Tentative Translation

Executive Summary
Japan’s Policy to promote R&D for a fusion DEMO reactor (December 18, 2017)

1. Background

○ Over 10 years have passed since the formulation of the “Future Fusion Research and Development Strategy” (formulated by the Japan Atomic Energy Commission’s Advisory Committee on Nuclear Fusion in October 2005, hereinafter referred to as Fusion R&D Strategy). Amid various changes over the years, the Science and Technology Committee on Fusion Energy of MEXT believed it necessary to prepare a new report on the course of research and development of the DEMO reactor, considering the internal and external factors surrounding fusion research and development.

2. Changes in the Energy Situation and Societal Demands

○ Since the accident at Tokyo Electric Power Company’s Fukushima Daiichi Nuclear Power Plant, people have been losing confidence in nuclear power. The principle of nuclear fusion differs from that of nuclear fission and can be said to be intrinsically safe. However, the accident mentioned above should be a lesson for those who are involved in nuclear fusion since it deals with neutron and radioactive substances as is the case with nuclear fission. It should be understood while establishing the fusion DEMO reactor that the reactor is expected to have an even higher level of safety than the current level of nuclear safety technology because it would not be possible to introduce a fusion DEMO reactor in Japan without first obtaining the confidence of the public.

○ This research and development should be advanced focusing on the economic rationality of fusion technology compared with other greenhouse gas emission reducing technologies, such as renewable energy and nuclear power, while also being positioned as a revolutionary technology capable of changing the correlation between economic development and the emission of greenhouse gases.

3. Strategy for Developing Fusion Technology for Demo Reactors

○ The common objective set for the entire fusion community including industry, academia and the government is to develop a technology that fulfills the conditions required for transitioning to the fourth phase of fusion science and development process with a tokamak, which is the most advanced reactor type at present.

○ With safety at the DEMO reactor as a major premise, the technical practicality of reactor engineering should be demonstrated and research conducted to achieve a realistic reactor in line with the economic situation at the period of commercialization.

○ Comprehensive activities characterized by a degree of diversity should be advanced to promote the acceleration of research and development and to resolve various issues.

While striving for steady progress on the tokamak reactor, research on helical and laser systems which are complementary and alternative to tokamak as well as other innovative concepts should also be conducted in parallel.

4. Basic Concept Required for the DEMO Reactor

○For commercialization of fusion energy, the objective of the DEMO reactor is to (1) realize a steady and stable electric output of over several hundred thousand kilowatts, (2) availability sufficient for commercialization and (3) overall tritium breeding that fulfills self-sufficiency in fuel.

○ To achieve the basic concepts mentioned above, it is necessary to (1) ensure safety base on ALARA, (2) achieve an acceptable level of construction costs, and (3) design a flexible blanket and divertor.

○ Additionally, during the operational development phase of the DEMO reactor, it is also important to realize (1) particle control and plasma control; (2) a practical maintenance scenario and availability; and (3) high performance of the blanket and divertor.

5. Advancement of Development for Resolution of Technological Issues

○ In formulating the development plan, issues and development targets should be identified based on the finalized technical specifications, keeping in mind plant construction and operation costs, the operation scenario, as well as technical consistency. The development plan should classify the technological issues that include superconducting coils, and organize and analyze the progress of each issue and the connection between issues as an action plan.

○ With a view to steadily resolving such technological issues, there is a need to strengthen research and development by building an all-Japan framework comprising industry, academia and government. To make this effective, the Rokkasho site should be upgraded as the central hub for developing the DEMO reactor.

○ To promote long-term research and development, the necessary human resources for research and development of the DEMO reactor must be nurtured through close collaboration among industry, academia and government by promoting organic cooperation of the ITER project, BA activities and advanced academic research. A reactor design framework comprising diverse human resources with multiple perspectives will be drawn up as well through various collaborations that include the humanities and social sciences, along with promoting participation from other fields.

○ For promoting international collaboration, issues that Japan must resolve alone and issues it must resolve through international collaboration should be distinguished strategically and rationally. Moreover, from the perspective of international contribution, Japan must play a leading role amid the development of DEMO reactors around the world.

○ Safety guidelines and safety requirements for the fusion DEMO reactor, which is required to have high intrinsic safety, must be promptly formulated from the viewpoint of the public and the environment. This should be done in cooperation with experts from various fields in Japan and abroad, promoting comprehensive fusion safety research.

○ To build a framework for the technical base, a DEMO reactor development roadmap will be formulated integrating the overall development process, including development priorities, milestones and areas for international collaboration, along with the action plan.

6. Approach for Transitioning to the DEMO Phase

○ The decision to transition to the DEMO phase will be taken in the 2030s when fusion operation (DT) of ITER is expected. It is necessary that the economic feasibility of a commercial reactor is foreseeable when transitioning to the DEMO phase.

○ The Intermediate C&R will be reexamined and implemented in two parts:

(1) When JT-60SA is expected to begin operations in around 2020

(2) Within a few years of 2025 when ITER's first plasma is scheduled (with the suitability of starting engineering development of the necessary components of the DEMO reactor also determined)

○ The Taskforce on DEMO Comprehensive Strategy under the Science and Technology Committee on Fusion Energy of MEXT will regularly review the timeline of the action plan and the items and timing of the intermediate check and review through debates within and outside the fusion science community in light of the status of the ITER project and the results of the BA activities.

○ To obtain the confidence of the public and make fusion energy the public's energy source of choice, outreach activities will be strategically advanced, with a headquarters established for overall management of activities in Japan, thereby planning and advancing collaborative activities aimed at optimizing the social value of fusion energy.

Tentative Translation

Japan's Policy to promote R&D for a fusion DEMO reactor

Decided on December 18, 2017 by
Science and Technology Committee on Fusion Energy
Subdivision on R&D Planning and Evaluation, Council for Science and Technology

Introduction

The objective of this report is to present the basic guidelines for future research and development of the fusion demonstration reactor (DEMO) in Japan. To this end, the report presents a summary of (1) the strategy necessary to develop a DEMO reactor, (2) basic concepts required for the DEMO reactor and methods for advancing development to resolve technological issues, and (3) views on transitioning to the DEMO phase, based on the "Future Fusion Research and Development Strategy" (formulated by the Atomic Energy Commission (AEC)'s Advisory Committee on Nuclear Fusion in October 2005, hereinafter referred to as "Fusion R&D Strategy").

1. Background

(1) Japan is currently conducting research and development in the field of nuclear fusion based on the "Third Phase Basic Program of Fusion Research and Development" (decided by the AEC in June 1992). Furthermore, the concrete policy towards the Fourth Phase Program, which is centered on a DEMO project aimed at "technological demonstration and economic feasibility" of fusion energy, is indicated in the Fusion R&D Strategy.

(2) After the Fusion R&D Strategy, the AEC's Advisory Committee on Nuclear Fusion released the "Evaluation of the Basic Concepts of Approaches to Fusion Research and Development, Specified in the Framework for Nuclear Energy Policy, Etc." report in 2009, which noted the need to create a strategic roadmap clarifying the technology Japan needed to secure, maintain and develop for the realization of the DEMO reactor, and to share this roadmap among industry, academia and government to advance efforts with an all-Japan framework.

(3) After receiving the report on "The Way Forward to Establish a Technological Base for DEMO Reactor Development" (January 2013) from the Working Group on Fusion Research, the Joint-Core Team for the Establishment of Technology Bases Required for the Development of a Fusion DEMO Reactor (Joint-Core Team) was formed. The Joint-Core Team presented the report in July 2014 after considering the structure of the technological base necessary for developing a fusion DEMO reactor, by taking into account the ITER project and BA activities, advances in academic

research, including LHD, as well as the collective opinion of the fusion science and development community in Japan. The formulation of the Taskforce on DEMO Comprehensive Strategy (Taskforce) was approved by the Science and Technology Committee on Fusion Energy in March 2015 to grasp a comprehensive view of the overall status of fusion research and development and deliberate upon items that include the formation of an action plan towards DEMO reactor. Moreover, the Joint Special Design Team for Fusion DEMO was established with the objective to advance the building of a technological base for developing the DEMO reactor through an all-Japan framework of industry, academia and government, and work began on the conceptual design and research and development of the DEMO reactor.

(4) The Science and Technology Committee on Fusion Energy referred to the various discussions held on the development of the DEMO reactor up until now, and taking as the base the Joint-Core Team reports that contained recent discussion results, the committee decided it was necessary to draw up a report on the form of research and development of the DEMO reactor that widely reflects the views of society considering both internal and external factors, including the status of the latest research and development and the latest schedule of the ITER project.

2. Changes in the Energy Situation and Societal Demands

Four major changes related to fusion research and development occurred in the social environment after the AEC released the Fusion R&D Strategy report in 2005. These changes include the recession that began with the Lehman Shock (bankruptcy of Lehman Brothers in 2008), the shortage of electricity suffered after the Great East Japan Earthquake (2011), the accident at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Plant, and the rise of shale oil/gas.

Through the experience of the recession and electricity shortage, Japan came to recognize with pain that it is possible to give preference to the reduction of greenhouse gas emissions only when economic conditions are good and power supply is sufficient. The shortage of electricity makes it necessary to use natural gas and oil even though they emit greenhouse gases. Thermal power production using oil and natural gas increased by 2.4 billion kWh (65%) in FY2012 compared with FY2010 (according to the Federation of Electric Power Companies of Japan).

With the long-term suspension of all nuclear power plants in Japan, people have come to realize that the country has not yet obtained an alternative technology to fossil fuels, even though it possesses few energy resources. Although the expectations of renewable energy are high, its limitations are also becoming known. It has become necessary to propose once again the importance of research and development of nuclear fusion against the backdrop of the public opinion that

Japan’s assets lie in technological innovation for generating power.

Fusion reactors are intrinsically safe without the possibility of re-criticality. In addition, the hazard potential*[2-2] of tritium*[2-1], the radioactive substance inside the reactor, is three digits fewer than light-water reactors in terms of iodine 131*[2-3] conversion (according to ”Report on the Technological Feasibility of Fusion Energy and Basic Research to support the Project” (May 17, 2000. Sub-committee on Development Strategy, Advisory Committee on Nuclear Fusion, Japan Atomic Energy Commission)). On the other hand, people are losing faith in nuclear power after the Fukushima Daiichi Nuclear Power Plant accident. Although the principle of nuclear fission used in nuclear power plants completely differs from that of nuclear fusion, the accident mentioned above should be a lesson for those who are involved in nuclear fusion since it deals with neutron and radioactive substances as is the case with nuclear fission. It should be understood while designing the fusion DEMO reactor, which is directly linked to early realization of nuclear energy, that the reactor is expected to have an even higher level of safety than the current level of nuclear safety technology because it would not be possible to introduce a fusion DEMO reactor in Japan without first obtaining the confidence of the public. The development of fusion technology requires sustained efforts aimed at securing a source of energy accepted by the public, leveraging its special characteristic of intrinsic safety.

The supply and demand relationship of gas and oil has drastically changed with the commercialization of shale gas/oil. An abundance of fossil fuel resources remains available if unconventional fossil fuels, commercialized by technological innovations, are also included with traditional fossil fuels. At the same time, power sources with high load following capability*[2-4] are required to sustain the stability of the power system as the use of renewable energies such as wind and solar power generation is expected to increase. Although the use of fossil fuels involves the danger of global warming, thermal power generation will still be playing a certain role in the middle of this century, when fusion energy is aimed to be commercialized.

The Plan for Global Warming Countermeasures approved by the Japanese government in May 2016 sets the long-term objective of reducing greenhouse gas emissions by 80% by 2050, in addition to taking measures to achieve the promises outlined in the Paris Agreement (reducing greenhouse gas emissions by 26% in 2030 compared with 2013). It has been indicated that the attainment of this objective requires the development of innovative technologies. A strong correlation can be seen between the increase in GDP and the emission of greenhouse gases. A balance between economic development and reduction of greenhouse gases cannot be anticipated with only existing technologies. Research and development of fusion energy, which aims to be realized in the mid-21st century, should be advanced in a way that positions it as an innovative technology capable of changing the correlation between future economic development and greenhouse gas emissions, while stressing its economic rationality over other technologies for reducing greenhouse gas emissions.

Japan’s future energy mix and measures to reduce greenhouse gases remain uncertain. In order for fusion energy to enter the market, however, it is expected to complementing thermal power generation thus contributing to the reduction of total greenhouse gases emission along with other power sources. To meet that expectation, the research and development should be promoted in order that fusion energy be positioned not only as a base load power source, but also as a power source that can deal with changes in electricity demand, and become a flexible power source with high added-value.

3. Strategy for Developing Nuclear Fusion Technology for DEMO Reactors

The development of nuclear fusion technology in Japan is in the third phase that targets demonstrating “scientific and technological feasibility” of fusion energy. At present, research and development is being promoted with the view to achieving the self-ignition condition*[3-2] and long-duration burn with the ITER project*[3-1] at the core, as well as building the reactor technology base necessary for the development of the DEMO reactor based around BA activities*[3-3].

The fourth phase revolves around the DEMO reactor program and aims for “technological demonstration and economic feasibility” of fusion energy. To transition to the fourth phase, the common objective set for the entire fusion science and development community including industry, academia and government is to achieve technological solutions that fulfill the conditions for transitioning to the fourth phase with a tokamak*[3-4] reactor, which is the most advanced type of reactor at the current stage of development. The ITER project and BA activities will serve as the main pillars for achieving technological solutions and building the technical base for the DEMO reactor. Planning and implementation of research and development of the technology necessary for a DEMO reactor will be carried out through an all-Japan framework of industry, academia and government, leveraging the experience of ITER. In ITER, Japan must lead the collaborating nations during the construction and experimentation periods to obtain sufficient results that can contribute to achieving solutions for technical development.

Economic feasibility during the commercialization of the fusion reactor will be founded on safety and technological viability. It will also be influenced by the social and energy context at the time of construction. With safety as the major premise, demonstration of the technological viability of reactor engineering will be carried out, and research will be conducted to realize its economic feasibility during the commercialization stage in accordance with the situation at that time. The design concept of the DEMO reactor will aim at the implementation of both objectives. The construction and operation costs of the DEMO reactor will be an important indicator for estimating the economic feasibility of commercializing the reactor. Therefore, the design concept of the reactor must provide an appropriate estimate of the construction and operation costs. While advancing the design of the reactor from the above perspectives, early validation of those items, among the factors that will determine the economic feasibility of the construction and operation costs of the DEMO reactor, will begin to a certain extent in the ITER project and BA activities.

On the other hand, activities characterized by a certain degree of diversity will be advanced because of the need for a multidimensional approach to promote the acceleration of research and development and to resolve various issues. While striving for steady progress on the tokamak reactor, which is the main option, it will be important to also conduct balanced research on complementary, alternative and more innovative concepts such as helical*[3-5] and laser*[3-6] systems. In existing fusion research, academic research has been improving the reliability of reactor design, which in turn is providing new issues for academic research, thereby creating a synergistic effect. One such example is zonal flow*[3-7], which was earlier a topic of academic research that has now become essential for the prediction of burning plasmas. Therefore, it is important to sustain the base of academic research in universities, and it is important to reduce the research achievements to elements, and systematize and generalize them as academic entities.

4. Basic Concept Required for the DEMO Reactor

The objective of the DEMO reactor is to validate its technical and economic viability. It is also extremely important for fusion energy research and development to leverage the merits of nuclear fusion and give maximum preference to its intrinsic safety in order to gain public acceptance and allow it to be selected as a new source of energy

Under the development strategy mentioned in Chapter 3, the objective of the DEMO reactor is to realize a steady and stable electric output of over several hundred thousand kilowatts, availability sufficient for commercialization and overall tritium breeding*[4-1] that fulfills self-sufficiency in fuel to prepare for the commercialization of fusion energy by the mid-21st century. There is a need to divide the operational development period of the DEMO reactor into stages with respective milestones and make the development and demonstration of advanced technology possible in stages.

In particular, the following design requirements must be considered while designing the reactor with a view to achieving the basic concepts.

- Ensuring a safety level that reasonably reduces radiation exposure of the public at the time of accidents as well as during normal operation, and of workers at a DEMO plant (ALARA[*4-2]).
- From the viewpoint of commercialization, achieving an acceptable level of construction costs, including the cost of decommissioning reactors and processing radioactive waste.
- Basing the divertor*[4-3] and blanket on the ITER project and ITER Test Blanket Module*[4-4] technology in the initial phase of operating the DEMO reactor, but also ensuring flexibility and the ability to change based on the knowledge gained after starting operation.

Furthermore, the following must be fulfilled at the time of operational development of the DEMO reactor.

- Plasma control, such as heat and particle control and disruption*[4-5] avoidance, for operating the reactor for long hours or over a long-term period.
- A practical maintenance scenario that can be used for a commercial reactor, and availability sufficient for commercialization at the last stage of the DEMO reactor.
- Enhancing performance of the blanket and divertor reflecting the knowledge gained from the DEMO reactor.

A development plan for technical problems that require solving will be formulated as an action plan, as mentioned later, with a view to realizing a DEMO reactor with these basic concepts.

5. Advancement of Development for Resolution of Technological Issues

5.1. Formulating the Development Plan

In formulating the development program, it is necessary to examine and quantitatively define technological specifications (heat flux[*5-2], neutron flux[*5-3], etc.) for a system to achieve the targeted capacity of the DEMO reactor, including fusion output[*5-1]. The reactor design is the control tower for DEMO reactor development based on such criteria. It identifies issues and development targets based on the finalized technical specifications, keeping in mind plant construction and operation costs, the operation scenario, as well as technical consistency. The development plan should classify the technological issues under elements that include superconducting coils*[5-4] and blanket, and organize and analyze the progress of each issue and the connection between issues as an action plan. The timeline of the development program will be determined in light of the results of the ongoing ITER project, BA activities, check and review, mentioned later in this report, and the timing of the decision to transition. There is a need to clearly indicate the implementation bodies and the necessary facilities for each issue.

5.2. Research and Development Framework Comprising Industry, Academia and Government

With a view to steadily resolving such technological issues, there is a need to strengthen research and development by building an all-Japan framework comprising industry, academia and government, and leveraging resources to the maximum. To make the framework effective, the Rokkasho site*[5-5] should be upgraded as the central hub for developing the DEMO reactor. A development plan should be drawn up to advance reactor design, with the Joint Special Design Team for Fusion DEMO at the center, and responsibilities should be divided among the National Institutes for Quantum and Radiological Science and Technology, the National Institute for Fusion Science, universities and industry. Moreover, the government and respective institutions should share strategies and problem awareness, preparing a framework, including the establishment of new systems, to conjointly conduct research and development of the DEMO reactor.

The National Institutes for Quantum and Radiological Science and Technology will advance the ITER project, BA activities and DEMO reactor design through collaboration within and outside the country as the core research and development institution for tokamaks and strive to develop human resources as well. The National Institute for Fusion Science and universities will work on promoting complementary and alternative technologies, such as helical or laser systems, building the academic foundation for fusion plasma and reactor engineering, providing education and developing human resources. Apart from autonomously and independently conducting these activities, universities are also expected to take an active part in ITER, JT-60SA*[5-6], LHD*[5-7] and BA activities. Industries are required to develop and accumulate manufacturing technology for fusion devices through the construction of facilities in Japan and abroad, starting with ITER and JT-60SA. Their sustained participation is necessary from the initial stage of conceptual design based on the requirement that the DEMO reactor have a rational design in view of its future prospects as an industry. In particular, collaboration with the nuclear energy field will be extremely advantageous in terms of the formulation of safety requirements.

Mobility and diversity of human resources are important aspects in sharing problem awareness among institutions and increasing the efficacy of collaboration. One effective way to promote this is to introduce a cross-appointment system*[5-8] among institutions. Moreover, collaborations with other fields will not only be beneficial for securing personnel for the future, as mentioned in the forthcoming section, but can also be connected to more efficient development of fusion technology and the creation of innovation and its ripple effects.

5.3. Developing and Securing Human Resources

The development of human resources is extremely important for sustained advancement of long-term research and development. To this end, personnel needed for research and development of the DEMO reactor must be nurtured through close collaboration among industry, academia and government by encouraging organic cooperation between the ITER project and BA activities and advanced academic research. The fields of radiation use and nuclear power share many features with the field of nuclear fusion. Therefore, it is beneficial to develop human resources in collaboration with such fields. Additionally, there is a need to build a system for ensuring the mobility of human resources so that the experience they accumulate at ITER is reflected in the knowledge they bring back to the development of the DEMO reactor. Universities should promote unique and attractive academic research to develop greater numbers of excellent human resources, and provide diverse research opportunities to students and young researchers through collaborative research within the country and abroad.

Because fusion technology is a comprehensive field, it is also important to secure human resources by promoting participation from other fields, along with human resource development within the field of nuclear fusion itself. Collaboration and interaction with a wide range of fields, including the humanities and social sciences, should be promoted keeping in mind risk communication and other perspectives, apart from continuing to strengthen relations with traditional collaborative fields, for example, those related to machines or electricity. Such activities will also contribute to nurturing human resources capable of performing in other fields. It is necessary to implement the DEMO reactor design from an integrated viewpoint that considers technical feasibility as well as societal demands and acceptance. For this reason, it is important to build a reactor design framework comprising diverse human resources with multiple perspectives through such collaborations as those mentioned above.

5.4. International Collaboration

International collaboration, including the ITER project and BA activities, can be extremely effective in reducing development risks and costs. The decision about which problems Japan must resolve alone and which problems it must resolve through international collaboration should be taken after analyzing the strategy for the technologies to be possessed, priority of issues, complementarity with domestic research and development, and the development situation in other countries. These must then be reflected in the action plan and roadmap. Furthermore, from the viewpoint of international contribution, Japan should play a leading role in DEMO reactor development by leveraging its high potential for research and development and its human resources to take an active part in the ITER project and various other international activities. Japan should lead the ITER project and BA activities to advance the resolution of technological issues related to the DEMO reactor. The accumulation of achievements and experience in the ITER project and BA activities, including operational aspects, will contribute to joint international development in the future.

5.5. Formulation of Safety Requirements for the DEMO Reactor

Although fusion reactors are inherently safe, they are expected to possess unique safety technology during design and development, such as countermeasures for environmental migration of tritium. Concrete problems in building a DEMO reactor include understanding the behavior of tritium and establishing safety management technology. Moreover, safety methods should be incorporated during design and development of the fusion reactor for investigating major accident sequences and preventing further accidents, anticipating situations without the constraints of conventional ways of thinking, while also incorporating the safety measures of nuclear power plants in view of the Fukushima Daiichi Nuclear Power Plant accident. The safety guidelines and safety requirements for the DEMO reactor will be formulated early from the viewpoint of the public and the environment, and in accordance with Japan’s climate and social conditions. This should be done in cooperation with experts from various fields from Japan and abroad, including experts on safety engineering, plant engineering, impact of radiation, the environment, society, regulations and licensing, and other areas, apart from fusion researchers, thus promoting comprehensive nuclear fusion safety research.

5.6. Creation of a Development Roadmap

To build a framework for the technical base, a comprehensive action plan should be formulated to enable effective follow-up and timely confirmation of the status of the framework, based on reports from the Joint-Core Team and development charts with timelines for each element in the research and development program. Moreover, a roadmap for developing the DEMO reactor should be devised based on the action plan to indicate the vision for developing the fusion reactor. The roadmap will provide a comprehensive development process that includes priority levels, milestones, areas for international collaboration, and other details.

6. Approach for Transitioning to the DEMO Phase

For transitioning to the DEMO phase, it is essential to build public confidence in fusion and its technological maturity. Therefore, an intermediate check and review should be conducted by the Science and Technology Committee on Fusion Energy to determine technological maturity as mentioned below. The intermediate check and review should be sufficiently flexible to handle future uncertainties. Additionally, a framework should be prepared for systematically conducting outreach activities based on mutual interaction and dialogue with society and a wide range of outreach activities should be actively promoted.

6.1. Decision to Transition and Check and Review

The decision to transition to the DEMO phase will be taken in the 2030s when ITER is expected to demonstrate DT burning*[6-2] with deuterium*[6-1] and tritium as fuels. Moreover, a check and review will be implemented to confirm the status, as a guideline for the timeline for research and development. In the Fusion R&D Strategy, it was mentioned that an intermediate check and review will be conducted once before making the decision to transition. However, the intermediate check and review will be carried out in two parts, as mentioned below, to effectively implement research and development up to the point of decision of transition based on the status of the ITER project and BA activities, including JT-60SA, while keeping in mind prospective achievements.

- The first intermediate check and review: This will be implemented in around 2020 when the basic conceptual design by the Joint Special Design Team for Fusion DEMO is to be completed and JT-60SA is scheduled to begin operation.
- The second intermediate check and review: This will be implemented after the completion of the DEMO reactor conceptual design by the special team within a few years of 2025, when ITER's first plasma is scheduled.

Regarding the degree of DEMO design completion, it is necessary that the overall objective of the DEMO reactor is defined and the viability of its conceptual design is backed by the prospect of building a technological base at the stage of the second intermediate check and review. It is also necessary that the consistency of the DEMO reactor design and the achievements in research and development are reached at the time of the transition to the DEMO reactor, and that the economic feasibility of a commercial reactor is foreseeable.

Moreover, to enable the commercialization of fusion energy by the mid-21st century, engineering development activities conducted on an adequate scale should begin between the intermediate check and review and the decision on the transition as the preparatory period for the fourth phase to ensure prompt implementation. To this end, the launch of the engineering design of the DEMO reactor and the engineering development activities for the necessary components should be determined at the time of the second intermediate check and review.

6.2. Review in Light of the ITER Project and BA Activities

The ITER project is clearly a critical path for providing a timeline for research and development, and the timing of the first plasma and demonstration of DT burning, results of energy gain*[6-3] and long-pulse operation, and demonstration of the blanket function, among others, are directly connected to the development program, intermediate check and review, and the conditions for deciding to transition. Therefore, the Taskforce will regularly review the timeline of the action plan and the items and timing of the intermediate check and review through debates within and outside the fusion science and development community, so that rational and efficient actions can be taken based on the status of the ITER project and the results of the BA activities.

6.3. Outreach Activities

For fusion energy to become the public's energy source of choice, it is necessary to share information and engage in continuous dialogue with society about the special characteristics, usefulness and safety of fusion energy. It is also necessary to build confidence in the public and develop human resources from a long-term perspective because the development of fusion energy will span a long period of time. Strategic outreach activities for domestic and foreign fusion research and development, including DEMO reactor design, are important for this purpose. Therefore, a collaborative framework of related institutions will be established, along with a headquarters for overall management of activities across the country. Collaborative activities aimed at optimizing the social value of fusion energy will be planned and promoted from diverse and varied viewpoints of the public, industries, economic sectors, and the academic world. It is necessary to carefully respond to public concerns and doubts one by one, providing sustained and proper risk communication and data-based explanations about the safety of fusion energy to build public confidence. One effective means for this is to disseminate information widely through the mass media. In addition, it is also important to engage in confidence building at various occasions by deepening the mutual understanding between people of varied age groups, including children, and researchers and related institutions through collaborative activities with educational institutions and dialogue meetings with local community. Moreover, outreach activities should be organized to raise interest in fusion technology across a broad range of people, with the awareness that this could also serve as an opportunity for human resources from other fields to take part in the program.

Glossary

Chapter 2

[2-1] Tritium

An isotope (isotopes are variants of an element with the same number of protons but different number of neutrons) of hydrogen with a nucleus consisting of one proton and two neutrons. Symbolized with ^3H or T. It has a radioactive half-life of 12.3 years and emits beta rays with a maximum energy of 18.6 keV, the average being 5.7 keV.

[2-2] Hazard Potential

Also known as the Hazard Index. It shows the quantitative impact of a hazardous substance when it enters the human body. It is expressed as the volume of air (in case of gases) or volume of water (in case of liquids) required to decrease the density of a substance to a legally accepted safety level. The higher the value, the larger the total amount and the higher the risk level of hazardous substances.

[2-3] Iodine 131

A radioisotope with a half-life of about eight days. It is one of the major fission products produced in nuclear reactors, and is also used in INES (International Nuclear Event Scale) evaluations as an indicator of the amount of radiation emitted into the atmosphere at the time of an accident. (For example, level 7 (major accident): Chernobyl Nuclear Power Plant accident, Fukushima Daiichi Power Plant accident; level 5 (accident with off-site risk): Three Mile Island Nuclear Power Plant accident, etc.)

[2-4] Load Following Capability

The ability to adjust the power output in accordance with time-based or season-based power demand fluctuations (load from the perspective of the power generator). There are some research papers on load following capacity for fusion energy. In addition to controlling the heat output itself (K. Okano et. al., "Compact Reversed Shear Tokamak Reactor with a Superheated Steam Cycle", Nuclear Fusion 40, 635 (2000)), research has been done for rate adjustment between the electric power sent to the power system and that for hydrogen production, which combines hydrogen production by high-temperature steam electrolysis (K. Okano et. al., "Efficient Hydrogen Production Using Heat in Neutron Shield of Fusion Reactor", Journal of Plasma and Fusion Research 77, 601 (2001)) and hydrogen production using biomass as fuel. (S. Konishi, "Potential Fusion Market for Hydrogen Production under Environmental Constraints", Fusion Science and Technology 47 1205 (2005).)

Chapter 3

[3-1] ITER Project

The ITER project aims to demonstrate the scientific and technical feasibility of fusion energy and begin operations in 2025 (approved at the ITER Council meeting in June 2016). The council comprises seven members – Japan, the European Union (EU), Russia, the United States, South Korea, China and India. Project construction is currently underway in Saint-Paul-lez-Durance, France.

[3-2] Self-Ignition Condition

When the heating input for generating plasma is increased in a fusion facility, the fusion reaction inside the plasma increases the temperature. The condition of sustaining the fusion reaction without further external heating input is known as the self-ignition condition. In “Third Phase Basic Program of Fusion Research and Development” (decided by the AEC in June 1992), it is stated that Japan aims to achieve “Self-Ignition Condition (Fusion Energy Gain Factor*[6-3]: around 20)” in the third phase.

[3-3] BA Activities

Abbreviation of broader approach activities. In 2007, Japan and the EU signed the BA agreement in which they agreed to complement and support the ITER project while also conducting advanced research and development projects for establishing the technical base required for the DEMO reactor as part of the BA activities. BA activities include the International Fusion Energy Research Center (IFERC) project, the Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA) project, and the Satellite Tokamak (JT-60SA) Program project.

[3-4] Tokamak-type System

A symmetrical toroid-shaped confinement system or facility in which high-temperature plasma is confined by magnetic fields. TOKAMAK: Russian acronym for “electric current, container and magnetic field coil.” A toroidal magnetic field is created by generating an electric current in the toroidal coils. Then, a poloidal magnetic field is produced by generating a current in the plasma. The helical magnetic field cage produced by the two magnetic fields confines the plasma.

[3-5] Helical-type System

Unlike the tokamak-type system, this system uses a non-symmetrical toroid-shaped magnetic field that does not require a plasma current for plasma confinement. The two magnetic fields (toroidal and poloidal magnetic fields) necessary for plasma confinement are produced by external coils and structured as a magnetic cage from the beginning. This system is suited for steady-state operation.

[3-6] Laser-type System
A system in which a fuel pellet is imploded by a high-power density laser, which is then compressed and heated to a high density leading to a thermonuclear fusion reaction.

[3-7] Zonal Flow
A band-like flow formed spontaneously from a turbulent drift that is controlled by a shearing-like motion. Zonal flows are also formed in the striped pattern of Jupiter's atmosphere and in jet streams in the Earth's atmosphere.

Chapter 4

[4-1] Tritium Breeding
Tritium, the fuel for fusion reactors, only exists rarely in nature, but is produced by the nuclear reaction of neutrons with lithium contained in the blanket. This is known as tritium breeding.

[4-2] ALARA
Abbreviation of "As Low As Reasonably Achievable," a concept indicating the basic approach to radiological protection recommended by the International Commission on Radiological Protection in 1977. It is usually called ALARA. It refers to restricting exposure to radiation based on the basic philosophy that "all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account" to optimize radiological protection.

[4-3] Divertor
The divertor is a device used for removing from plasma the helium particles produced during the fusion reaction and traces of impurities that are released from the wall, thereby helping to sustain the fusion reaction for a long time. It reconverts the charged particles in the plasma to atoms and molecules, guiding low temperature plasma to divertor plates made of material strong in heat load along magnetic lines on the outside of the confined plasma where a fusion reaction takes place. Removing the material helps maintain the purity of the plasma.

[4-4] ITER Test Blanket Module
With the objective of shielding radioactive rays, the ITER blanket does not conduct tritium breeding. The ITER Test Blanket Module is a device for demonstrating how to extract heat for power generation and enable self-sufficiency in tritium fuel.

Source: Yoshinori Kawamura, et al., “Test Blanket Program in ITER”, Journal of Plasma and Fusion Research 92, 444 (2016).

[4-5] Disruption
In the tokamak system, the plasma-confining magnetic field breaks leading to a rapid collapse of the entire plasma. This can be caused by an excessive increase in the plasma current, density or pressure, among other reasons. It is necessary to consider disruption as an important condition while designing the device because a rapid decrease in the plasma current results in a strong electromagnetic force in the structure.

Chapter 5

[5-1] Fusion Power Output
Power output by neutrons and alpha particles (helium nuclei) resulting from a DT fusion reaction.

[5-2] Heat Flux
Heat flux is the quantity of heat energy that passes through the unit area (m^2) per second. Its unit is W/m^2.

[5-3] Neutron Flux
Neutron flux is the number of neutrons that pass through the unit area (m^2) per second. Its unit is the number of neutrons/(m^2/second).

[5-4] Superconducting Coil
Superconducting coils are made of a superconducting material. When a substance is cooled to a temperature close to absolute zero (-273℃), its electrical resistivity becomes zero. This is known as superconductivity and it is used in these coils. They do not yield joule loss because electrical resistivity is zero, thereby drastically reducing the required electric power. This characteristic is leveraged in fusion reactors to generate a strong magnetic field.

[5-5] Rokkasho Site
The joint project site in Rokkasho village, Kamikita-gun, Aomori Prefecture, where Japan and the EU support the ITER project and conduct research and development of a power generation fusion reactor, the next step of the ITER project, with a view to early realization of fusion energy. The site is involved in building a DEMO reactor, R&D, the Computational Simulation Center, the ITER Remote Experimentation Center as part of the IFERC project, and engineering validation and engineering design activities for the

International Fusion Materials Irradiation Facility (IFMIF) as part of the IFMIF/EVEDA project.

[5-6] JT-60SA
JT-60SA is the superconducting tokamak device being built by the Naka Fusion Institute, Fusion Energy Research and Development Directorate, National Institutes for Quantum and Radiological Science and Technology. It is a joint project of the Satellite Tokamak Program run by Japan and the EU as part of the BA activities to complement and support the ITER project and Japan's national centralized tokamak program.
Source: Website of the National Institutes for Quantum and Radiological Science and Technology

[5-7] LHD
Large Helical Device. A helical-type experimental device for superconducting plasma confinement at the National Institute for Fusion Science, National Institutes of Natural Sciences. It is used for stable, high-temperature, high-density plasma confinement research and broad-based academic research to build a helical-type fusion reactor in the future.

[5-8] Cross-appointment System
A system of employing researchers or experts in two or more organization. This can include universities, public research institutes or companies, allowing them to engage in research and development and education according to their role in the respective organization under a certain level of effort management.

Chapter 6
[6-1] Deuterium
A stable isotope of hydrogen, with a nucleus consisting of one proton and one neutron, and symbolized as D. It is found in nature to the extent of 0.014%-0.015%, mainly in seawater.

[6-2] DT Burning
Of various fusion reactions, a reaction between deuterium (D) and tritium (T) takes place most easily. The reaction produces neutrons (14 MeV) and alpha particles (helium nuclei) (3.5 MeV). Fusion reactors use this reaction.

[6-3] Fusion Energy Gain Factor
The ratio of the fusion reaction output to the external heating input required by plasma to maintain the plasma state. Also known as Q-value.

Note: The descriptions in the glossary above have been produced in reference to the following websites except for the item with a specific source;

-ATOMICA
- The Japan Society of Plasma Science and Nuclear Fusion Research
-Ministry of Economy, Trade and Industry
-National Institute for Fusion Science

Check and Review Items (plan)

Items	Objectives by the 1st intermediate C&R	Objectives by the 2nd intermediate C&R	Judgment criteria for transition to the prototype reactor stage
① Validation of burn control in the self-heating area by ITER	・ Create a technical target achievement plan for ITER.	・Reflect ITER's collaborative research in the ITER technical target achievement plan.	・ITER maintains fusion power of Q=10 or higher (for over several hundred seconds) and validates burn control.
② Establishment of an operational technique for stationary high-beta plasma for operation of the prototype reactor	・Proceed with ITER collaborative research and preparatory studies on stationary high-beta plasma and start JT-60SA research.	・JT-60SA achieves a high-beta non-inductive current drive. ・Have integrated simulations including the divertor verified by JT-60SA and other projects. ・Create a plan for JT-60SA divertor research compatible with the prototype reactor's plasma-facing walls.	・Gain prospects for non-inductive steady operation by ITER’s achievement of non-inductive current drive plasma and integrated simulations based on ITER's knowledge of burn control. ・JT-60SA validates the stationary operation of a high-beta ($b_N = 3.5$ or higher) collisionless plasma regime compatible with the prototype reactor’s plasma-facing walls.
③ Establishment of integrated technologies by ITER	・Establish ITER's manufacturing technologies for superconductive coils and other key components and build an integrated technological foundation through the construction of JT-60SA.	・Launch ITER operation. ・Acquire integrated technologies to manufacture, install and adjust the ITER apparatus.	・Establish integrated technologies through ITER operation and maintenance and confirm the safety technology.
④ Material development for the prototype reactor	・Obtain low activation ferrite steel's reactor irradiation data of dosages up to 80 dpa and finalize the materials for testing under a neutron irradiation environment similar to nuclear fusion. ・Complete the concept design of the nuclear fusion neutron source.	・Complete the validation of heavy irradiation data by reactor irradiation of low activation ferrite steel up to 80 dpa. ・Evaluate the initial irradiation behavior of blanket and diverter functional materials by reactor irradiation and validate the principles of lithium-securing technology. ・Start the construction of a nuclear fusion neutron source and create a plan for collecting material irradiation data.	・Draw up the structural design criteria. ・Establish lithium-securing techniques on a pilot-plant scale. ・Collect initial irradiation data on low activation ferrite steel and blanket and divertor functional materials with a nuclear fusion neutron source.
⑤ Technical development of reactor engineering for the prototype reactor	・Formulate divertor development policies. ・Create technical development plans for reactor engineering requiring early preparation, including superconductive coil technology. ・Collect the necessary data for blanket design from the cold testing facilities.	・JT-60SA, LHD, etc. collect the necessary data relevant to the divertor, including the properties of the plasma-facing materials. ・Create development plans for the superconductive coil, divertor, remote maintenance, heating/current drive, fuel system, measurement/control, etc. for the engineering technology of a medium- or plant-sized reactor, and complete the concept designs of these items for the development test facilities. ・Establish foundation technology for the power generation blanket, build ITER-TBM No. 1, and complete the safety verification tests on the actual device.	・Establish reactor engineering technologies that support prototype reactor design, including such items as the superconductive coil, divertor, remote maintenance, heating/current drive, fuel system and measurement/ control, based on the outcomes of the development test facilities and the performance results of ITER, JT-60SA, etc. ・ITER collects tritium and validates the evaluation technique for tritium behavior with the nuclear fusion neutron source.
⑥ Designing the prototype reactor	・Formulate the overall objectives for the prototype reactor. ・Draw up a basic concept design of the prototype reactor. ・Submit requests regarding reactor core and reactor engineering developments.	・Complete the prototype reactor’s concept design that ensures high safety standards and economic feasibility by incorporating reactor core and reactor engineering developments. ・Identify issues in developing reactor core and reactor engineering to establish a technological foundation for engineering design and create a development plan.	・Acquire social acceptability, confirm economic feasibility at the stage of practical use, and complete the prototype reactor engineering design by coordinating reactor core and reactor engineering developments. ・Draw up policies on safety laws and regulations.
⑦ Social relations	・Establish a headquarters for promoting social awareness. ・Draw up an awareness activity promotion plan.	・Promote social awareness initiatives and conduct social relations activities.	・Proceed with social relations activities toward the construction and operation of the prototype reactor.