“Monozukuri” (manufacturing) of Japan and synthesiology

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New advantage must be added to Japanese manufacturing (monozukuri) for which Japan has held the leading position. To do so, it is necessary to build a new mechanism for research and development and innovation. We heard from the people who have led the Japanese manufacturing about the new strategy for monozukuri, the importance of synthesis, and the role of *Full Research* that AIST is trying to achieve.

***Synthesiology* Editorial Board**

Participants of the round-table talk

Hideki Nariai Professor Emeritus, University of Tsukuba; and former President, Japan Nuclear Energy Safety Organization

Ayao Tsuge President, Shibaura Institute of Technology; former Executive Member, Council for Science and Technology Policy; and former Executive Representative Director, Mitsubishi Heavy Industries, Ltd.

Akira Yabe Vice-President, AIST (Editor, *Synthesiology*; Moderator)

Yabe

The main purpose of the journal, *Synthesiology*, is to appeal the importance of “synthesis in manufacturing” and to share the methodology of synthesis with all the people in the world.

For the result of an R&D to become practical, technological issues must be solved to overcome the “valley of death”. Giving some examples, the R&D for super heat pump energy integration system was a national project, in which I was involved, to double the performance of the heat pump in about 10 years up to 1993. When the project was completed, the late Dr. Katayama of the Tokyo Institute of Technology said, “We have a wonderful racing car, but we still don’t have a luxury commercial car”. After that, dozen more years were required before the technology could be commercialized. This period was called the “valley of death”, and it took over 10 years to improve both the economic feasibility and the performance, where various technologies were fortified and reinforced. Now, it has become widely utilized both in Japan and abroad. In the eco-energy city system, we developed the cold heat storage and transport system using the hydrate slurry, and it took six years until practical use. In the case of energy technology, economic feasibility is a major factor, and the six years was a period of challenge in economics. Another case is the automation of product inspection procedure of automobile, which was a project conducted jointly with a medium company. This automated inspection device employed the specular diffraction of the laser, and although the principle was set up in five years, it took seven years from the time we started to apply it to the automobile companies to actual practice. This was a challenge for reliability, durability, and achievement of high speed.

On the other hand, in the energy project called the New Sunshine and Moonlight Projects, there are many technologies that cannot find their way out of the valley of death. Therefore, I ask this question. Is there an effective method for overcoming the valley of death, and to what degree is the perspective of technology integration i.e. synthesis important in overcoming the valley of death? Also, which characteristic of the Japanese manufacturing should be emphasized to lead the world? I wish to open the discussion now.

Importance of synthesis in Monozukuri

Tsuge

“Japanese manufacturing or so called monozukuri that leads the world” is the creation of front-runner type innovation,

Dr. Ayao Tsuge

and we need both the ability to create the individual state-of-the-art science and technologies and the ability of integration for the large scale-complex socioeconomic system. The large scale-complex socioeconomic system is a giant sprawl of spatial, physical, social expanse, having complex interactions of the various elements within, and the performance and reliability affect society and economy significantly. It is exemplified by the social network of artifacts such as the Internet, the high-speed transportation systems, the nuclear power plant, and the space system. The creation of the life innovation and the green innovation launched in the 4^{th} Science and Technology Basic Plan can be called the creation of the large scale-complex socioeconomic system. The proposition of the high added value manufacturing (monozukuri) that leads the world involves the interaction of the recognition science or the "research of the existing" and the design science or the "study of things that should exist", as well as the integration of knowledge of these science and technologies. I think the importance of synthesiology lies here.

Yabe

The mega-complex socioeconomic system cannot be built without knowledge integration. Integration involves synthesis. Dr. Nariai, what is your view on this topic?

Nariai

I graduated from the Department of Mechanical Engineering of the university in 1962. In the classes at the time, importance was placed on the design and experiments, along with the four dynamics: mechanical, material, fluid, and thermal. In many classes, the actual mechanical systems were lectured. The core of the education at that time was to advance the technologies introduced from abroad since the Meiji Era, in a Japanese-manner. When designing or experimenting the rotating machines, we had to calculate the strength, vibration and thermal-fluid characteristics all by ourselves. They were synthetic classes.

In contrast, university education in the late 1960s began to emphasize the basic engineering. The universities were to teach the basics, and the companies were to train persons in the specialties after they became employed at the company. As a result, there was a diversification of the fields of specialty in university education. At the University of Tsukuba, the engineering field was established in 1977 under the new concept that emphasized design integration as well as basic engineering. In practice, however, not only education but also research at the university put emphasis on the basics.

Dr. Hideki Nariai

After the transition from the introduction of technology from abroad in the Meiji Era, to the self-development of technology, and now in the age of globalization, we must develop the technology with Japanese advantages. Therefore, synthesis is very important in such technological developments.

The characteristic of Japanese manufacturing is the presence of major companies that develop the devices and systems, and the small-medium companies that possess specific technologies to support them. In the 1960s when Japan started to take advantage of technology, excellent young people, known as the "golden eggs", came from the countryside to the small-medium companies and contributed significantly to the formation of the technological foundation. By the 1980s, however, young people from the countryside became scarce. At the same time, the technology became sophisticated with the advancement of computerization and IT. Despite such difficulties, it was wonderful that the small-medium companies adopted new technology to adapt to the sophistication of Japanese manufacturing. Dr. Tsuge called such transfer of technology as "Japanese style techno-genome". My current concern is: as industry globalizes with competition becoming increasingly fierce, is it possible to sustain the uniquely Japanese technological genetic information into the future? In any event, integration and synthesis of wide-ranging fields are important to reinforce the technological foundation of Japan.

Tsuge

I think there are two qualities of synthesis. One is the

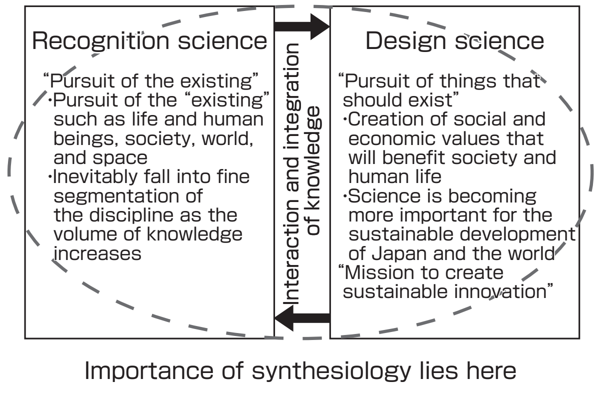


Fig. 1 Proposition of the high value added manufacturing (monozukuri) for leading the world in the "ability to create large scale-complex socioeconomic system"

"modular type architecture" where the world's leading state-of-the-art sciences and technologies are collected and connected through open innovation. And the other is the "integral type architecture" where socioeconomic values are generated by complex combination of the individual state-of-the-art science and technologies. Considering the process of creating the value including the time and collaboration of people-people and people-organization, I don't think we can simply call it the "age of open innovation".

The concept of "techno-genome" that denotes the genetic quality of technology is the terminology of Dr. Takemochi Ishii. When we were discussing the new opportunities for Japanese manufacturing as the developing countries are beginning to catch up, Dr. Ishii said, "There are technologies that can be transferred in a short time if you have money and guts, and there are those that require a long time to be transferred".

In organisms, it takes tens of thousands of years for the genome to change to adapt to the change in the environment. The time frame for technology is 10 or 20 years, but it tends to evolve like the genome over time. The Japanese manufacturing or monozukuri does not have to be so pessimistic as long as innovations in science and technology occur to maintain the 10 to 20 year lead, and by continuously making them part of the social values. This is the root of techno-genome.

On the generalized methodology for technological development to overcome the valley of death

Yabe

I think it is important to take advantage of the characteristic of Japanese manufacturing for the technological development to overcome the valley of death. How do you think about the methodologies? I think this is one of the characteristics of synthesis. How do you think about the characteristics of synthesis?

Tsuge

To overcome the valley of death in innovation process, I think the reconstruction of the innovation traction engine is one of the key solutions.

In the United States, the corporate central laboratories that functioned as the innovation traction engines collapsed over 10 years ago. The current traction engines are the combination of universities, venture companies surrounding the universities, and the venture capital that supports them. Education, R&D, and innovation work as three-in-one to germinate the seed. Then, when the early stage is completed, the major companies step in to invest and the innovation is kicked off. This engine structure is firmly established in the United States.

In Japan, the corporate central research centers have collapsed as well. The national research institutes, such as the labs of the Nippon Telegraph and Telephone (NTT) Corporation, were privatized, and the age of central labs ended. Although the R&D entities, some corporate labs, and universities are working hard, the abilities of knowledge creation and combination by these three kinds of research organizations are weak, and the collaboration between the higher education and R&D is fragile. Therefore, I think the general methodology for overcoming the valley of death in Japan is to strengthen the innovation pipeline network. The innovation process is nonlinear and probabilistic to the degree that one can say that "if he wasn't around or if this organization didn't do that, the innovation might have not occurred". Therefore, as a general method, it is necessary to strengthen the three-in-one collaboration of universities, R&D entities, and industry, and to build the three-in-one structure of the higher education, R&D, and innovation. It is important for the participants to be "under one roof" for education, R&D, and innovation. I think the Japanese-style innovation traction engine must be rebuilt from this perspective.

Yabe

Are you saying that there is insufficient interface function among the universities, companies, and the R&D entities, and to have this function under one roof is a requirement?

Tsuge

Yes. For example, there should be an emphasis on the flow or interface of values from universities to the R&D entities, or from the R&D entities to industry. To put it bluntly, it may not produce an academic paper, but it is vital to contribute to the socioeconomic value creation. To get the academia appreciate the fact that such activities are academically valuable; I think that is the mission of synthesiology. The students and researchers are not passionate about such things because they won't be recognized for doing them.

In industry, this accomplishment is recognized in the personnel evaluation. This individual combined the demand and potential of Business A and Laboratory B, and created the driving force for generating the new Product X. That is what the companies evaluate highly. Unless the academia recognizes this value on the academic table, I don't think the gap between industry and the academia will close.

Nariai

I still remember what a person from industry said a long time ago. He said "Say, that basic research need 1 effort and money, then, 10 times more effort and money are needed to make the actual product, and another 10 times more is needed to create a product that can sell". I felt that it was very difficult to create a selling product. The obstacles we faced on creating a product is, what we call, "the valley of death".

There are two valleys: one to actually create a product from the result of basic research, and the other to create a selling product. There is a difference between the two. The first valley involves the proper combination and integration of various kinds of findings, and the second valley requires wide-ranging integration of them so as to attain social acceptance.

Dr. Tsuge mentioned earlier that the collaboration of three-in-one is fragile in Japan, particularly the collaboration of universities with others. The research at universities had been only to search for the truth and the result was to be disclosed widely to the public. However, the corporated researches were limited. In the past 20 years, researches at universities shifted to what leads to produce an actual product, but still there are other problems, such as the barriers among the government agencies. I hope we can knock down the barriers and form good collaborations of three-in one.

Effective method for raising the level of synthesis

Yabe

I think the points of discussion will be how to knock down the barriers or how to deepen the collaboration. What are some of the effective methods for raising the level of synthesis?

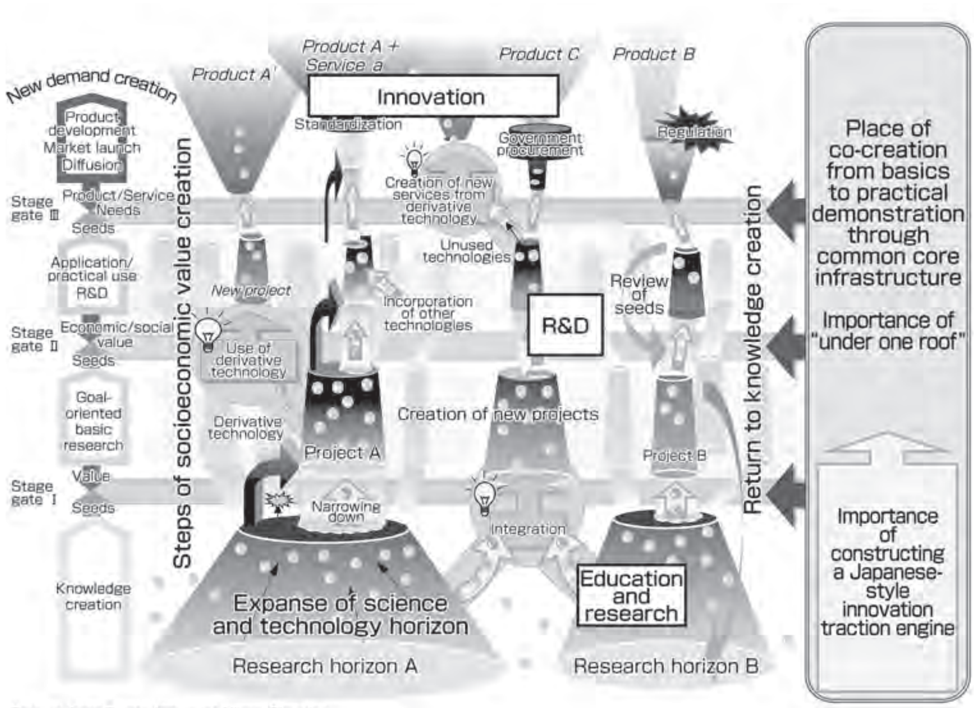
Tsuge

To raise the level of synthesis, I think we need a major reformation of the current situation where the pipeline that binds the knowledge creation and the socioeconomic value creation is broken, as shown in Fig. 2. We must not forget the fusion with education or the human resource training policy. If the government decides to provide the place of fusion, strengthen vertical collaboration among the agencies, or to advance the innovation policy, the education policy must be incorporated. I think building such mechanism is very important. The "realization of a strong economy, strong finance, and strong social welfare" as proposed by the government must be sustainable. To strengthen the sustainable innovation creation, the three-in-one advancement of education, R&D, and innovation is essential. If the innovation traction engine with such structure is set forth, the level of synthesis will automatically rise.

Nariai

As effective methods for raising the level of synthesis, I suggest the "use of human network in the local areas", the "tradition of technological development at companies", and the "Japanese decent character of helping each other".

As an example of the use of the human network in the local area, Tsukuba Science City is illustrated, where national research institutes and companies gathered in 1980. The researchers of heat transfer and thermal engineering gathered and started a study session in order to exchange information. It resulted not only in reports of the academic society, but also the publication of the book *Jisedai Gijutsu To Netsu (Next Generation Technology and Heat)*. Diverse researchers involved in basic research and in problem-



Source: Ayao Tsuge *Innovator Nihon*, Ohmsha

Fig. 2 Need for three-in-one promotion of education, research, and innovation

solving research got together, and the level of research was raised through these discussions at the study sessions. Now, the information technology has advanced, and there are other means for information exchange among researchers compared to 30 years ago. In the study sessions at Tsukuba, researchers could often see actual products at the study session and that was extremely useful to advance their studies. Thus, local human network can be utilized to raise the level of synthesis.

Yabe

People of universities, companies, and national research institutes gathered in Tsukuba to talk about the demand and potential, and how they were viewed by society. I think this is an example of being "under one roof" where the three parties gathered in one place. We are now building the "Tsukuba Innovation Arena", which is inspired by research associations. Gathering the universities, companies, and research institutes in one place is an excellent method for Japan.

Tsuge

I certainly think so. My view is that graduate students do not have to sit at the main table, but the professor may say, "Hey, there's an interesting session in the evening, so why don't you come along?" and the graduate students can participate. I wish to do that consciously. When I look back at my university years, Dr. Nariai was in the doctorate course and was studying in the engineering department. By participating in such study sessions, I could feel the energy and technologies that support society.

How synthesis can be utilized in creating a sustainable society

Yabe

You discussed that one of the effective methods to raise the level of synthesis is to establish a system where everyone can exchange information and share wisdom. Creating a "sustainable society" is extremely important for us. How can we incorporate the objective of sustainability into synthesis? Will that be at the individual or organizational level?

Tsuge

The important point in the methodology for building a sustainable society is to create a sustainable innovation traction engine structure. Furthermore, the "human resource education" is the most important. As shown in Fig. 3, there are roughly four types of human resources to propel the front-runner type innovation structure. One is Type D or the "differentiator" who creates the cutting edge of science and technology. This person may win the Nobel Prize. Type E is the "enabler" who creates the enabling technology. Type B or the "base" who truly supports the innovation structure and monozukuri tends to be forgotten, but this person has wide-ranging basic technology and possesses core technology and skills. I think a large part of engineering education is to nurture the Type B people. I fear what is forgotten in the current science and technology and the education policy is the so-called Type Σ. This is someone who works to create the socioeconomic values through vertical and horizontal integration of the innovation structure. Type Σ is the person who supports synthesiology and is crucial in building the sustainable society.

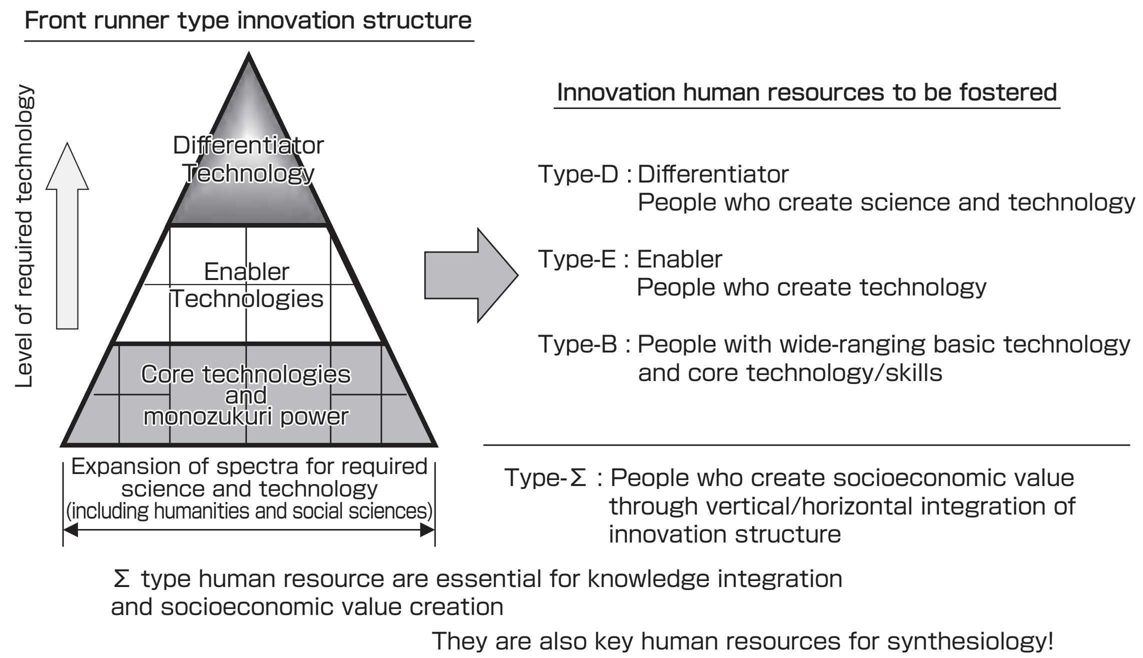


Fig. 3 Human resources essential for creating the sustainable society

Nariai

I consider establishing a sustainable society as making such a society utilize advanced science and technology sustainably. I have been involved in researches and regulations pertaining to the safety of nuclear power. The nuclear power plants were developed abroad, mainly in the United States. Japan imported the technology, and then manufactured, constructed, and operated the plants. The researchers studied hard and investigated carefully about how to protect the safety of the residents and the workers, even in case of any accidents. In the nuclear power plant, the heated fuel melts when the cooling water is depleted, which leads to the release of the radioactive materials. Therefore, the researchers conduct analyses and experiments for the extremely complex phenomena to prevent the fuel meltdown by injecting emergency cooling water when the water pipes are broken and the cooling water is depleted. The late Dr. Hideo Uchida has called such research as "the development of nuclear safety". Through the goal-oriented R&D, the research is conducted by mobilizing various knowledge to achieve an objective. The basic point is synthesis.

Regulatory science is proposed in the fields of food and drugs. It is the research involving risk evaluation, risk management, and risk communication which needs all related disciplines including humanities and social sciences. At this point, regulatory science belongs to the goal-oriented domain, rather than the domain of the conventional basic applied sciences. In nuclear power, the issues of risk evaluation, risk communication, and risk management including the role of the regulatory agencies are indicated. In order to gain social acceptance in society of advanced technology, the methodology or science to guarantee safety and security is necessary. I think the synthetic way of thinking is important.

Tsuge

Dr. Nariai's discussion that views including the humanities and social sciences are necessary for goal-oriented research is pointing to design science or the science for the pursuit of things that should exist, isn't it? I think it is necessary to understand design science when creating a sustainable society. Moreover, design science cannot exist without recognition science. Therefore, we must set up an education program for people with birds-eye-view that enables such collaboration, and the government should support it. Similar proposal was made in "Japan Perspective: Proposals from the Science Community" published by the Science Council of Japan in April 2010.

Yabe

How to get the importance of design science and synthesis accepted by society; I think this is a topic on which it is rather difficult to write a scientific paper.

Tsuge

To practice science and technology for society, it is necessary to nurture human resources for design science. That is to educate people with ability for bird's-eye-view, synthesis, and co-creation. That is why the evaluation standards are different in design science and recognition science. It is necessary to clarify each evaluation standard, and we must engage in activities that deepen the understanding of the Japanese people for "science and technology for society".

What can synthesis do for technological innovation?

Yabe

Because we want people to recognize the importance of design science, we use the word "social technology" or the technology at the contact point with society. Dr. Tsuge discussed earlier about the creation of technological innovations, such as green innovation and life innovation. What can synthesis accomplish, and what is expected of synthesiology?

Tsuge

Synthesiology is a foundational discipline that supports the creative power of the large scale-complex socioeconomic system, Japan's advantage in monozukuri, and the creativity of front-runner type innovation. At the same time, it is a practical science. I would like synthesiology to establish an academic evaluation standard, as well as play the part as a practical science on site.

I believe design science or synthesiology can provide academic meaning. That will be the academic evaluation standard, and for example, the standard for funding a project can be discussed in terms of whether it is valuable as design science. I think it is a challenge for the academia.

Yabe

Applying this to *Synthesiology*, what AIST has been stating as synthesiology must be organized from the viewpoint of design science and then transmitted further.

Dr. Akira Yabe

Nariai

When looking through *Synthesiology*, I felt AIST has done quite a few useful researches. It is important to think about the world of a globalized society and the developing countries, in order to grasp the social needs. The countries with certain technology will compete and the one with superior technology will win. To prepare for such competition, it is sometimes necessary to reform the conventional Japanese system and perhaps to change the consciousness of the Japanese people.

I heard the terminologies *Type 2 Basic Research* and *Full Research* for the first time, but I've always been concerned about technological development. As for my expectations for *Synthesiology*, I look forward to the new issues of the journal on this matter. AIST proposes an important methodology in today's advanced technological society. I hope this will spread to wide-ranging fields, not just within the researches at AIST. It will help train human resources to get the researchers to think widely and deeply about practical research, as Dr. Tsuge mentioned. The discussions are especially very valuable and interesting. This should be carried on so editors can be trained. I hope this will lead to the training of program managers and research coordinators in Japan.

Yabe

To bring out Japan's strength from synthesis and to point the direction the world should take; I think these are the important roles of synthesiology. The ideas transmitted as synthesiology must be organized and then re-organized from the perspective of design science. By transmitting the importance, we would like to lead the world. I think that is important for the future of Japan. Thank you very much.

(This round-table talk was held at AIST Akihabara Office in Chiyoda-ku, Tokyo on September 6, 2010.)

Profiles

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Born in Tokyo in 1938. Graduated from the Department of Mechanical Engineering, Faculty of Engineering, the University of Tokyo in 1962. Completed the doctorate course at the Graduate School of Engineering, the University of Tokyo in 1967. Doctor of Engineering. Joined the Ship Research Institute, Ministry of Transport in April 1967 as a researcher, then became the Senior Researcher. Assistant Professor of Structural Engineering System, University of Tsukuba in April 1980; Professor in November 1987; retired in March 2002 as Professor Emeritus. Chairman, Atomic Energy Society of Japan from 2002 to 2003. President, Japan Nuclear Energy Safety Organization from October 2003 to March 2009; Special Adviser from April 2009 to March 2010. Collaborating Member of the Japan Council for Science. Specialties are thermal engineering and nuclear safety.

Ayao Tsuge

Born in Tokyo in 1943. Graduated from the Faculty of Engineering, the University of Tokyo in 1967. Completed the doctorate course at the Graduate School of Engineering, the University of Tokyo in 1973. Doctor of Engineering. Completed AMP 101 at the Harvard Business School in 1987. Joined Mitsubishi Heavy Industries, Ltd. in 1969, and engaged in the R&D for nuclear power generation. Manager of Nuclear Power Research Promotion; Director of Takasago Research & Development Center; Director and General Manager of Technological Headquarters; and Executive Director of Technological Headquarters. Executive Member, Council for Science and Technology Policy, Cabinet Office in January 2005. Special Adviser, Mitsubishi Heavy Industries, Ltd. in January 2007. President of Shibaura Institute of Technology in December 2007. Member, Japan Council for Science; and Vice Chairman, Engineering Academy of Japan.