China ~ Science and Technology Superpower

(Extract, Tentative English Translation)

July 2013

Japan Science and Technology Agency（JST）

Center for Research and Development Strategy（CRDS)

Principal Fellow, Overseas Unit

Yukihide Hayashi

[1] Introduction

Chinese S&T showed no huge presence until very recently, and it did not attract much attention from other countries around the world including Japan. China, however, accelerated its economic development starting in the 1990s and maintained rapid growth into the 21st century thanks to its policy of reform and door-opening. In 2010, the Chinese GDP overtook that of Japan and ranked as the second largest economy in the world following the U.S. In keeping with the progress of economic development, China's S&T has been changing greatly.

A survey was conducted by the National Institute of Science and Technology Policy in Japan based on data of Thomson Reuters, and the world's share of research article publication output is indicated as shown in Table 1 below. The U.S. still has an almost 30% share of the world's research output and ranks first. China has increased its share rapidly to move up in the ranking. Most recently, China ranks second, leaving behind major European developed countries such as the U.K., Germany and France. If China continues to increase the number of researchers and research funds at the current high speed, the country can press hard on the world's top-ranked U.S. Japan increased its share around 2000, but since then has had a declining trend.

Table 1 Share in the world's research article publication output (counting whole numbers only)

(Unit: %; rank)

Country	1989-1991 (Average)		1999-2001 (Average)		2009-2011 (Average)	
	Share	Rank	Share	Rank	Share	Rank
China	1.4	14	3.9	8	12.0	2
U.S.	34.6	1	31.0	1	26.8	1
Japan	7.7	3	9.5	2	6.6	5

Note: In this table, only whole numbers are counted. An article is counted as one for each country even if it is published by multiple authors who have different nationality.

Source: Based on "Science and Technology Benchmarking 2012," National Institute of Science and Technology Policy in Japan.

In a different survey for international comparison of advanced technology fields conducted every two years by the Center for Research and Technology Strategy of JST in Japan, based on input from Japanese experts, China's S&T capabilities are not found to be very strong. Using data of the center's 2011 report, the author of this document created Table 2 below.

Table 2 International Comparison of S&T Capabilities conducted by Japanese Experts (2011)

Electronics, Information and Communications	U.S. > Europe ~ Japan > South Korea > China
Life Science	U.S. > Europe > Japan > China ~ South Korea
Clinical Medicine	U.S. > Europe > South Korea ~ Japan > China
Environment and Energy	U.S. ~ Europe ~ Japan > South Korea ~ China
Nanotechnology and Material	U.S. ~ Japan ~ Europe > South Korea > China

Source: Based on "International Comparison of S&T Capabilities conducted by Japanese Experts," JST.

While, the Korean Institute of S&T Evaluation and Planning (KISTEP), an institute operated by the South Korean government, has also conducted an international comparison and survey based on input from their own experts in order to evaluate their own technological level and promote S&T policies. Most recently, KISTEP conducted a survey in 2010. Table 3 below is created by the author based on a translation of their survey reports and data included in them.

Table 3 International Comparison conducted by South Korean Experts (2010)

Electronics, Information and Communications	U.S. ~ Europe ~ Japan > South Korea ~ China
Biotechnology	U.S. ~ Europe ~ Japan > South Korea ~ China
Medicine	U.S. ~ Europe ~ Japan > South Korea ~ China
Energy and Resources	U.S. ~ Europe ~ Japan > South Korea ~ China
Nanomaterial	U.S. ~ Europe ~ Japan > South Korea ~ China

Source: Based on "Comparison of International Comparisons conducted by Experts of South Korea and Japan," KISTEP.

When comparing the results of surveys conducted concerning all the technological fields in Japan and South Korea, respectively, it was found that the U.S. had the dominant and strongest capabilities, followed by Europe and Japan. China was behind other countries, being on the back foot of even South Korea. It was also concluded that China had a gap between these developed countries and regions of the U.S., Europe and Japan. As the result of the international comparison surveys conducted by Japanese and South Korean experts, a large gap in S&T capabilities was found between China and other countries, which is quite different from the survey results on capabilities measured with regards to research article publication output.

As above mentioned, there are some indicators showing that Chinese S&T is very strong, already overtaking Japan and Europe and closing in on the U.S., while some survey results show that China still lags behind. In order to get the whole picture of Chinese S&T, I conducted a survey in China. The survey targeted a total of 6 topics that China currently has had the world-leading S&T facilities.

[2] Supercomputers, Tianhe-1A and Nebulae

1. Chinese supercomputer development and Tianhe-1A and Nebulae

Although China embarked on the development of supercomputers behind the U.S., Europe and Japan, it has succeeded in making remarkably rapid growth in the field. Supercomputers developed in China in the past did not attract any particular attention as they were relatively mediocre in terms of performance. In November 2010, however, a supercomputer located at the National Supercomputing Center of Tianjin, “Tianhe-1A,” was recognized as the world’s fastest supercomputer in the list of the world’s fastest supercomputers, “TOP500.”

The National Supercomputing Center of Tianjin and its Tianhe-1A supercomputer are located in the research park in Tianjin Binhai New Area. The developer of the supercomputer is the National University of Defense Technology. The development cost was 0.6 billion yuan (approx. 8 billion yen), which is rather a small amount when compared to costs spent on the world’s top-level supercomputers in Japan or the U.S. The processors of this supercomputer, are mainly composed of central processing units (CPUs) manufactured by Intel, a U.S. company, and graphic accelerators (GPUs) for semiconductors to process graphical computing manufactured by another U.S. company, NVIDIA.

In November 2009, the “TOP500” list placed Tianhe-1 as the fifth. Later, some changes were made, and the new model, Tianhe-1A, ranked first in the list. The change was adding more of Intel’s CPUs and shifting its GPUs from AMD to those from NVIDIA. This change allowed the new model to compute at a speed of 2.57 petaFLOPs (computing speed at 1,000 trillion floating-point operations per second).

However, although Tianhe-1A is already placed in service, there is no sign that it is being actively used. On the PR panel set up on the wall of the National Supercomputing Center of Tianjin, a series of simulated usage is displayed and how to use the supercomputer in high-tech areas is indicated as an example, but it is not known whether the supercomputer is used actually or not. It cannot be denied that hardware receives greater focus in supercomputer development in China.

Another supercomputer developed in China, Nebulae, is housed in the National Supercomputing Center in Shenzhen, and in November 2011, it started operating on a full scale. This supercomputer was developed by the Institute of Computing Technology, Chinese Academy of Sciences and manufactured by Dawning Information Industry Co., Ltd. The development cost is not known, but is considered to be several hundred million yuan, similar to that of Tianhe-1A. Nebulae is equipped with CPUs made in China, named Longson. But Intel's CPUs and NVIDIA's GPUs are also used, and main computing ability of Nebulae still depends on chips manufactured in the U.S.

2. The world's fastest computing speed

After being ranked first in November 2010 in the "TOP500" list, which updates the ranking every 6 months, Tianhe-1A continued to keep the second rank for a while and most recently in December 2012, it was placed at the eighth rank. Moreover, Nebulae also had kept a strong position. It ranked second in June 2010 and then stayed at the third once and the fourth twice. Most recently, in December 2012, it ranked 12th in the list. In supercomputer development, the U.S. has overwhelming strength, which Japan is chasing after. China, however, has recorded groundbreaking achievements in this field, by developing Tehanhe-1A and Nebulae. It can be said that China has established a strong position in the competition of supercomputer development that was previously fought dominantly between Japan and the U.S.

3. Extensive use of GPUs and low use rate

Tianhe-1A and Nebulae are characteristic in that they use GPUs extensively. A number of countries including the U.S. have tried to use GPUs greatly in supercomputers. In Japan, too, a supercomputer housed and operated at Tokyo Institute of Technology, Tsubame, uses quite a large number of GPUs. Supercomputers are manufactured at a cheaper cost when using GPUs extensively than those not doing so. A supercomputer, however, cannot be of use as a supercomputer if it uses GPUs only and CPUs are necessary. Therefore, it needs to adjust the combination of GPUs and CPUs used in the supercomputer, which makes the use and operation more difficult than those using CPUs only.

The challenge for Tianhe-1A and Nebulae is how to increase their usage rate. The usage rate of Nebulae is less than 10%, and in case of Tianhe-1A as well, how to improve the usage rate is a large issue. They are not used sufficiently because these two supercomputers were developed with a focus on hardware to rank in the "TOP500" list, while their usage has not been reviewed and clarified. Another reason is that supercomputers using GPUs extensively have been actively developed only very recently, and software to match such supercomputers has not been developed yet to meet demands. Although Chinese developers mentioned keywords for their possible application, including climate change, protein analysis and disaster response, it does not seem that potential users' input has been obtained properly and this results in such low usage rates.

4. Positive results in commercial application

In comparison with Japan's supercomputer, "Earth Simulator,"[1] China has a clear advantage over Japan in some areas. That is, commercial application of supercomputers after completion of development. Simply put, China's approach for supercomputer development is like this. It develops highly advanced supercomputers in order to be highly recognized in the "TOP500" list, while developing more inexpensive supercomputers to dominate China's domestic market. For example, Dawning Information Industry Co., Ltd, the manufacturer of a brother supercomputer of Nebulae, the Dawning 5000 series, has been supplying supercomputers in and around the nation from its factory in Tianjin. They manufacture both inexpensive commercial supercomputers and high-performance servers, and sales of their inexpensive supercomputers have been extremely good.

While, Japan's Earth Simulator delivered a great shock to the supercomputer superpower, the U.S., and has achieved world-class success also in operation. Earth Simulator, however, is seen with a question mark about whether it yields a profit for its developer, NEC. The supercomputer does not appear to be paying off the cost spent on the development. Japan needs to learn a sense of business from China.

5. China has not yet risen to the truly top level

Although Tianhe-1A and Nebulae are catching up with other world-leading supercomputers in terms of computing speed, they cannot be deemed to be at the world's top level in terms of general strength, including how they are used and operated. In the future, China will face a challenge concerning what will be done with their supercomputer capabilities instead of just increasing the computing speed. We should wait and see how Chinese supercomputer performance will be evaluated as their first-generation supercomputers have just been constructed and started operation.

[3] Manned submersible research vessel, "Jiaolong"

1. "Jiaolong"

In China, the project of the manned submersible research vessel, Jiaolong, was proposed in 1992, and following reviews conducted by the Chinese government, the development work started in 2002. The entity in charge of the design, development and testing of Jiaolong is the 702 Research Institute (CSSRC) located in Wuxi City, Jiangsu Province, an affiliate of the China Shipbuilding Industry Corporation. The entity owning and operating Jiaolong is China Ocean Mineral Resources Research and Development Association (COMRA) based in Beijing.

2. Ranked at the top overtaking “Shinkai 6500”

In January 2008, an operation test for the entire system of Jiaolong was completed in an outdoor water tank of CSSRC and in August 2009, the vessel set off for an at-sea test. After clearing a cruising depth of 3,759m in 2010 and 5,057m in 2011 steadily, in June 2012, about four years and a half from the land-based system test, it successfully went underwater to a depth of 7,062m in the Mariana Trench. Jiaolong exceeded the record of 6,527m established by Japan’s Shinkai 6500 in 1989. It can be deemed a remarkable accomplishment that evidences the strength of Chinese S&T capabilities.

It is necessary, however, to make some reservation in this achievement. In 1960, almost 50 years before now, a manned submersible vessel called “Trieste” owned by the U.S. Navy successfully submerged to the depth of 10,911m in the Challenger Deep, the Mariana Trench. In March 2012, a movie director, James Cameron, also succeeded to submerge in his one-seat submersible vessel, “Deep Sea Challenger” to the cruising depth of 10,898m in the Challenger Deep. Japan’s Shinkai 6500 was highly evaluated around the world because it has gone underwater repeatedly and steadily to perform scientific research in ocean depths, not trying to make adventurous records on an isolated occasion like Trieste and Director Cameron.

3. China’s S&T capability evidences by Jiaolong

China has a coherent approach for R&D, as the country emphasizes final goals and does not question whether or not they use domestically developed technologies or components. In constructing a manned submersible vessel, it is usually considered most technologically important to manufacture a pressure hull that can endure deep-sea water pressure to protect the crew’s safety. Japan develops the pressure hulls for its vessels on its own, while China did not perform development, and imported the hull from Russia for Jiaolong. Also, according to experts in Japan, the appearance of Jiaolong is similar to that of the Russian manned deep-sea research vessel, Mir. It is highly likely that the design of Jiaolong as a whole reflects Russian technology. In addition, the floating buoyant material used in Jiaolong was manufactured in the U.K., and most of major sensors such as obstacle sensing sonars and Doppler velocity loggers (DVLs) were manufactured in countries other than China.

Another characteristic found in Chinese S&T is that the country is quick to gain economic benefits even during the development phase. About 4 years and a half after the completion of the ground-based system operation test, Jiaolong did not reach its designed maximum cruising depth of 7,000m and was still under development. Even during this development process, they conducted a survey commissioned by the International Seabed Authority (ISBA) under a contract in order to recover the development cost.

4. China's challenge is in operation performance

Jiaolong is a manned submersible vessel having the purposes similar to that of Shinkai 6500. China is likely to operate the vessel mainly for scientific survey including resource exploration. In the future, Jiaolong could receive greater recognition, when it steadily increases the number of times of successful submersion and performs scientific research more frequently.

Based on information available now, it is not clear what kind of scientific research will be performed by Jiaolong, which has the world's top designed maximum cruising depth. In the case of Japan, the Japan Agency for Marine-Earth Science and Technology in charge of the operation of Shinkai 6500 has its own team of researchers as well as invites researchers from universities and other research institutes and offers a forum for discussion. If China is to exploit Jiaolong more effectively, it will be important to establish a collaborative linkage within the research community in China, and the future challenge for China will be how to construct a mechanism for such a linkage.

One more aspect to be noted about the future operation of Jiaolong is where it will be located. CSSRC responsible for the development and testing of Jiaolong is not located near the coast, and whenever Jiaolong needs maintenance, it needs to be transported to the storage location by land. Naturally, it is inconvenient if a submersible research vessel is maintained in a location away from the coast and its operational efficiency may deteriorate significantly. In addition, the vessel may be rocked and shaken during transport, which can negatively affect the vessel body.

Another important factor related to the operation of Jiaolong is the performance of the batteries that supply power during cruising. Currently, Jiaolong uses silver oxide batteries. On the other hand, Japan's Shinkai 6500 uses lithium-ion batteries, which is said to have an excellent property in terms of energy density and product lifetime. In the future, replacement of the Jiaolong batteries will probably need to be considered.

[4] Astronomic telescope, "LAMOST"

1. LAMOST

The telescope, "LAMOST," owned by the National Astronomical Observatories, Chinese Academy of Sciences, is formally called the "Large Sky Area Multi-Object Fiber Spectroscopic Telescope." LAMOST is located in Xinglong County, Chengde City, Heibei Province, which is approx. 120km to the northeast of Beijing. LAMOST is located on the top of a mountain approx. 900m above sea level in the eastern part of Xinglong County. In 1993, the LAMOST project was started, in 2001, the manufacture and construction of the system began and in 2008 it was completed. LAMOST is specialized in whole-sky surveys and operation started in October 2011.

2. The world's highest rate of acquiring celestial body's optical spectra

LAMOST is characteristic in that it can collect a large number of optical spectra of celestial bodies at one time. Within its 5 degree field of view, it can observe as many as 4,000 fixed stars and galaxies at the same time. On a winter night suitable for observation, it can observe the sky five times and collect a total of 20,000 pieces of stellar data in one night. Officials in China claim that LAMOST is the world's top level observatory in terms of the number of stellar optical spectra of it can collect. Before LAMOST, the world record was established by the reflector telescope located at the Apache Point Observatory in the U.S., which collects a maximum of 640 optical spectra at a time. At LAMOST, the system is capable of combining a large caliber and a large field of view to acquire a huge number of optical spectra at one time. This evidences that China has high-level astronomical technology, particularly technology related to optics.

The issue lies in what the National Astronomical Observatories, Chinese Academy of Sciences is doing by collecting such a large amount of stellar data with LAMOST. Even if we asked astronomical experts about the detailed mission of LAMOST, we could receive only vague responses. It is unprecedented that the telescope can collect a significantly large amount of stellar data in a very short time period, but scientific implication of this is not clear. We suppose that they are trying to understand the "large-scale structure of the universe as a whole."

3. Commissioning of primary mirror polishing service to Russia

Also for LAMOST, China adopted the same approach to advance the project by commissioning S&T to other countries if it is not available domestically. Specifically, China commissioned the polishing service of an important element of the telescope, the primary mirror. LAMOST has two main mirrors, a primary mirror and a reflective mirror. Either is a combined mirror manufactured to have a mosaic structure with flat, multiple hexagon-shaped mirrors having a 1.1-meter diagonal. These smaller component mirrors were manufactured in China and the reflective mirror was polished and combined domestically. While, for the primary mirror, smaller mirrors manufactured in China were transported to Russia for polishing and later polished mirrors were returned to China to be structured into a mosaic and installed. In Japan's telescope, "Subaru", which is located in Hawaii, in the U.S., polishing was the most important process in development, and technical experts were sent from Japan to Hawaii for the polishing process.

4. Accuracy and efficiency of observation

Astronomic facilities are usually located so that they can take advantage of the most suitable conditions for observation, since accuracy and efficiency of observation is affected by air currents and pollution in the air, existence of artificial light sources or stability of the weather (fine weather is desirable). Japan’s observatory, “Subaru,” is intentionally located in Hawaii, quite distant from Japan, while the “ALMA” telescope of an international joint project is located on a highland 5,000m above the sea level in the Atacama Desert in Chili.

Heibei Province where LAMOST is located is a suburban area of the megacity of Beijing and there are concerns about the environment such as artificial light sources and air polluting substances. In addition, the infamous yellow dust storm that even reaches Japan every year passes through the area, which should cause a struggle with yellow dust for the observatory. Another concern is the weather. Although there are a number of sunny days during the wintertime, the rate of occurrence of sunny days in summer is relatively low. These meteorological and other conditions affect the accuracy and efficiency of observation. In October 2011, LAMOST started whole sky observation, and it is said that about 1,000,000 stellar optical spectra were acquired in about 1 year. When considering that it has a capacity to acquire 20,000 stellar optical spectra in one night, China is probably struggling with observation efficiency, because, technically it should be possible to acquire 1,000,000 optical spectra in just 50 days.

5. Data analysis capability

A huge amount of data acquired through observation will be wasted if they are not analyzed appropriately. The U.S., Germany and Japan joined in a project to create a “3D map of the universe” entitled, “Sloan Digital Sky Survey” (SDSS), which is considered to be close to the goal of LAMOST. In this project, data collected at the Apache Point Observatory in New Mexico, the U.S. are recorded and stored in the magnetic tape and transported to the Feynman Computing Center at the Fermi National Accelerator Laboratory so that the data can be analyzed with a supercomputer by a special software. The special software was developed jointly by scientists of the US Navy Observatory, Princeton University and Chicago University. On the other hand, LAMOST has several concerns. What is the capability of the data processing computer installed in the same building? Was the special software developed appropriately? If there is no proper processing capability or software as described above, LAMOST will have no scientific implication even if it can collect the world’s largest amount of stellar optical spectra. We will have to pay careful attention to the outcome of LAMOST, as it has just started operation.

[5] Nuclear fusion research facility, “EAST”

1. The world’s first fully superconducting Tokamak reactor, EAST

The Institute of Plasma Physics (ASIPP), Chinese Academy of Sciences, a center of nuclear fusion research in China, is located in the suburb of Heifei City, Anhui Province. “EAST” is the most advanced Tokamak facility[2] of ASIPP. The name EAST came from the combination of the first letter of the four words, “Experiment,” “Advanced,” “Superconductivity” and “Tokamak.”

In order to generate nuclear fusion, it is necessary to confine plasma which is obtained from hydrogen, etc., and for confining plasma, magnetic energy caused by strong electric magnets is also needed. If the electric magnets are made from normal copper (normal conducting), much electric power will be consumed, exceeding the amount of input power. As a result, no power will be generated. In putting nuclear fusion to practical energy generation, then, it is necessary to make magnets from superconducting material to control power consumption and confine plasma. In the 1980s, the world’s three largest Tokamak reactors constructed by the U.S., Europe and Japan made significant achievement, but at that time technology for superconductivity had not yet been advanced and magnets were produced from copper with normal conductivity. China focused its attention on this fact, and for the first time in the world, succeeded in making all coils have superconductivity when constructing EAST. In 2006, the construction was completed and in the same year, EAST successfully generated the first plasma (an experiment started with the first plasma generation) to complete the world’s first superconducting Tokamak reactor.

The completion of EAST is a remarkable achievement in the world. Based on EAST, China gained a good position in putting nuclear fusion to practical application, since China can now work on technology development for analyzing properties specific to superconducting facility, and for controlling and maintaining the superconducting facility, and on human resource development. Now China also emphasizes that EAST, as a test bed, is effectively contributing to the ITER project[3] in which the country is also involved.

2. Design developed in collaboration with the U.S. and superconducting material produced in Russia

A typical approach to S&T in China can be found in the development of EAST, as well. EAST was designed in collaboration with Princeton University and General Atomics of the U.S. The material of superconducting magnets, the most important aspect of EAST, was imported from Russia.

The manufacture and assembly of important components were performed by the employees of ASIPP. Also for the doughnut-shaped vacuum vessel, tiles were cladded by employees of ASIPP. Although the material to manufacture the superconducting coils was imported from Russia, the coils were processed and produced at a manufacturing and assembly plant constructed in the site of ASIPP.

3. Limit of plasma capacity

Even after EAST was completed, it cannot necessarily be said that China is now equivalent to other countries having advanced nuclear fusion technology like the U.S., Europe and Japan. The main reason is the size of EAST. In order to confine plasma to generate nuclear fusion, the doughnut-shaped vessel needs to be as large as possible. The size of ITER now under construction is approx. 1,000m^3, and one of the world's largest three Tokamak reactors located in Japan, "JT-60," is approx. 60m^3, while EAST has a size of only approx. 10m^3. In order to put nuclear fusion to practical application, it is necessary to have larger energy (output energy) generated by nuclear fusion reaction than the power that is spent on the electric magnets. Therefore, the capacity of the nuclear fusion facility itself needs to be large. In order to confine plasma in a steady manner in the large vessel and increase the temperature and density, technology development is necessary for producing larger magnets, improving the heating system and creating a more accurate measuring system, etc. Therefore, it is important to produce a larger fusion facility and to advance research and development (R&D) using such larger facility. We need to fully recognize that EAST has a limit in that regard.

4. Active effort to develop human resources

ASIPP has been accepting a large number of graduate students who intend to earn a doctoral degree, and this contributes to the revitalization of the laboratory. ASIPP receives positive influence on its human resource development through China's participation in ITER with EAST playing a certain role in the project. In the 10 years until 2020, the Chinese government plans to develop about 2,000 researchers for nuclear fusion. The government set up a policy to support up to 200 doctoral students as well as establish a department dedicated to nuclear fusion at its five leading universities, including Peking University, Tsinghua University (Beijing), Shanghai Jiao Tong University, Fudan University (Shanghai) and University of Science and Technology of China (Heifei City, Anhui Province). If this effort is promoted, it is expected that the Chinese academic level, which is currently considered weaker than that of the U.S., Europe and Japan, will steadily improve.

[6] iPS cell programmed mouse, "Xiao Xiao"

1. iPS cell research in China

Prof. Shinya Yamanaka of Kyoto University who developed iPS cells received the 2012 Nobel Prize in medicine and biology and his success has had a great impact on researchers around the world, including those in China, of course.

In China, research in cloning has a long history and accumulated experiences. A Chinese researcher, Dr. Tong Dizhou, successfully cloned a fish for the first time in the world. In 1963, Dr. Tong succeeded to clone a carp, by extracting DNA from a male carp and transplanting it to a female carp. Cloning research is categorized into the field of embryology along with stem cell research. If a country has high level research capabilities in cloning, it has great potential on its stem cell research. In China, following the remarkable success made by Dr. Tong, research into cloning of cows and sheep was advanced, which contributed to an early catch-up with the current trend in the world's ES cell research. After the successful development of iPS cell by Dr. Yamanaka and his team, China is promoting research in the field of stem cells by taking advantage of its experience and accumulated know-how of cloning and ES cell research.

2. iPS cell mouse, Xiao Xiao

In recent years, China has made significant advancement in iPS cell research, one of which is success in the production of an iPS cell-derived mouse. Dr. Qi Zhou of the Institute of Zoology, Chinese Academy of Sciences and his team succeeded in producing a mouse, "Xiao Xiao," (English name: Tiny) from iPS cells for the first time in the world using the tetraploid complementation technique, and in July 2009, published the success in the electronic edition of the scientific journal, *Nature*. In order to prove that iPS cells are multifunctional cells like ES cells, it had been said that an iPS cell-derived mouse had to be generated. Despite rigorous efforts made by researchers in Japan, Europe and the U.S., the production of such a mouse was not successful. Some scientists in Europe and the U.S. even had argued that iPS cells were different from ES cells and not sufficiently multifunctional.

Dr. Qi Zhou named the world's first iPS cell-derived mouse Xiao Xiao (Chinese word meaning tiny). Being asked if he named it Xiao Xiao because it was tiny, Dr. Qi Zhou responded humbly that it is "because the research outcome is not very significant." In spite of his humbleness, however, the success in generating the mouse was highly praised around the world, and, for instance, the U.S. magazine, *Time*, selected Dr. Qi Zhou's achievement in "research on generation of an iPS cell-induced mouse" and ranked it fifth in the "Top 10 breakthroughs in medicine" in 2009.

3. Level of iPS cell research in China

According to Japanese experts of iPS cell research, China's research level in this field has been improving very rapidly. Until just several years ago, China showed no particular achievement since their research was conventional and poor in quality. Since 2008, however, particularly for the past one or two years, there has been extraordinary momentum in China's research efforts. Some of their research papers have the world's standard level in quality and a few can be considered to be at the top level.

An example of remarkable research results is Dr. Qi Zhou's Xiao Xiao, and research articles authored by China's highest-level researchers are often published in the leading journals including *Nature*, *Science* and *Cell Stem Cell*. One of the reasons for this may be that highly capable researchers who studied in Europe or the U.S. are returning to China and, as a result, the research level in China is improving, while data are increasingly well organized and controlled.

The pool of researchers in China has been growing, too. In 2011, the number of published iPS cell-related research articles was 172 in the U.S. and 68 in Japan, followed by China that published 29 in total and ranked third in the world. Based on data for 2010, when looking at stem cell research as a whole, the number of published articles was 3,643 in the U.S. and 741 in Japan, followed by 677 in China ranking third here again. It is clear, therefore, that the presence of China in this field in the world is getting stronger.

4. Support of the Chinese government

Reflecting these achievements made by Chinese researchers, the Chinese government is actively supporting stem cell research including research on iPS cells, by providing funds and developing research centers. In the "12th 5-year Science and Technology Plan (2011-2015) ", the government plans to invest approx. 3 billion yuan in total in stem cell research over 5 years. Starting January 2011, the Chinese Academy of Sciences, the leading organization for research in China, established a total of 4 core research centers in Beijing, Shanghai, Guangzhou of Guangdong Province and Kunming of Yunnan Province to promote the establishment of a world-class research platform in stem cell and regenerative medicine. The Chinese Academy of Sciences plans to invest approx. 940 million yuan in these research areas over 5 years, including investment in the above core research centers. In addition, the Chinese government is now working to develop stem cell banks at 6 locations, Beijing (location of the Institute of Zoology Dr. Qi Zhou belongs), Shanghai (2 banks), Guangzhou of Guangdong Province, Tianjin and Changsha of Hunan Province, to make them serve commonly as an important base for research on stem cells including iPS cells.

5. Clinical application system in China

Japanese experts also focus on the clinical application system in China. China has newly set up university-affiliated hospitals with several thousands of beds to support clinical application, at Peking University, Tsinghua University, Tongji University (Shanghai), Sun Yat-sen University (Guangzhou of Guangdong Province). In order to advance stem cell research steadily, it is essential to set up guidelines for clinical application in which stem cells are used. In 2003, the Chinese government, as a joint effort with both the Ministry of Science and Technology and the Ministry of Health, issued a notice on "official ethical guidelines for human embryonic stem cell research". As a result, China can now generate clones for medical treatment, which is currently not allowed in Japan. Therefore, there exists a big gap in developing clinical research by iPS cells between Japan and China. Even if Japanese researchers publish academically excellent research papers, they will face an increasingly large risk that Japan will lag behind China in clinical medicine to exploit research products.

6. Lack of originality

Japanese researchers do not regard Chinese iPS cell researchers as rival in the same way they consider European or the U.S. researchers. They see Chinese researchers with cool eyes. This is particularly because Chinese researchers lack originality to a certain degree.

In general, Chinese iPS cell research is mostly not producing new discoveries and it lacks originality to a certain degree. Chinese research is often about changing experimental conditions, improving efficiency of reprogramming or performing trials for individualization using species other than humans or mice.

In the future, China will need to promote research having a high-level of originality, and to this end, China should encourage researchers who studied in Europe and the U.S. to return and establish leading research bases in China to perform original research that can exceed what they learned overseas. It is expected that researchers such as postdoctoral researchers[4] to be trained at those of research bases above will become the next generation of principal investigators (PIs) to produce excellent research results. If this happens, Chinese researchers will be able to perform truly original research in China.

[7] Genome analysis company, BGI

1. Genome analysis in China and BGI

In China, genome analysis was traditionally carried out mainly by researchers returning from Europe or the U.S. with genetic sequencers. However, new genome determining procedures were not developed in China and researchers were not involved in the development of genome sequencers. In this area, China somewhat lagged behind U.S., Europe and Japan. A change in such a situation occurred when China belatedly joined the international Human Genome Project targeting genome sequencing, and BGI was established to represent China and contribute to the project. BGI, Beijing Genomics Institute, was founded in Beijing, in 1999. Through BGI, China gained a position of catching up with countries that have already gone steps ahead in genome analysis such as the U.S., the U.K., Germany, France and Japan.

In China's "11th 5-year Science and Technology Plan (2006-2010)", any commitment to investment in genome sequence was not clearly made. Facing the uneasiness of future funding to genome sequence by Chinese Government, BGI decided to trust to Shenzhen Municipal Government, which in 2007 promised to fund a total of 20 million yuan (about 300 million yen) over 4 years, as well as provided a site for the company's headquarters. In response to the support of Shenzhen Municipal Government, BGI moved its headquarters from Beijing to Shenzhen and changed its name formally from "Beijing Genomics Institute" to just "BGI."

In 2010, BGI purchased newly developed high-speed 128 genetic sequencers, obtaining a credit of 10 billion yuan (approx. 130 billion yen) from the China Development Bank. Thanks to the credit, BGI could purchase such a large number of sequencers at once, which was around three times more than those owned by the world-leading laboratories such as Broad Institute of the U.S. and Wellcome Trust Sanger Institute of the U.K. The news gave a huge impact on those who have interest in life science around the world, and BGI increased its presence in the world as well.

As of July 2012, BGI had a total of about 3,500 staff members, of which, about 700 were researchers, about 450 were bio-informaticians (experts in handling a huge amount of life science data in a manner of informatics) and about 1,000 were engineers. As an institute specializing in life science, BGI has one of the world's largest numbers of personnel, and it can be deemed as a body specializing in genome analysis with an unprecedented size in the world, as well. BGI is characteristic in that its personnel are quite young, with the average age between 25 and 26 as of 2012.

2. **Leveraging Hong Kong's two systems in one country**

BGI is based in Shenzhen City, and in 2009 it established a branch office in Hong Kong. Since 2010, when it acquired a large number of high-speed genetic sequencers, BGI has continued to invest in equipment and facilities. As of July 2012, it owned approx. 200 sequencers, of which, 100 units were located in Hong Kong. The Hong Kong branch office builds trust, and using those sequencers they perform base sequence analysis contracted by clients around the world, particularly clients in Europe and the U.S. If they need to perform in-depth analysis, data will be sent to the headquarters in Shenzhen, and the analytical result will be returned to Hong Kong to deliver to the client.

Even after it was returned to China from the U.K., Hong Kong has had a special status of two systems in one country. Procedures are relatively more relaxed when bringing goods into Hong Kong than to the mainland China, and information is controlled in a more westernized manner. As a result, it is said that overseas companies and organizations feel more comfortable about contracting analysis to BGI in Hong Kong. As Hong Kong is located adjacent to Shenzhen and there is a subway in operation, it is convenient to come and go between the two locations.

3. **Is BGI doing S&T?**

BGI installed a large number of sequencers and carries out genome analysis employing a large number of workers, mainly young workers. BGI only mechanically reads genome sequence as a series of genetic code information (ATGC) and researchers of contractors who receive the analytical result from BGI will carry out scientific works including identification of amino acids and proteins and understanding of proteins' 3D conformation or research into gene-related diseases or inheritability. Therefore, when genome mapping works are completed, BGI will only have a huge amount of mapped gene sequence data and compensation for their service, which cannot be deemed as true outcome of S&T efforts.

In addition, their service can be offered to any country and region of the world. Although BGI has its headquarters in China and employs Chinese workers, service is performed for the world rather than for China. The company plays a role in promoting employment of Chinese people, but it does not enhance China's research and development capabilities. BGI's operational direction is quite different from the S&T direction of other major countries, which is to try to convert research outcome to innovation and compete with other countries or regions.

Despite that they purchased a large number of advanced, high-speed genetic sequencers from overseas manufacturers, BGI has no interest in developing its own sequencers, which also reduces the company's status as a company of S&T.

4. **Enhancing academic capabilities**

It is considered that officials of BGI are also well aware of the risk of relying too much on commercial contracts to map genome, and they are trying to develop their own S&T capabilities gradually.

When requested to offer gene mapping service under a commercial agreement, BGI tries to implement a joint research program with the contractor. The company also tries to offer more value-added service in addition to gene sequencing, and actively participates in and contributes to international cooperative projects.

It is highly possible that BGI will accumulate a range of information, know-how and analytical methods as they participate in joint research programs with the world-leading companies or in international projects. A sign of such has already been seen, and according to a JST survey, BGI published in total 6 research articles in 2007, and in 2010 the number of published research articles increased to a total of 31, including 5 in *Nature* and 2 in *Science*.

5. **How to interact with BGI**

There is no company in the world other than BGI that is extensively and exclusively specializing in DNA gene sequencing. Universities and research laboratories in the U.S. and Europe seem to have a strategy to take advantage of the service offered by BGI to compete in the world's research competition. In this context, Japan will need to establish a better approach and incorporate BGI's potential into Japan's research efforts, while paying attention not to allow BGI to take advantage of or initiative in Japan's scientific activity.

[8] Characteristics of Chinese S&T

In the above sections, discussions were made concerning the most recent situations of selected S&T fields in China. When reviewing how China is doing in S&T as a whole, we can identify characteristic aspects of Chinese S&T. In this section, current situations of Chinese S&T will be analyzed, and a discussion on characteristics of China will be made in combinaton with other fields like space and nuclear energy.

1. Focus on hardware and somewhat lagging operation and use

China already has a quite large number of S&T facilities and equipment that we can deem has having the world's highest quality. China has or once had the world's highest-level facilities, such as the supercomputer, Tianhe-1A, the manned submersible research vessel, Jiaolong, and the astronomic telescope, LAMOST. It also has the world's first superconducting fusion research facilities, EAST. China has other world-class facilities and equipment, including the Pulsed High Magnetic Field Center in Wuhan City of Hubei Province and the Shanghai Synchrotron Radiation Facility (SSRF) located in Shanghai, which is China's largest third-generation high-performance radiation facility.

In modern China, S&T began to develop on a full scale after 1977 when the Great Cultural Revolution ended, so it was only 30 years ago. For a very short period of time, China developed very rapidly, and some of its S&T facilities and equipment succeeded to reach the world's highest level, which is, to be honest, a great surprise. This fact indicates China's strong S&T capabilities. Also, it is a result of the country's attitude of not sticking too much to domestically developed technologies as mentioned later.

However, it is questionable that we should consider that China's world-leading facilities and equipment are used to perform world-leading research. We see those facilities and equipment are often not used in such a way. The construction and introduction of hardware is prioritized, while their operation and use lag behind. This is mainly because China has been trying to catch up with S&T advanced countries, as Japan once did with Europe and the U.S. If there is a supply of necessary funds and a well-trained workforce, it will be relatively easy to construct and introduce world-class facilities and equipment, however it will not be so easy to operate these hardware to generate outcome as S&T advanced countries like Europe and the U.S. do. Particularly, if science is not deep-rooted in the society and culture, it cannot create truly valuable outcome. Since the Meiji Restoration, Japan has actively taken in western-style S&T. And even more than 140 years later, Japan is sometimes criticized as it still cannot get rid of that attitude.

In case of China, researchers who were trained in S&T advanced countries and returning to China play an important role in S&T. Therefore, it is expected that the country will become deep-rooted in the S&T culture much faster than Japan. Still, it will take some more time.

2. Active introduction of better technologies and equipment from overseas

China is different from Japan in the way it promotes S&T. China strives to achieve the final goal without questioning whether the technology or equipment is made domestically or overseas.

For example, Japan's supercomputer, "Kyo," jointly developed by RIKEN and Fujitsu Ltd. uses chips developed and manufactured by themselves. On the other hand, China focuses on the performance of supercomputers, and they consider that it should ultimately reach the world's top level. China, therefore, does not care about using chips manufactured overseas, mainly in the U.S., for their supercomputers, Tianhe-1A and Nebulae. The core component of the manned submersible research vessel, Jiaolong, the titanium alloy pressure hull, was manufactured in and imported from Russia. The nuclear fusion research facility, EAST, is unique in its superconductive magnets, however the material used in the magnets was also manufactured in Russia. China's proud manned spacecraft, Shenzhou, was developed in accordance with a technological introduction agreement with Russia.

In recent years, open innovation is main stream in S&T, and maybe we are in an environment in which we can select and acquire advanced technologies relatively easily from a wide range of available technologies. In such an environment, China's approach to S&T allows the country to achieve the project goal in a relatively short term and with fewer funds. In addition, if the technology is wrongly chosen, it will be easy to replace it with another technology, since large-scale investment was not made in technology development. Japan, too, will need to adopt this Chinese approach for S&T, depending on the nature of R&D projects.

On the other hand, there is a risk in this type of approach for R&D, because we may be forced to depend on core technologies, equipment and components of other countries, and will not be able to move on to the next development steps on our own. This approach is highly effective when a country is in the process of catching up, but we need to be careful, too. We will very likely run up against a wall when we want to develop the most advanced technologies and outperform other countries.

3. Steadily performed R&D

A characteristic of the Chinese way to perform S&T is that they advance projects steadily. China is under the one-party domination of the Chinese Communist Party, and traditionally, people are used to top-down decision-making. It is natural, we can imagine, that they want to achieve great results or complete the development projects as early as possible even if they have to work too hard. However, if we visit the development site, our assumption will be often betrayed in a positive way. We can see that Chinese advance R&D projects has been done in a steady manner, step by step.

For example, in January 2008, the manned submersible vessel, Jiaolong, completed an operation test in an outdoor water tank at CSSRC and four years later, in July 2012, it recorded a cruising depth of 7,062m in the Mariana Trench. While, in Japan, the launching ceremony for Shinkai 6500 took place in January 1989 and only six months later in August of the same year, it recorded a cruising depth of 6,527m, exceeding the original target of 6,500m.

China also succeeded in manned space travels with its “Shenzhou” series. However, prior to which, China launched unmanned space crafts in a series from the first launch of Shenzhou 1 in 1999 to the last unmanned Shenzhou 4 at the end of 2002, accumulating experience steadily. Based on this accumulated experience, in October 2003, four years from the first launch of the unmanned Shenzhou, China, for the first time, embarked on launching a manned spacecraft, Shenzhou 5. As the success of Shenzhou 5 exclusively was reported around the world, including Japan, some considered that China took a scientific risk baldly to launch a manned spacecraft to display national prestige. It is, however, not true and in fact China achieved this remarkable success by taking all the necessary steps and climbing up the technological stairway step by step.

As mentioned above, we can see a different approach to R&D in China, which is not similar to the top-down method found in the country’s political arena.

4. Practical and commercial application at an early phase

What is recognized as a difference in technology development between Japan and China is the distance between technology development and practical/commercial application. In Japan, in general, technology development is performed fairly in depth and the result will be advanced to practical/commercial application when the time is finally ripe. While, China often undertakes the commercialization process even along with the technology development in order to promptly realize practical/commercial application.

One of the most typical examples is China's attempt to export nuclear power plants to Pakistan. In 1985, the construction of China's first nuclear power plant, Qinshan I, started mainly based on domestically developed technologies, and in 1991 the plant started generation and distribution of electric power, and later in 1994 it started practical operation. As early as 1989 when Qinshan I was under construction, however, China tried to sell nuclear power plants of the same system to Pakistan, and succeeded to export two units to Pakistan. If it were Japan, it would do so after having accumulated enough operational experience spending several years from the start of operation, which would be the usual approach for Japan. It is, therefore, a surprise that China exported nuclear power plants actually under construction in China, without any operational experience.

In Japan, recently, one of the Chinese technologies was talked about widely, which is high-speed railway technology. The main players in the world's high-speed railway market are Japan and France and following these two countries, Germany is increasing its strength gradually. In China, a high-speed railway was realized only very recently in 2005 by introducing Japan's bullet train technology, as well as other technologies from France and Germany. However, it was found that China at the same time was trying to export high-speed railway systems to overseas, which surprised a lot of Japanese people. Later in July 2011, when a collision occurred along the high-speed railway in Whenzhou City, Zhenjian Province that resulted in 40 deaths, China's attempt to export seemed to end in smoke. In April 2012, however, the China CNR Corporation Ltd. succeeded to receive an order from Bangladesh for a high-speed railway along with associated facilities such as 60 train cars, train control and operation system [5].

Even if technology development is not fully completed or they are just combining some technological elements generated overseas, China tries to put the technology into practical/commercial application. This may seem dubious. Safety-related problems will possibly occur. Or, planned performance may not be achieved. Considering that these problems can occur, experts in Japan often tend to be careful and have concern about marketing incomplete products and technologies. It can be said that, thanks to this discreet attitude, Japan succeeded to become a technology-oriented nation.

On the other hand, when viewing how vigorously China has been growing and developing economically recently, we have another concern that having an attitude such as Japan cannot be considered as a world standard. If a technology is introduced from overseas or several technologies generated overseas are combined together, China considers it as their own technology when Chinese technology, capital or knowledge is incorporated in it. The country deems it natural to put the technology to practical/commercial application as early as possible. Nowadays, huge investment in research fund or equipment is necessary even in basic research. In the case of nuclear energy or high-speed railway development, much more funds and human resources are invested. It may be important to doubt if Japan is suffering from the Galapagos syndrome here, when we try to put technology to practical/commercial application by spending a lot of time and money in R&D to be sure, as we have already experienced in electronic appliances.

5. Manufactured by researchers

In China, when constructing large-scale experimental facilities, there is a tendency that workers in the R&D unit are willing to construct as much as possible by themselves. It may sound paradoxical and against the above-mentioned tendency of China to actively introduce foreign technologies and procure foreign components. But these two tendencies coexist effectively in China's R&D. Probably, Chinese people do not feel any contradiction in this regard, as, in a large-scale experimental facilities construction program, they identify what can be created by themselves and what should be turned over to foreign countries before actual construction works begin.

There is a more detailed example. The nuclear fusion research facilities, EAST, was partly constructed by researchers of the laboratory. When constructing nuclear fusion research facilities, the manufacturing of a large vacuum vessel and coils to be wound around magnets is difficult. The inside wall of the vacuum vessel needs to be cladded with tiles. It is said that, at EAST, researchers completed this work themselves, placing tiles one by one. For coils, superconductive niobium-titanium alloy was imported from Russia and researchers studied how to process the alloy to make it into wire form and wind it around magnets at a factory located at the EAST site. In Japan, the Japan Atomic Research Agency has similar facilities in Naka City, Ibaraki Prefecture and the National Institute for Fusion Science affiliated with the National Institute of Natural Sciences has facilities in Toki City, Gifu Prefecture, but both purchase vacuum vessels and coils from domestic manufacturers. Naturally, the construction costs increase. Moreover, if any trouble occurs, they have to rely on the manufacturers even if only some of the components are purchased from them.

Research institutes are supposed to fulfill their mission to produce outcome through research efforts. Therefore, they can't afford to spend time to further sophisticate the technology they used in the construction of some research equipment. In that case, it is impossible for them to improve the equipment with advanced technology, or apply advanced technology to other fields. In contrast, in the past, the U.S. mobilized domestic efforts together to tackle space technology development by involving the private sector during the cold war era when the U.S. and the former Soviet Union competed fiercely. And later, the U.S. could apply the outcome of their efforts to a wide range of fields. Some people even say that the rise of the IT industry in the Silicon Valley in California was a hidden contribution of the past space R&D efforts. On the other hand, in the Soviet Union, since only space-related R&D institutes were involved in space development efforts, a new industry did not evolve. And later, space technology development capabilities of Russia inherited from the former Soviet Union's competence have managed to maintain a fairly good level of development capabilities, however have not succeeded in overwhelming other countries in this field.

In the past, China did not have sufficient economic strength, even though it had a huge population. China had a system to promote R&D in a closed circle within the government, as the former Soviet Union did. This background probably contributed to China's current approach to S&T. As the country's economy grows and technological capabilities are strengthened significantly, China may soon face a need to change its approach.

6. Introduction of a large amount of highly advanced research equipment and weakness in their operational system

At the world class research laboratories in China, we can see various experimental, analytical and measurement equipment. Their quality is similar or even higher than those of Europe, the U.S. and Japan. In the arena of R&D, China started behind other countries like Europe, the U.S. and Japan, and as the result, China is now able to introduce the most advanced equipment with no difficulty since they have no remorse or constraints arising from obsolete equipment and an old-fashioned personnel system. The fact that China does not stick too much to the development of indigenous technologies is one reason why the country has no hesitation to use the world's most advanced research equipment from abroad. In the case of Japan, managers at research institutes often feel guilty when they have a large amount of foreign-produced equipment in their laboratories, as if they pay too much tax-payers' money to foreign manufacturers, even though they know that those equipment are the most advanced and essential to perform world-class research.

When asked about their impression about the most advanced equipment installed in Chinese research institutes during a visit, however, Japanese experts often mention that the advanced equipment does not look like it is being well utilized. Some Chinese researchers respond that the equipment does not work well and so they stopped using it. It requires a huge amount of money to purchase world-class research equipment, while operating and maintaining such equipment also requires money and knowhow as well as technicians who are familiar with the way to operate it. China has a weakness in operating and maintaining equipment after introducing it into their laboratories. Researchers are highly eager to introduce high-performance equipment and facilities, however they seem not to pay much attention to how to operate and maintain them later.

[9] Conclusion

In terms of S&T activities, China does not have a long history, sufficient experience and accumulated know-how in western-style S&T, which no doubt forces the country to lag behind the U.S., Europe and Japan at the moment. China is a late-comer giant in the field of S&T and is in the process of catching up.

From China's S&T potential including talented human resources, however, we can expect the country will become an S&T superpower in the future. If China continues to grow economically, it is expected that the country will become the world-leading superpower of this century within a relatively short period and acquire enough strength to promote S&T policies on a full scale. It means that China will become competitive with the U.S. and Europe on its own in any S&T field, and it is clear that China has a potential to do so as we can see from the country's long history and large population. Considering the fact that China has such a huge S&T potential, how should Japan face this country?

Although China has almost reached the world's highest level in terms of research facilities and equipment, the country is not yet in a position to go neck and neck soon with the U.S. or major European countries, and still lags behind Japan in many aspects. For the moment, therefore, China will benefit from enhanced R&D cooperation or people-to-people exchange with Japan.

On the other hand, Japan will benefit from S&T cooperation with China, particularly in terms of exchange of people. Japan is facing a rapidly declining birth rate and growing population of elderly people and it will be highly difficult to secure a stable source of high-quality researchers. There are always concerns about technological outflow and hollowing out of national human resources, when we argue that research cooperation and human exchange should be promoted between China. In order for Japan to maintain and further improve its position as a leading S&T country in the world, however, it is extremely important to continue to secure a certain number of researchers. In this sense, China's high-quality human resources are attractive.

In addition, Chinese people have a much better sense of economy. China still shows a non-sophisticated side in terms of technology, however, China's approach to S&T has succeeded to gain commercial benefits, which then generate funds to be invested in next-generation technology development. In the world, there are only a very few people who have this kind of sense of economy like Chinese people. It can be said proudly that Japan is a country that has the strongest persistence to perfection of technology in the world. If Japanese and Chinese people capitalize on their own strength and get together in collaboration, the two countries will possibly enjoy a win-win situation.

Although Japan and China have a range of issues to solve between each other, bilateral S&T cooperation should be continued for an extended period. Japan should face China squarely and maintain a fifty-fifty partnership to seek out peaceful and prosperous interactions.

[Reference]

"China's Science and Technology Capabilities: World-leading Research and Development Facilities," Center for Research Development Strategy, Japan Science and Technology Agency, 2012. (Written in Japanese)

"Scientific Research Benchmarking 2011," National Institute of Science and Technology Policy of the Ministry of Education, Culture, Sports, Science and Technology, 2011. (Written in Japanese)

"International comparison of S&T capabilities made by Japanese experts," Center for Research Development Strategy, Japan Science and Technology Agency, 2011. (Written in Japanese)

"Comparison of international comparisons made by South Korean and Japanese experts," Center for Research Development Strategy, Japan Science and Technology Agency, 2011. (Written in Japanese)

---

[1] "Earth Simulator" is a distributed-memory type vector-parallel computer with the world's highest level of execution performance. Until June 2004, the TOP500 list ranked the supercomputer at the top, five

times in a row.

[2] In order to generate nuclear fusion, it is necessary to confine ultra-high temperature plasma using a magnetic field. Currently, the confinement device, Tokamak, invented in 1950 by physicists in the former Soviet Union including Dr. Andrei Sakharov, is said to be the closest to practical application. The word, Tokamak, is a coin word created by combining the initial letters of Russian words indicating the device's structure, "torus," "chamber," "magnet" and "coil."

[3] It is a supersized international project to construct the first nuclear fusion experimental reactor with the purpose of scientifically and technologically demonstrating whether nuclear fusion can be an energy source. Participants in the project include Japan, EU (represented by the European Atomic Energy Community), China, India, South Korea, Russia and the U.S.

[4] Researchers who completed a doctorate course and are not yet given the status of full-time researcher.

[5] "Beijing Times," April 5, 2012.