

The Canon Institute for Global Studies
Interim Recommendations of “Study Group on Next-generation Nuclear Energy Utilization”
“Facilitating Revitalization of Nuclear Energy in Japan”
October 2022

According to the consensus of all members, the chairperson, Nobuo Tanaka, compiled these recommendations based on the discussions of the study group.

Summary of the Recommendations

Identifying the Issue

Although the momentum toward carbon neutrality has been on the rise since the COP26 of last year, the circumstances related to global balance of energy demand and supply, and the national energy policy, such as the significant influence caused by the invasion of Ukraine by Russia since this February, are changing dramatically. In such a situation, the importance of nuclear power generation is once again recognized and is currently being reevaluated.

In these circumstances, an important question arises: what should Japan think and do about the future of nuclear power, especially after the restart of existing power plants? These interim recommendations aim to answer this question, and at the same time, trigger a broader discussion on the issue of nuclear energy.

Nuclear Power Generation in the Future

We believe that nuclear power is indispensable to form an energy mix in Japan. Past experiences tell us that, in the future, Japan must take a completely different approach from the conventional path to meet the following three conditions.

(1) More Realistic Method of High-level Radioactive Waste Treatment

The traditional nuclear power generation relied on large light-water reactor and the fuel cycle based on the reactor type. When this system is employed, high-level radioactive waste is produced, and such waste must be stored in geological disposal facilities and kept isolated from the human living environment for several hundred thousand years. Not only is this problem of nuclear waste difficult to solve, it is also one of the major reasons for the lack of general understanding towards nuclear power. On the other hand, pyroprocessing technology for metal fuel cycle succeeded in shortening the isolation period of radioactive waste to 300 years by extracting plutonium and minor actinides (MA). This technology was tested using simulated fuel debris which had the same elements as TMI-2 fuel debris. Although this debris could not be reprocessed by the conventional reprocessing method, it was successfully reprocessed when this technology was applied. This means that both spent fuel that has been exposed to sea water and fuel debris that should be retrieved in the future from damaged reactors of Fukushima Daiichi Nuclear Power Plant could be reduced to radioactive substances, which merely requires isolation for 300 years. It should be noticed that the problems associated with the use of the light-water reactor system may be able to be skirted around when this technology is introduced in the future.

(2) Contribution to Nuclear Non-proliferation

Besides the problem of high-level radioactive waste disposal, the light-water reactor system also poses difficulties when viewed from the angle of nuclear non-proliferation. The uranium enrichment technology that is essential for fabricating fuel of light-water reactors, together with spent fuel reprocessing technology, can be easily applied to development of nuclear weapons. Therefore, future nuclear power generation systems must be as unlikely as possible to produce materials that could lead to nuclear proliferation. Also, it will be necessary to review the management system of nuclear substances in line with the development of novel technologies and the associated nuclear proliferation risks.

(3) Risk Minimization

Since the risk in nuclear power generation cannot be made zero, the idea of risk minimization is quite important. Even in case of a nuclear accident, smaller scale nuclear reactors with smaller fuel inventories could reduce the area affected, such as emergency evacuation zones. It is also necessary to develop technology for enhancing passive safety, so that the operation of a reactor can be stopped as safely and quickly as possible. As part of this process, if the design of the reactor can be made as locally acceptable as possible, it will help to gain the understanding of the local community where the reactor is located and encourage the participation of local residents.

Improvement of Environment

Supposing that such a kind of nuclear power generation is indispensable, It is difficult to be realized and maintained without an appropriate “environment”. Therefore, Environment of the next-generation nuclear power is also required in the meanwhile.

(1) Political Leadership

If Japan intends to build new nuclear power plants in the future, it must review and evaluate its past nuclear energy policies including the nuclear fuel cycle, and present a clear future vision based on identifying achievement made and lessons learned. Strong leadership is important for this purpose. This is the time for the political leaders to take a serious look at nuclear power, objectively assess Japan's situation, and make decisions.

(2) Obligation of the Government

The Government must be more upfront and clearly explain to the public the necessity for nuclear power plants and its vision for the future of nuclear energy in the power system, based on transparent discussions with a wide range of experts. Also, the Government needs to implement effective policy measures, enact appropriate legislation, and create an attractive business environment that allows companies to rationalize the huge investment and the risks associated with nuclear power generation.

(3) Residents' Participation and Interactive Communication

The issue of energy and global warming is of critical importance because it is closely related to civilian life and their economic activities. Therefore, at each stage of planning and implementation of energy and climate policies, including nuclear power, the participation of citizens of the location area in discussions must be ensured. To this end, the government must also increase the transparency of the policy process and strive for two-way communication with local citizens.

(4) Reconstruction of Fukushima and Peaceful Uses of Nuclear Energy

Revitalization of nuclear engineering is important for Japan to reconstruct Fukushima and overcome difficulties still existing in areas damaged by the nuclear accident. Fukushima must become the place to watch over Japan's renewed attempts at science and technology related to nuclear power. Japan, which experienced the tragedy of Hiroshima and Nagasaki, must overcome difficulties and maintain the use of nuclear power to ensure security and provide an effective model for peaceful uses of nuclear energy.

1. Introduction

The Canon Institute for Global Studies organized the “Study Group on Next-Generation Nuclear Energy Utilization” in March 2021, ten years after the accident at Fukushima Daiichi Nuclear Power Plant. This Study Group aims to conduct an intensive discussion on the future of nuclear energy appropriate for Japan, which has played a central role in the peaceful use of nuclear energy by presenting a concrete model, and to make recommendations towards the future. This will be done from a long-term perspective and considering the multifaceted aspects of nuclear energy, in light of the situation where carbon neutrality by 2050 has become a shared mission for the entire globe.

Although the momentum toward carbon neutrality has been on the rise since the COP26 of last year, the invasion of Ukraine by Russia, which started in February this year, significantly affected the balance of energy demand and supply in the world, forcing a dramatic change of energy policy around the globe. In such a situation, the importance of nuclear power generation is once again recognized and is currently being reevaluated. In Japan, nuclear power played an important role in energy supply before the accident at Fukushima Daiichi NPP, by supplying approximately 30% of electricity.¹ It still supplies a certain percentage of electricity right now. Japan has also invested heavily in the field of nuclear power generation and has a history of investing resources to lead the world in the peaceful use of nuclear energy. In addition, regrettably, Japan experienced the severe nuclear accident at Fukushima Daiichi NPP. In the worldwide movement toward decarbonization, we must seriously face the nuclear issue no matter what the end to be reached on how to deal with nuclear and what extent to rely on nuclear power. The present interim recommendations have been put together under such considerations. Although the issue of nuclear energy is multifaceted and has not yet been fully examined, it is intended that these proposals would provide an opportunity for nationwide discussion beyond those directly involved. We believe that nuclear power is an important energy source that Japan should continue to utilize. As we will discuss later, we believe that there are some important “conditions” to be met for this to happen, including exercise of political leadership, and that a “discontinuous” as well as “innovative” policy response is necessary. We would begin our discussion with the hope that readers’ critical comments will further promote this study.

2. Recognition of Current Situation

After the accident at Fukushima Daiichi NPP, 21 nuclear reactors were decommissioned. At present, there are 36 nuclear reactors (33 in operation and 3 under construction) in various districts of Japan, ranging from Hokkaido in the north to Kyushu in the south.² In Aomori, a plant for reprocessing spent fuel expended in these nuclear power plants is about to start operation. Japan has invested considerable resources into construction of nuclear-related facilities, and a huge asset has been formed even though taking the nuclear power plants into account only. Although consideration should be given to a decrease in asset value due to depreciation and necessity of additional investment for construction of safety facilities, it is important as a first step in a broader discussion to consider how to utilize them in a meaningful way, in light of the situation where life extension has been achieved around the world.

That said, even if the use of nuclear power gets halted in the future, it will still be our obligation to decommission existing nuclear power reactors and dispose of spent fuel and radioactive waste produced by the operation of nuclear power plants. We must not forget that operation systems, funds, and human resources for management of such facilities should be maintained even if Japan would abandon the use of nuclear power.

When observing the present situation, it must be said that nuclear power generation in Japan is on the verge of extinction. Although the Government is trying to facilitate restart of existing nuclear power plants, it is not going smoothly in reality, and national discussions are insufficient. As a result, the ratio of nuclear-generated

¹ For data of 2009 and before, refer to “Outline of the Electric Power Development” and “Outline of the Power Supply Plan,” both issued by the Agency for Natural Resources and Energy, and for data of 2010 and later refer to “Comprehensive Energy Statistics” issued by the Agency for Natural Resources and Energy.

² Agency for Natural Resources and Energy, “Present Situation of the Nuclear Power Stations,” September 13, 2022

electricity is drastically lower (approximately 4%) than that achieved before the accident at Fukushima Daiichi NPP.³ Even if the existing nuclear power plants are restarted smoothly, there would be only 8 operable nuclear power plants in 2040, and all the reactors would be decommissioned by 2070, based on the current life span regulation.⁴ Therefore, besides the acceleration of nuclear power plant restart, discussion on life extension must begin immediately.

Although the tone of explanation is changing slightly, the Government consistently maintains its basic policy of reducing the degree of dependency on nuclear power to the greatest possible extent.⁵ The future of nuclear power generation in Japan remains obscure, and the Government has not given a clear direction regarding further utilization of nuclear power following restart of existing nuclear power plants, taking a negative attitude to construct new nuclear power plants. Since, by its nature, construction of a nuclear power plant requires a vast amount of investment and a long payback period, it is indispensable for the Government to have a medium- and long-term consistent and clear policy so that businesses in nuclear power generation and related fields can be developed. Businesses and personals that have supported nuclear power generation technology have been seriously affected by such adverse conditions, and the situation of nuclear power generation in Japan is becoming more difficult than ever.

Problems in nuclear power utilization cannot be solved if the Government avoids detailed discussion on the nuclear issue because of the strong negative sentiment of the public. Time is not on our side.

3. Contemporary Social Demand

The world is now pushing forward toward decarbonization. The invasion of Ukraine by Russia has revealed the importance of balancing 3Es in making an energy policy; i.e., energy security, environment, and economy. Particularly, the significance of energy security has been highlighted. Nuclear power generation based on large light-water reactor has been considered an energy source with excellent 3E balance.⁶ This is the reason why the role of nuclear power is being reevaluated under the current circumstance.

We must admit that Japan is facing a difficult situation after the invasion of Ukraine by Russia due to the low degree of its energy self-sufficiency. The prices of petroleum and natural gas are now kept high, and the electricity reserve rate is decreasing. To realize a decarbonized society, nuclear power can be effectively used as an energy source that contributes to realizing stable electricity supply and carbon neutrality without imposing excessive load on the economy. The present energy crisis was triggered by the invasion of Ukraine by Russia. To reduce the degree of dependency on Russia and prepare for unexpected situations in the future, utilization of nuclear power should be an important option for Japan to hold. It must also be kept in mind that Japan used to provide effective models for peaceful uses of nuclear power as a world leader.

4. Going through the Accident at Fukushima Daiichi NPP

(1) Lessons Learned

Although Japan is one of the most earthquake-prone countries in the world, the Great East Japan Earthquake was a disaster that could only happen once every several hundred years. As reported by the nuclear accident investigation committees of the National Diet of Japan and the Government, the accident at Fukushima Daiichi NPP was an unfortunate man-made disaster which was caused by inadequate assumptions on the effects of massive earthquakes leading to loss of power on the site.⁷ It should be noted that an accident was not caused

³ Agency for Natural Resources and Energy, “Comprehensive Energy Statistics,” April 15, 2022

⁴ Agency for Natural Resources and Energy, “Present Situation of the Nuclear Power Stations,” September 13, 2022

⁵ Agency for Natural Resources and Energy, “Energy White Paper 2022,” page 191, August 3, 2022

⁶ Agency for Natural Resources and Energy, “Merit of Developing Advanced Reactors in Consideration of the Present Social Trend for Energy Uses (Contribution to Solve Problems of Energy Security and Waste Disposal),” May 19, 2022

⁷ The National Diet of Japan, the Fukushima Nuclear Accident Independent Investigation Commission, the official report of “The Fukushima Nuclear Accident Independent Investigation Commission,” September 11, 2012; Investigation Committee on the

at Onagawa Nuclear Power Plant, which is located nearer to the epicenter and was attacked by tsunami of larger scale, and no serious problems occurred in other nuclear power plants located in the area affected by the earthquake.⁸

We must learn that humans, including political leaders and the public, could easily misjudge and cause serious damage in an emergency such as the Great East Japan Earthquake. We also must study not only technological problems but also regulations for safety assurance and risk reduction. We must review continuously and thoroughly the legislations, systems, consciousness, and other aspects concerning safety assurance based on the results obtained by technological innovation and investigation of the worldwide experience and knowledge such as Defense in Depth of IAEA and B5b of NRC.

After the accident at Fukushima Daiichi NPP, reconstruction of the whole Fukushima district including the damaged areas has been a huge challenge for Japan, and we still have a long way to go to overcome the difficulties. A major problem in decommissioning is disposal of fuel debris and spent fuel, and we must not forget the point that this can be solved only by utilizing nuclear technology. When considering the damage received by people in Fukushima, we should seriously think of using nuclear technology effectively for Fukushima instead of turning our eyes from its difficult situation. It is important to use nuclear technology in an active manner. Damages caused in Fukushima must be recovered by appropriate uses of nuclear technology.

(2) Actions Taken after the Accident

The nuclear accident at Fukushima Daiichi NPP and actions taken after the accident were extremely important issues in making an energy policy in Japan. In 2015, the Paris Agreement was adopted in COP21, and a new era was started for the world to take countermeasures against global warming by practicing carbon emission reduction.⁹ During the period of joining the world to prepare for a new era, however, Japan had to deal with issues related to the accident.

After the accident at Fukushima Daiichi NPP, the Government has taken various measures to cope with the disaster. As the first step, it investigated the site situation and compiled a report on the causes and other aspects of the accident which they found through the investigation.¹⁰ In 2012, the Nuclear Regulatory Authority was established as an affiliated agency of the Ministry of Environment, and it has been developing the “most rigorous regulations in the world.”¹¹

Under the basic policy of reducing dependence on nuclear power to the greatest possible extent, the Government plans to restart nuclear power plants that stopped operation after the accident of Fukushima Daiichi NPP only if they comply with the new regulation standards. As shown in the “6th Strategic Energy Plan,” the Government expects that the ratio of nuclear-generated electricity would be 20 to 22% in 2030.¹² In the “Green Growth Strategy” issued in June 2021, the Government pointed out nuclear power generation as one of the 14 important sectors to be promoted, raising four optional technologies: fast reactors, small modular reactors (SMR), high-temperature gas-cooled reactors, and nuclear fusion technology.¹³ In July 2022, it issued “Advanced Reactor Technology Roadmap toward Realization of Carbon Neutrality and Energy Security

Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company, “The Final Report,” July 23, 2012

⁸ Website of Tohoku Electric Power Company, “Safety Measures of Nuclear Power Station – Great East Japan Earthquake and Onagawa Nuclear Power Station”

⁹ Website of the Ministry of Foreign Affairs of Japan, “Convention—Paris Agreement,” December 8, 2016

¹⁰ Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company, “The Final Report”

¹¹ Ministry of Environment, “50-Year History of the Ministry of Environment (December 2021)”

¹² Ministry of Economy, Trade and Industry, “Strategic Energy Plan,” page 106, October 2021

¹³ Cabinet Secretariat and related organizations, “Green Growth Strategy Through Achieving Carbon Neutrality in 2050,” page 142, June 2021

(Draft),”¹⁴and in the “Basic Policy on Economic and Fiscal Management and Reform 2022,” the Government expressed that it would make the best use of nuclear power, although its fundamental policy will remain intact.¹⁵ In the GX Implementation Council of August 2022, the Prime Minister showed a positive attitude toward nuclear power utilization. He said that “the Government would take leadership in making every effort to assure continuous operation of 10 nuclear power plants which had already been restarted and to support restart of other nuclear power plants which have an operation license.” He also expressed a forward-looking stance where a list of items which require political decision were stated, including “maximum utilization of existing nuclear power plants, such as rallying the collective efforts of all parties involved and extension of operation period with safety as a major prerequisite, as well as the development and construction of next-generation advanced reactors incorporating new safety mechanisms.”¹⁶

5. What Actions Should We Take?

Unfortunately, we cannot say that the Government has presented to the public a clear determinative vision of future use of nuclear power after the nuclear accident of Fukushima Daiichi NPP. In that sense, we have to say that the Government has been backing away from the issue of nuclear power development. It has not given a clear direction regarding further utilization of nuclear power following restart of existing nuclear power plants, and it has not shown a comprehensive policy on the nuclear power generation in the future. What is needed is a “Nuclear Vision” which describes the future of nuclear energy and the necessary policy to realize that goal, and a power generation system accompanied with a nationwide power supply system that is consistent with the said Vision. It is desirable to contain in this vision not only nuclear power generation but the entire nuclear fuel cycle, including a policy on radioactive waste disposal, and it should also show future prospects of nuclear power by positioning it under various perspectives such as its relation with Japan’s national security. As for nuclear power generation, it is particularly important to investigate the issues of its relationship with the power market and the role it should play in the future energy mix, such as the provision of funding for nuclear power generation in the context of ongoing reform in the energy system

Besides, another important factor is the existence of a national-level support for the Government’s nuclear energy policy. Currently, discussion on nuclear energy policy seems hardly sufficient. To get out of this situation, the Government must establish a “Nuclear Vision” mentioned above based on transparent discussions with a wide range of experts, and carry on opinion exchange with the people.

6. Revitalization of Nuclear Power Generation and Realization of a Flexible Energy Mix in Japan

Even if nuclear power generation is essential in Japan’s future, it seems that the present system, policy, and environment are quite insufficient. It is inevitable for the Government to view the situation from different angles and take a completely different approach to solve such difficult problems.

We now propose conditions required to this end, dividing them into two categories.

6-1. Improvement of Environment

(1) Political Leadership

Although Japan experienced the atomic bombings in Hiroshima and Nagasaki, it started planning of nuclear power utilization shortly after the World War II. In 1955, the Atomic Energy Basic Law was enacted. When Japan wants to construct new nuclear power plants in the future, it must begin with reviewing and reevaluating its past nuclear policies, including the nuclear fuel cycle, and show the future perspective based on the achievements made and lessons learned. The Government must assume its responsibility in making decisions for future uses of nuclear energy, when considering that it has carried on its nuclear power development policy spending huge amount of money, working forces, and resources, that Japanese people are still suspicious about nuclear power generation after experiencing the nuclear accident at Fukushima Daiichi NPP and responding

¹⁴ Ministry of Economy, Trade and Industry, “Advanced Reactor Technology Roadmap Toward Realization of Carbon Neutrality and Energy Security (Draft),” page 3, July 29, 2022

¹⁵ Cabinet Secretariat, “Basic Policy on Economic and Fiscal Management and Reform 2022,” page 23, June 2022

¹⁶ Prime Minister’s Office of Japan, “GX Implementation Council,” August 24, 2022

to serious situations that followed, that global nuclear environment is drastically changing, and that Japan's nuclear community is in an acute crisis caused by shortage of human resources for next generation. If the Government decides to change its current basic policy of "reducing the degree of dependency on nuclear power to the greatest possible extent," the Government must make further efforts to convince people of the necessity of nuclear power generation. Since this is a difficult job for the Government involving so many people concerned, much stronger political leadership is needed. By its nature, nuclear power generation together with radioactive waste disposal involves a problem of long-term responsibility. Since political judgment is needed in determining these issues, such review work must naturally be done by the political leaders. This is the time for the political leaders to take leadership in addressing the nuclear issue sincerely and observe the situation of Japan objectively to make correct decisions.

Based on sufficient communication with people, the "Nuclear Vision" mentioned above must be established from the medium- and long-term standpoint, and it must show a consistent trend of nuclear policy. Although the concept of small reactors and multi-purpose reactors, which are now being highlighted as advanced reactors, was proposed decades ago, and research and development of these reactors has been carried on by excellent engineers, they have not reached the level of practical use. We should clarify the reason why such attractive concepts have not been accepted and spread in society, and the importance of such concepts.

(2) Obligation of the Japanese Government

The Government has promoted reform of the power generation system. Supposing that it expects more active use of nuclear power rather than merely restarting existing nuclear power plants in the reformed system, the Government must clearly explain the necessity of nuclear power plants and the future nuclear vision to people. Since electric power companies must invest a lot and bear a big risk to operate nuclear power plants, the Government needs to implement effective policy measures, enact appropriate legislation, and create an attractive business environment so that companies can consider the business to be rational from the managerial standpoint. Therefore, the Government must take the primary responsibility to formulate the overall scheme of nuclear power generation.

(3) Resident's Participation and Interactive Communication

As has been clearly proven in Europe and in other countries, the issue of energy and global warming is of critical importance because it is closely related to civilian life and their economic activities. In the circumstances that renewable energy is widely used, and diversification of electric power sources and energy sources is drawing attention, the participation of citizens of the location area in discussions must be ensured at each stage of planning and implementation of energy and climate policies, including nuclear power. To this end, the government must also increase the transparency of the policy process and strive for two-way communication with local citizens. When doing so, the Government must not forget to persist with explanations, based on scientific and objective evidence, including the risks that may arise.

(4) Reconstruction of Fukushima and Peaceful Uses of Nuclear Energy

Revitalization of nuclear engineering is of critical importance for Japan to reconstruct Fukushima and overcome difficulties still existing in areas damaged by the nuclear accident. Fukushima must become the place to watch over Japan's renewed attempts at science and technology related to nuclear power. Japan, which experienced the tragedy of Hiroshima and Nagasaki, must overcome difficulties and maintain the use of nuclear power to ensure security and provide an effective model for peaceful uses of nuclear energy.

6-2. "Conditions" for Revitalizing Nuclear Power Generation and Making Nuclear Power Sustainable

For nuclear power to fulfill its proper role in Japan's energy mix over the future, the aforementioned environmental improvement alone is not enough. Especially, given the accident at Fukushima Daiichi NPP and the firm-rooted, nation-wide suspicion towards nuclear power generation, the Government must take a completely different approach. In Japan, large light-water reactors have been used for nuclear power generation. When considering the issues of further harmonization with the environment, nuclear non-proliferation, sustainability, etc., it may be necessary for Japan to reconsider and make a shift in its policy. Therefore, we now propose conditions required to achieve sustainability in nuclear power utilization in an era of post-large

light-water reactors.

(1) High-level Radioactive Waste Disposal

The conventional way of nuclear power generation has relied mostly on large light-water reactors and the nuclear fuel cycle based on the use of these reactors. In this system, uranium is enriched to manufacture nuclear fuel, and spent nuclear fuel is reprocessed to extract plutonium, which can be used in light-water reactors and fast reactors.¹⁷ This reprocessing process produces high-level radioactive waste including spent fuel of secondary use. This high-level radioactive waste is supposed to be sent to geological disposal facilities to remain isolated from the human living environment for several hundred thousand years. We now face difficulties in finding final disposal sites for such waste, because it is extremely difficult to keep assuring safety of people for such a long period of time.¹⁸ The nuclear waste problem of the light water reactor cycle has become a difficult issue to solve, also known as the "apartment without a toilet," and as a result, it is one of the major reasons why it is difficult to gain understanding of nuclear energy. Since the 1960s, The Idaho National Laboratory had been testing separation of minor actinides (MA) together with plutonium employing pyroprocessing in the metal nuclear fuel cycle, and it succeeded in reducing the isolation term of high-level radioactive waste to 300 years. After the occurrence of the nuclear accident at Fukushima Daiichi NPP, the laboratory used this technology instead of the conventional Purex method, and succeeded in reprocessing simulated fuel debris which has the same elements as TMI-2 fuel debris.^{19,20,21} The use of that technology could similarly turn the fuel debris from the Fukushima Daiichi Nuclear Power Plant into a mere 300-year radioactive waste.²² It should be noticed that the problem of using the light-water reactor system may be able to be skirted around when this pyroprocessing technology and the metal fuel cycle, that can be referred to as "waste disposal power generation", are introduced in the future.

(2) Contribution to Nuclear Non-proliferation

Besides the problem of high-level radioactive waste disposal, the light-water reactor system also poses difficulties from the viewpoint of nuclear non-proliferation. The uranium enrichment technology that is essential for fabricating fuel of light-water reactors, together with spent fuel reprocessing technology, can be easily applied to development of nuclear weapons. Therefore, future nuclear power generation systems must become as unlikely as possible to produce materials that could lead to nuclear proliferation. Also, it will be necessary to review the management system of nuclear substances in line with the development of novel technologies and the associated nuclear proliferation risks.

(3) Risk Minimization

Since the risk in nuclear power generation cannot be made zero, efforts to make the risk as low as possible must be continued. Therefore, the idea of risk minimization is quite important. Even in case of a nuclear accident, a smaller-scale nuclear reactor with a smaller fuel inventory could reduce the area affected, such as emergency evacuation zones. It is also necessary to develop technology for enhancing passive safety, so that the operation of the reactor can be stopped as safely and quickly as possible. As part of this process, if the design of the reactor can be made as locally acceptable as possible, it will help to gain the understanding of the local community where the reactor is located and encourage the participation of local residents.

¹⁷ Japan Atomic Energy Relations Organization, "Chapter 2, Nuclear Power Development and Utilization for Electricity Generation," "Brochure for Comprehensive Uses of Nuclear Power 2021," December 2021

¹⁸ Website of Agency for Natural Resources and Energy, "Radioactive Waste—High-Level Radioactive Waste"

¹⁹ R.K.Mccardell et al., *Nucl.Eng. Design*, 118, 441 (1990)

²⁰ D.W.Akers et al., *EGG-OECD-9168* (1992)

²¹ Washiya et al. "Chemical Characteristics of Debris and Adoptability of Various Reprocessing Techniques," Academic Lecture Session of "Spring Meeting 2012" of Atomic Energy Society of Japan; Report by Research Committee on "Next-Generation Disposal Technology," "Technical Problems in Debris Disposal in View of Next-Generation Reprocessing Technology," 2012

²² Takanari Ogata, "Attractive Points of Metal Fuel Cycles and Research and Development for Them," Nuclear Technology Laboratory, Central Research Institute of Electric Power Industry, March 24, 2021

6-3. Future Vision of Nuclear Power—Concept We Propose—

Considering that Japanese electric power demand would not rise substantially in the future and that the trend of local production for local consumption of energy, mainly renewables, would keep growing, we should not only keep the conventional system of large light water reactors to supply power to urban areas via the backbone grid as baseload, but also take the option of introducing safe small reactors to meet local demand for a sustainable nuclear future. Designing a nuclear reactor that could be supplementary with the fluctuating natural energy by means of output control operation, heat storage, and hydrogen utilization is an example.²³ As planned in Wyoming, USA, it is also possible to replace coal-fired power plants with advanced nuclear power plants to contribute to carbon emission reduction.²⁴ In Canada, small-scale nuclear power is thought to be used as heat resources for oil sand refinement.²⁵ Research has been carried on for some time to make use of nuclear power in carbon intense sector such as steel industry, cement manufacturing industry, etc. Russia has realized the use of small light-water reactors put on a ship as heat resources to be supplied to the coast of the Arctic Ocean.²⁶ Onsite nuclear waste incinerator that could consume the plutonium and MA extracted from spent fuel and fuel debris of Fukushima Daiichi NPP might be an optional solution. Nuclear sustainability could be increased if the residents can take part in new project from the design stage.

7. Concluding Remarks

Since the study group has found many problems to be discussed further, including the relationship between nuclear power and national security, the trend of nuclear technology development, the prospects of science and technology and contribution to engineering innovation in the field of nuclear power utilization in Japan, the world trend of nuclear non-proliferation and possible contribution of Japan, etc., it will continue investigation to clarify these issues. Not limited to nuclear power generation, we intend to present a comprehensive proposal for wide use of next-generation nuclear energy in the final recommendations, which we plan to give by the end of Fiscal 2023.

²³ Sector of Fast Reactor and Advanced Reactor Research and Development of Japan Atomic Energy Agency (JAEA), “World Trend of Development and Introduction of SMR,” October 14, 2021

²⁴ U.S. Department of Energy, “Next-Gen Nuclear Plant and Jobs Are Coming to Wyoming,” November 16, 2021.

²⁵ Energy Council of Canada, “TC Energy contemplating small-scale nuclear power among its portfolio of electricity sources in the future,” April 30, 2022.

²⁶ Digital Version of the Electric Daily News, “Floating Nuclear Power Plant Constructed by Rosatom, and Started Sailing toward the Arctic Ocean,” May 7, 2018

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