number will finally reach 50,000,000. The Sirius satellites (3.8 ton/satellite) were launched one by one using the Proton K launch vehicle provided by International Launch Services (ILS). The satellite bus for the Sirius system is the LS-1300 series provided by Space Systems/Loral, the same series as Japan's MTSAT-1 (Multi-functional Transport Satellite). Because of the vast stretches of the American continent, "near-zenith" conditions cannot be maintained at all places. It is therefore questionable to classify the Sirius constellation as a Quasi-Zenith Satellite system. Figure 3 shows the Sirius constellation orbits, which look similar to those of QZSS.

The idea of Quasi-Zenith Satellites is long standing in Japan. For example, the idea was put forward in 1972 by the Radio Research Laboratories (Ministry of Post and Telecommunications), which was the predecessor of the current NiCT (National Institute of Information and Communication Technology)[8]. Based on the technology level of that time, the plan to launch a constellation of satellites was abandoned; decision and control of the orbit was difficult, and the amount of fuel required for orbital modification was excessive. Later that decade (1997), as awareness of the importance of proprietary positioning satellites as a national infrastructure deepened, discussion resumed, and a national project for Quasi-Zenith Satellites was conducted. In 2002, Advanced Space Business Corporation (ASBC) was established to promote QZSS development. ASBC is a joint venture between private companies. From 2003, with the decision to allocate government budget to related ministries (MIAC, MEXT, METI, and MLIT), the full-fledged project has just begun.

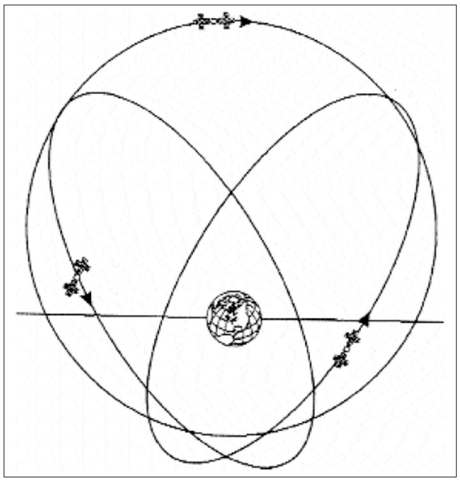
5-3 Basic structure and role of GPS complementation QZSS

(1) Functions of satellite

For GPS complementation, the Quasi-Zenith Satellite must carry atomic clocks and antenna for broadcasting as required mission instruments. It also includes satellite bus including body structure, solar panels, power equipments, altitude control system (including propulsion systems), TT&C systems, and thermal control systems. The satellite is launched by a launch vehicle into the geostationary transfer orbit, and then the final transition is made to a predetermined satellite orbit using an apogee engine. The satellite must be mounted with an apogee engine for this operation (note that, if the satellite is launched using a four-stage launch vehicle, such as Russia's Proton, an apogee engine is not required on the satellite side).

To transmit GPS augmentation information, the satellite must carry transponders to receive augmentation information from the ground station and broadcast to the ground. Figure 4 shows an external view of planned full-fledged version (with positioning, communication, and broadcast capability) of the Quasi-Zenith Satellite.

Figure 3 : Orbital planes of Sirius satellites

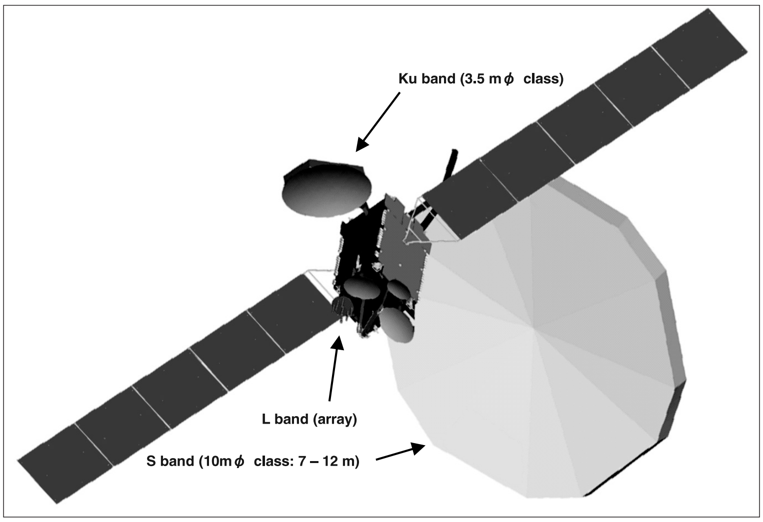


Source: ILS document[7]

(2) Orbit of Quasi-Zenith Satellite

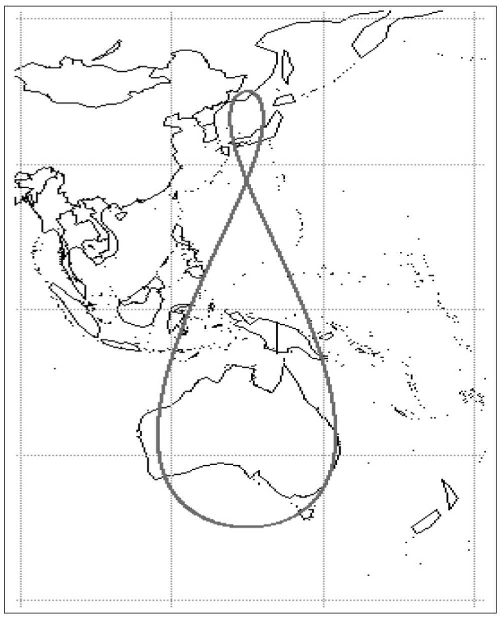
Figure 5 shows the planned trajectory of the Quasi-Zenith Satellite. To realize this trajectory, orbital elements are designed in the following way. First, semi-major axis is designed to be the same as that of the geostationary orbit. The apogee must be larger than this by 3,000 to 5,000 km, and the perigee must be smaller by the same amount. The resultant ellipsoid is relatively near to a regular circle, with one of the two focal points coinciding with the center of

Figure 4 : External view of Quasi-Zenith Satellite (plan)



Source: ASBC document

Figure 5 Example of Quasi-Zenith Satellite trajectory projected on the earth's surface



the earth and other focal point lying within the earth. The eccentricity for this ellipsoidal orbit is approximately 0.1.

The orbital inclination is about 45°, covering the sky in Japan to as far as Australia.

Placing three satellites those are shifted 120° RAAN (Right Ascension of Ascending Node) to each other makes three orbital planes, enabling a constellation arrangement so that the satellite in each orbital plane covers the Zenith over Japan in succession. The argument of perigee is an important parameter in determining the 8-shaped trajectory; setting this parameter to 270° enables the placement of the apogee in the northern hemisphere. Figure 6 shows an example of the zenith viewed from the bottom of an urban canyon. It is almost impossible in this location to receive a signal from a geostationary satellite as it is placed south at a small solid angle extending from east to west. The Quasi-Zenith Satellite remains overhead for approximately eight hours with an elevation angle of 70° or more. As it heads south, another satellite comes overhead from the south (hand-over) and remains in sight for 8 hours. Thus, three satellites enable round-the-clock coverage.

(3) Applications other than positioning

As an option, a Quasi-Zenith Satellite System design that includes broadcasting and communication capability is also under consideration. As the satellite moves at a near-zenith angle, it will enable communication and TV-broadcasting even in urban canyons and deep mountainous areas with a help of large antenna-carrying vehicles in place. At present, many communication/broadcast carriers prioritize the application of geostationary satellites and surface waves. They are not very eager to promote QZSS for these purposes. However, when QZSS is realized and starts providing positioning information services, it may trigger new applications in the communication and broadcasting area.

Figure 6 : Overhead view from the bottom of an urban canyon

Source: Courtesy of National Institute of Information and Communications Technology

(4) New business opportunities in aerospace industries

The successful application of the Quasi-Zenith Satellite System in Japan to implement ubiquitous positioning can trigger needs in other countries, which may result in business inquiries. Depending on the size of the 8-figured orbit, more than one QZSS constellation may be required in regions with wide stretches of land such as Europe and the American continent. The orbit of Quasi-Zenith Satellite is still an untapped resource with great promise compared with the geostationary orbit already in a state of depletion. The success of the QZSS project can bring new business opportunities to aerospace industries in Japan.

6 Research trends for enhanced positioning accuracy in Japan

6-1 High precision time control technology (MIAC)

The National Institute of Information and Communication Technology (NiCT: an independent administrative entity) is developing a hydrogen maser clock, a high-precision atomic clock that will be mounted on the Quasi-Zenith Satellite. In addition, research on the timing control system used in ground stations is underway, which will enable synchronization with the satellite to sub-nano-second precision (< 10^{-8} sec)[9]. Using this hydrogen maser clock, it is expected that the Japanese QZSS will have the world's best timing accuracy.

To support these efforts, the Information and Communication Policy Bureau of MIAC is now drafting technical guidelines for S-band satellite communication, which will be required in GPS augmentation using Quasi-Zenith Satellites.

6-2 High-precision positioning experiment system (MEXT)

In the joint effort of four ministries, the Research and Development Bureau of MEXT presides over the entire progress of the experimental system for high-precision positioning. JAXA is undertaking research to estimate and forecast orbital information with very high precision, and broadcast it to users. Multiple monitor stations located in and outside Japan receive positioning signal broadcast by the Quasi-Zenith Satellite, and the orbit and time information of the Quasi-Zenith and GPS orbital elements are estimated and forecast based on these signals. The feasibility of satellite-borne experimental instruments is also under study aimed at higher performance and precision in the next-generation positioning system. These include a device for inter-satellite ranging and an ultra-high-precision accelerometer.

6-3 Key technology for a lighter satellite with longer operating life (METI)

METI's "Development of Fundamental Technologies for Next-Generation Satellites" project is undertaking a variety of elemental technology developments including: a high-efficiency thermal control system incorporated in satellite body structures, next-generation ion engine, a composite material for large body structures, and a satellite-borne lithium battery. The ion engine has a larger specific impulse and longer life than conventional chemical rockets, which make it a better thrust source for controlling the Quasi-Zenith Satellite orbit. Elemental technology development for the lithium battery has been assigned to New Energy and Industrial Technology Development Organization (NEDO: an independent administrative entity).

6-4 High-precision positioning system with GPS (MLIT)

Civil Aviation Bureau of MLIT is developing MTSAT Satellite-based Augmentation System (MSAS). This MTSAT (Multi-functional Transport Satellite)-aided system was planned for advanced air navigation, and it has almost reached the stage ready for operation. Reliability factors for this system such as integrity and service consistency, as well as accuracy and availability, have already been verified[10]. However, MTSAT must be put into practical operation before MSAS starts operation. The launch of the MTSAT-1R satellite is scheduled for February 2005 (this is a replacement satellite for the MTSAT-1 that was lost in 1999 due to the unsuccessful launch of the H-II launch vehicle).

The Electronic Navigation Research Institute (ENRI: an independent administrative entity) is undertaking, as well as MSAS-related studies, research into Quasi-Zenith Satellite-aided high-accuracy positioning systems. In 2003 and 2004, ENRI developed an analysis system that generates GPS augmentation information from the GPS signal received by electric reference points located throughout Japan. This was an off-line data processing system. From 2005, ENRI has started developing an on-line real-time system for processing data from electronic reference points and for generating GPS augmentation information. The development of receiver prototypes is also included in the project. ENRI is also studying an integrity monitoring method for Quasi-Zenith Satellites based on the results of the MSAS research.

6-5 Enhancement of positioning accuracy

Thanks to the concerted efforts of three Ministries (MIAC, MEXT, and MLIT) to refine high-precision positioning technology and application to the Quasi-Zenith Satellite System, the current level of lateral error by GPS positioning (approx. 11 m) will be reduced to less than 1 m. In addition, contribution to errors from such factors including the ionosphere, time accuracy, satellite position, and troposphere are reduced by magnitude of 1-digit to a level measured in centimeters. With these enhancements in positional accuracy, position display in 0.1 sec will serve its purpose.

7 QZSS will further expand GPS applications

The complementary effect provided by QZSS to GPS will not be limited to enhancing emergency call processing. Various GPS applications have been explained in 4-2. The following are some examples of how QZSS can complement and augment GPS in many fields of application.

(1) Navigation

Car navigation systems commonly used in Japan have on-board autonomous navigation or map-matching functions, as well as having GPS receivers. They navigate the driver by displaying the car's present position on the map using a combination of these technologies. The current level of accuracy is sufficient for ordinary car drivers. For the main navigation system for pedestrians, KDDI provides mobile phones with a GPS receiver function. However, automatic position notification to the police in the case of emergency has not been implemented. The E911 system in the U.S. is not necessarily highly valued because of the low availability of the required number of GPS signals. Areas where four or more GPS satellites are simultaneously in sight are scattered. By the same token, the enhanced emergency call system to be introduced in Japan in 2007 may not show its full potential. However, by complementing and augmenting GPS using QZSS, this problem will largely disappear. At the same time, I confidently expect that the hand-held navigation device and Location-Based Service (LBS) market will grow dramatically.

(2) Railway traffic control

When applying control using GPS to a railway network that includes mountainous areas, the unavailability of the required number of GPS signals will largely nullify the benefit of the control system, just as is the case with car navigation. This problem can be largely solved if a satellite is always positioned at a near-zenith angle. The National Traffic Safety and Environment Laboratory (an independent administrative entity) installed a pseudo Quasi-Zenith Satellite in Kumamoto city and carried out a control experiment using GPS[11]. The experiment was carried out in cooperation with the Kumamoto city transportation authority.

According to the report, the time ratio with signal availability increased from 24% to 72%, which clearly demonstrated the effect of the Quasi-Zenith Satellite. In addition, the feasibility of train position detection with 1-m precision was well demonstrated. It pointed out, however, that to control trains running at high speed, measures are required to eliminate the blurring effect caused by multipaths.

A similar experiment was carried out by Future University-Hakodate (Hakodate city).

(3) Land Survey

The use of GPS will promote efficiency in land survey. Conflict of interest often occurs in relation to demarcation of land, and differences of interest are often settled in court. The future trend in this field is that land demarcation will be determined by electronic means, based on the exact electronic survey results of public property (including roads and rivers). The "Electric Survey and Demarcation of Public Properties" project is in progress supported by more than hundred members of the Diet. According to the Japan Federation of Survey Planning Association, surveys using GPS are only useful in limited areas and at certain times, so the project presupposes the use of conventional transit surveys, eliminating the use of GPS. In this case, it is forecast that it will take nearly 200 years to complete the demarcation of all places in Japan (including privately owned land). The reason for the elimination of GPS is that the satellite is in sight for only a limited period of time, and the signal is easily obstructed by mountains and nearby buildings (generally, GPS survey is unavailable in places where the elevation angle is less than 15°). Introduction of the Quasi-Zenith Satellite that complements the GPS signal will enable more efficient GPS-aided surveys, and the whole process of land demarcation will very probably be completed in the first half of this century.

(4) Other applications

The Forum for Social Basis in Enhanced Positioning (a Non-Profit Organization) set up a committee (Round-Table Conference of Satellite Positioning Users: chaired by Prof. Ryosuke Shibasaki, University of Tokyo) and compiled a report "Proposals for Satellite Positioning System: Perspective from Private Sector"[12]. This report pointed out that, in addition to the applications mentioned in the previous sections, various sectors would greatly benefit from ubiquitous positioning including quick-to-spot businesses, sightseeing, management of goods or waste disposal, maritime construction, and robotics.

Only a few possible QZSS applications are given above. QZSS, as one of the key national infrastructures, will activate various sectors in industry, and promote the development of new products and services.

8 Conclusions — Proposals to promote QZSS development—

Ubiquitous positioning will change many aspects of our lives; it is expected to improve the level of security and safety, and to enhance economic activities. However, the U.S. GPS, an essential part of ubiquitous positioning, has a serious blind side, because it is a go-around satellite, it is obstructed depending on the location and time. This is the inherent nature of GPS that can hinder the full exploitation of its capacity as the most basic positioning method. Truly ubiquitous positioning requires a quasi-zenith satellite to be positioned above us at all times, and complements and augments GPS. It has often been pointed out that aerospace development projects in Japan have few elements that arouse the interest of the general public. The Quasi-Zenith Satellite is an exception in this respect, and can be a national infrastructure that will support our lives and industries for 50 or 100 years to come. The project is gathering huge interest from all quarters, and will be pushed forward by the Japanese government.

Although QZSS has great technical potential such as communication and broadcasting as well as positioning application, it seems that implementing all these aspects simultaneously will entail excessive difficulties in terms of technology and development framework. This approach may hinder the early completion of the system. Among these aspects, positioning application is of utmost importance and urgency as a key infrastructure of a nation, and can be a driving force of social renovation and the creation of new values. I propose that the first QZSS concentrate on functions that complement and augment GPS. This will enable steady, rapid development and the early implementation of ubiquitous positioning, which will greatly contribute to the enhanced safety and security of citizens, and to activating the economy by providing brand new services.

The Council for Science and Technology Policy (CSTP) decided in Sept. 2004 that the governmental organization by which all development efforts and operation framework of the QZSS "should be determined at the early stage before completion of QZSS feasibility studies." This was a step forward; before this, CSTP had proposed that government organization was to be decided "when QZSS feasibility studies were complete." However, Japan is still lagging behind U.S., which already has an organization called Interagency GPS Executive Board (IGEB) and its sub-committee, GPS Interagency Advisory Council (GIAC)[13], which decides development policy and distribute resources. Although each organization is making efforts to solve its own technical problems, we do not have the principal organization to lead the whole process of development and to be responsible for the collective agenda such as the economic feasibility and integrity of the satellite system.

To promote the well balanced development of the wide area relating ubiquitous positioning, and especially for the rapid realization of the QZSS, I strongly recommends the establishment of a governmental organization, like the IGEB in U.S.A, that will preside over the entire progress in related fields.

Acknowledgements

The subjects and discussion in this paper are inspired by the lecture delivered by Mr. Hiroshi

Nishiguchi in the National Institute of Science and Technology Policy (NISTEP) on Aug. 4, 2004 ("Effectiveness of Quasi-Zenith Satellite System as Viewed from National Strategy"). I am also indebted to those concerned in MIAC, MEXT, NiCT, ENRI, JAXA, ASBC for their kind offers of materials and useful discussion.

Notes

*1 One tenth second of latitude (north/south direction) is equivalent to approximately 3m on the earth's surface everywhere in the world, but a distance equivalent to one tenth second of longitude becomes shorter in high-latitude regions. The typical value in Japan is approximately 2m.

Acronyms and full spellings

- *ASBC* Advanced Space Business Corporation
- *DoD* Department of Defense
- *DOP* Dilution of Precision
- *ENRI* Electronic Navigation Research Institute
- *GPS* Global Positioning System
- *JAXA* Japan Aerospace eXploration Agency
- *METI* Ministry of Economy, Trade and Industry
- *MEXT* Ministry of Education, Culture, Sports, Science and Technology
- *MIAC* Ministry of Internal Affairs and Communications
- *MLIT* Ministry of Land, Infrastructure and Transportation
- *NAVSTAR* NAVigation System with Timing And Ranging
- *NiCT* National Institute of Information and Communications Technology
- *QZSS* Quasi-Zenith Satellite System
- *RAAN* Right Ascension of Ascendingl globe through which a satellite travels from south to north crossing the equatorial plane. Zero of right ascension is defined as the direction of the sun on Vernal Equinox Day.)

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(Original Japanese version: published in January 2005)

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.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provide timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

Beneath the Director are five units, each of which conducts surveys of trends in their respective science and technology fields. STFC conducts surveys and analyses from a broad range of perspectives, including the future outlook for society.

The research results will form a basic reference database for MEXT, CSTP, and other ministries. STFC makes them widely available to private companies, organizations outside the administrative departments, mass media, etc. on NISTEP website.

The following are major activities:

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— Through the network, STFC collects information in various science and technology fields via the Internet, analyzes trends both in Japan and overseas, identifies important R&D activities, and prospects the future directions. STFC also collects information on its own terms from vast resources.

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2. Research into trends in major science and technology fields

— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments to set priority in policy formulating.

— STFC publishes the research results as feature articles for "Science Technology Trends" (monthly report).

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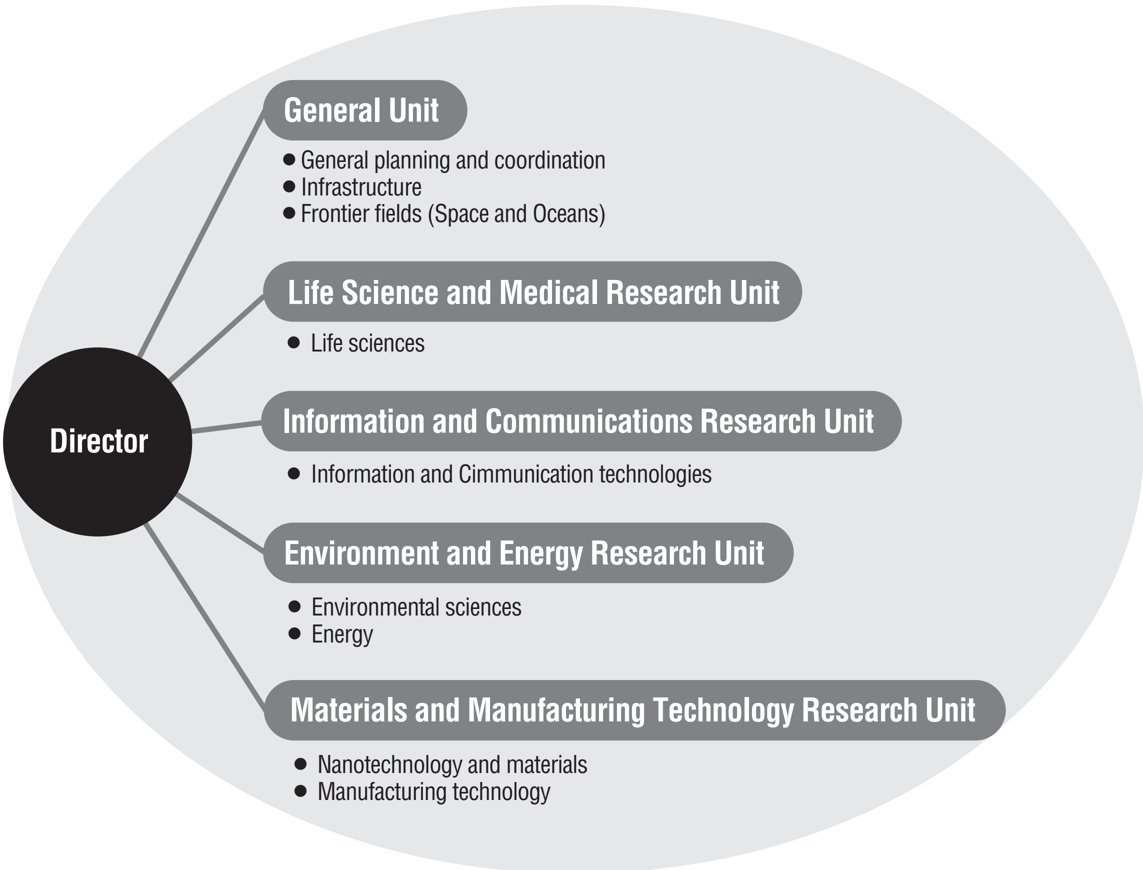
— STFC conducts S&T foresight survey every five years to grasp the direction of technological development in coming 30 years with the cooperation of experts in various fields.

— STFC benchmarks Japan's current and future position in key technologies of various fields with those of the U.S ,EU and Asian countries.

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



* Units comprise permanent staff and visiting reseachers (non-permanent staff)
* The Center's organization and responsible are reviewed as required

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