National Policy of Future Nuclear Fusion Research and Development
(Tentative Translation)

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Contents

Reference

Supplementary Volume: Glossary

Preface

On fusion research and development (hereafter, Fusion R&D) of our country, the Atomic Energy Commission of Japan laid down "the Third Phase Basic Program of Fusion Research and Development" (hereafter, the Third Phase Program) in June 1992, with the major objective of "achievement of self-ignition condition[*1], realization of a long-duration burning[*2] and establishment of reactor technology basis required for the development of fusion DEMO reactor". In this program, the Atomic Energy Commission noted "check and review will be made in appropriate periods from the overall view points" [1], [2], [3].

Since then, 10 years have passed and significant research progress has been made. As for International Thermonuclear Experimental Reactor (ITER) project[*3] which will demonstrate the scientific and technological feasibility of fusion reactor, the agreement that ITER shall be sited at Cadarache (France) has been made at the second six-party ministerial-level meeting in June 2005, and international negotiation toward the establishment of international organization for its implementation is now undertaken.

Meanwhile, the circumstance of fusion in our country has been changed. Unification of Fusion R&D promotion has been made by the integration of the Ministry of Education, and the Science and Technology Agency, to the Ministry of Education, Culture, Sports, Science and Technology. Furthermore, the independent administrative agency, Japan Atomic Energy Agency (hereafter, JAEA) has been established (October 2005) as a result of the integration of the Japan Atomic Energy Research Institute (hereafter, JAERI) and the Japan Nuclear Cycle Development Institute (hereafter, JNC). Also the national universities and the inter-university research institutes were reorganized into independent administrative entities in April 2004. National Institute for Fusion Science (hereafter, NIFS) becomes one of the five research institutes of the Inter-University Research Institute, National Institutes of Natural Sciences.

Taking into account the above progress, the Committee on Basic Issue on Fusion Research has been established to carry out check and review of the progress of Fusion R&D and to investigate future basic program of Fusion R&D under the Technical Working Group of the Atomic Energy Commission's Advisory Committee on Nuclear Fusion. This committee consists of members of specialists in energy, environment, nuclear fission, and fusion and made the following investigation and deliberation on the Third Phase Program, based on the research progress after its formulation.

Subjects of investigation and deliberation: Clarify the meaning, necessity and basic form of Fusion R&D under the Nuclear Energy Policy, and investigate basic program of Fusion R&D consistent with those items.

Principal subjects of investigation are, role of fusion in solving energy and environmental problems, positioning of Fusion R&D in the Nuclear Energy Policy, check and review on the progress of the Third Phase Program, development strategy to realize fusion energy with maximum utilization of ITER, meaning and positioning of Academic Research on fusion in universities and NIFS, training and education of researchers, means of securing human resources, and the utilization of international collaboration. The Technical Working Group of the Advisory Committee on Nuclear

Fusion has made further investigation after receiving the result of investigation and deliberation made by the Committee on Basic Issue on Fusion Research.

This report overviews the past achievement of Fusion R&D based on the 21 times of investigation and deliberation in the Committee on Basic Issue on Fusion Research and the 3 times of deliberation in the Technical Working Group of the Advisory Committee on Nuclear Fusion. It also summarizes the basic approach and contents of the future research and development in the Third Phase Program as the opinion of academic standing in carrying out Fusion R&D under the Advisory Committee on Nuclear Fusion. We expect that this report clarifies the policy to be undertaken in the Third Phase Program, and will become the basic guidelines for future Fusion R&D of our country. In the process of Fusion R&D promotion by the responsible government office, it is necessary to take into account the international circumstance of the time and very severe fiscal circumstance.

Chapter 1 Significance of Fusion Research and Development

1.1 Role of Fusion Energy in Solving Energy and Environmental Problems

Energy is a fundamental element for mankind's activity. The human being has established the present civilized society by skillful utilization of energy. On the other hand, heavy consumption of energy after the industrial revolution caused exhaustion of energy resources and global scale environmental problems. Security of energy, which is environmentally friendly, abundant and safe, is a continuously important issue not only for our country but also for whole mankind.

Although near-term exhaustion is not predicted for fossil energy because of relatively abundant coal, etc., it is still a finite resource. Also a fear on global environmental problem is now rising such as global warming problem associated with the increase of carbon dioxide concentration in the atmosphere. The increment of average global temperature is predicted to be 1 to 6 degrees centigrade in various future scenarios evaluated by IPCC as shown in Attachment 1.

Although it is very difficult to predict the long-term supply and demand of energy and the associated environmental problem, the necessity of considerable amount of non-fossil energy is pointed out in the later half of the 21st century.

In addition to their stable supply, new energy sources alternative to fossil energy are required to have the following properties: resource abundance capable of supplying energy on a global scale; less regional localization of resource; less social restriction in introduction; and high self-sufficiency in our country. Furthermore, it is also desirable that various forms of energy utilization are possible.

Non-fossil energies having past records are fission energy and renewable energies such as water-power, wind, biomass and solar. It is needless to say that the promotion of utilization and development of fission energy and renewable energy is necessary to depart from the reliance on the fossil energy. However, global expansion of environmentally benign non-fossil energy supply is desirable in the later half of the 21st century, taking account of social acceptance and resource localization and supply stability of those energies.

Therefore development of more attractive non-fossil energy is a duty of our generation for widening the choice for future mankind.

As described in Appendix 1, the nuclear fusion energy[*4] is respected to have excellent potential and social acceptance in the resource abundance, supply stability, safety, environmental compatibility, nuclear proliferation resistance, processing and disposal of radioactive waste, and is an attractive candidate as the eternal energy resource for mankind.

Possible significant reduction of carbon dioxide concentration in the end of this century is pointed out by the Institute of Energy Economics, Japan, as shown in the Attachment 2, if highly economic fusion energy is soon introduced in addition to energy-saving and use of renewable energy.

Having such possibilities, early realization of fusion energy is important from the viewpoint of solving the global environmental problem, which becomes more serious in the future. It is also important to ensure the energy security of our country by increasing its self-sufficiency presently in low level in energy resources.

Furthermore, since fusion energy has less resource localization and less restriction in introduction to society, active introduction to developing counties is also expected where growth of energy consumption is foreseen.

Japan is a responsible country to actively contribute to the world prosperity and promotion of international cooperation as a nation based on the creativity of science and technology. Japan should take a leadership in early realization of fusion energy toward resolution of energy and environmental problems.

1.2 Significance and Necessity of Fusion R&D in Nuclear Energy Policy

The Nuclear Energy Policy of our country is administrated under the Atomic Energy Basic Law with the objective of contributing to the welfare of human society and improvement of people's living by promoting research, development and utilization of nuclear energy, leading to the security of the future energy resources and the progress in academic science and industrial development.

The nuclear energy refers to all kinds of released energy in the process of nuclear transformation. The goal of Fusion R&D is to realize the extraction of nuclear energy by fusing multiple nuclei, in a principle different from that of nuclear fission as already commercialized in light water reactor.

The Nuclear Energy Policy of our country positions the electricity production by light water reactor and the research and development of nuclear fuel cycle as foundations of the secure supply of energy, and the fast breeder reactor as a most promising choice of future energy. Likewise, Fusion R&D has been promoted, being positioned as one that can provide wide choice of future energy resources. In addition, according to the basic principles of research, development, and utilization of nuclear energy, "To contribute to a stable energy supply, industrial promotion, improvement of people's living standard, and sustainable development of society in the future, the Government should rationally combine and promote these creative approaches from short-, medium- and long-term perspectives in parallel. Thus, in order to maintain and expand contributions and services of nuclear technologies, the Government and research and development institutions need to play a more prominent role in the area of nuclear research and development than in other science and technology areas, particularly, at the stage of upgrading the innovative technological system to a candidate for commercialization. Even in that case, however, the activities of the Government should be conducted effectively and efficiently by specifying expected outcomes from the perspective of public interests. Therefore, the Government should comprehensively evaluate and discuss various elements for each approach and allocate research and development resources effectively and efficiently in line with the concept of "selection and concentration." The elements to be evaluated and discussed include, expected outcomes and issues within a fixed period of time; cost effectiveness of

investment based on results of multilateral evaluation of the outcome taking into account consideration of the predicted environmental conditions during the period of application; separation of roles between the public and private sector and resource allocations according to the time frame or stages of research and development; feasibility of effective utilization of international collaboration, etc."

Since the Atomic Energy Commission designated Fusion R&D as a specific comprehensive research on nuclear energy and laid down the Basic Program (the First Phase Program) in July 1968, and thereafter the Second Phase Program in 1975 and the Third Phase Program in 1992, Fusion R&D in our country has been making steady progress as one of the important R&D fields in the Nuclear Energy Policy under the control of the Atomic Energy Commission, and as shown in Attachment 3, making world-leading achievements in tokamak[*5], helical[*6], and laser[*7] type systems. In particular, in the tokamak system, our country has taken over the world lead in the field of rapidly progressing plasma confinement performance.

In order to extract the fusion energy on earth, we have to produce and control plasmas[*8] with temperature higher than that at the center of the sun (15 million degrees centigrade). Fusion R&D of our country has demonstrated the scientific feasibility of nuclear fusion by the achievement of equivalent break-even plasma condition[*10] (zero output condition) and plasma temperature of 520 million degrees centigrade, which is high enough for fusion reaction, in the break-even plasma test facility, JT-60[*9] (JAEA). The objective of a fusion experimental reactor is to demonstrate the scientific and technological feasibility of fusion energy, by the production and control of fusion reaction in such very high temperature fusion core plasma[*11]. Our country promotes this as the ITER Project under international collaboration through the deliberation in the Fusion Council, the Special committee on ITER Project [4], [5], [6], [7], the Atomic Energy Commission, and the Council for Science and Technology Policy. In this ITER Project, the control of about 500 MW of fusion power will be demonstrated.

In the development of fusion energy, we should promote its R&D so as to make an early contribution to the resolution of global environmental problems, by making a firm demonstration of its scientific and technological feasibility in ITER, and by carrying out the R&D for DEMO reactor in parallel, expecting to get the prospect of putting fusion into practical use before the middle of the 21st century. Also in Europe and United States, strategies for the early realization of fusion power generation are investigated vigorously from the similar viewpoint.

The field of fusion research has great significance in the sense that it is a scientific and technological field where our country can lead the world based on our past experiences and achievements. Also by continuing the efforts for the realization of fusion power generation, our country can possibly play a leading role in establishing the world standard of fusion power generation technology. Furthermore, we can expect the fusion research to contribute to the academic fields[*12] especially in science and engineering, and to have a spin-off effect on social base technology such as industrial application. Fusion research is also characterized as a great challenge to unexplored territory for mankind.

When we consider Fusion R&D of our country, being aware that the construction of ITER becomes a reality, we should further promote the Fusion R&D via tokamak system in the R&D[*13] for the realization of fusion energy. Besides, in view of widening the choice of fusion energy implementation, we should aim at establishing – as academic researches – the scientific bases not only of the tokamak system but also of the helical and laser systems. Moreover, from the standpoint of accelerating its development by synergistic effect of developmental research and academic research, we should make the maximum use of ITER Project, and promote comprehensive R&D involving both developmental and academic researches toward the realization of nuclear fusion.

Chapter 2 Status of the Third Phase Basic Program of Fusion Research and Development

2.1 Outline

Fusion R&D extends over a long period of time and requires several enlargements and leaps in its scale of research. Thus, the Atomic Energy Commission has adapted a stepwise development policy that requires an evaluation of achievement in R&D before the decision of the plan for the following step.

In the Third Phase Program laid down in 1992, the followings were determined to be promoted: Development aiming at the attainment of ignition condition and the realization of long-duration burning by a tokamak experimental reactor; Research on the improvement of tokamak; Research on various confinement systems; Research on fusion technology necessary for the development of fusion experimental reactor; Research on the basis and safety of fusion technology toward DEMO reactor; Research on the design of fusion reactor system.

After about 10 years of R&D since 1992, we can summarize the progress in the planned research on the major issues described in the Third Phase Program as follows:

1) The Atomic Energy Commission has deemed it appropriate to realize experimental reactor program by international cooperation project, ITER. The R&D on fusion core plasma and fusion technology necessary for the construction of ITER[*14] (ITER physics R&D[*15] and ITER engineering R&D[*16]) has been carried out through international cooperation, wherein our country has played a major role. On fusion core plasma research, high temperature plasma satisfying the reactor condition with several hundreds million degrees of ion temperature has been successfully controlled and maintained as shown in Attachment 4. And on fusion technology research, planned trial manufacturing has been completed and the database necessary to start ITER construction has been prepared. ITER engineering design has been fixed with these accomplishments.

2) R&D such as research on tokamak improvement necessary for steps beyond experimental reactor and development of fusion technology for fusion DEMO reactor has been started. Great progress has been made in research such as on steady state operation of tokamak. Research on tokamak improvement toward getting better economical prospect of fusion energy becomes one of important subjects. Also through the development of breeding and power-generating blanket[*17] and the development of the first wall structural materials, etc., formation of fusion technology basis has advanced, and we have reached a stage of starting a full-fledged R&D for fusion DEMO reactor.

3) As alternatives to tokamak, helical and laser (inertial confinement by laser) systems have demonstrated the next highest performance to tokamak system (Attachment 4), and LHD and FIREX projects have reached a stage of starting further research aiming at the realization of confining high temperature plasmas. Also, researches including those on other systems have contributed not only to acquiring knowledge necessary for fusion core plasma research but also to establishing a broad range of academic research bases.

4) Many researchers and engineers have been brought up by education and research guidance in the universities. Also many excellent young researchers and engineers have been fostered through international research activities in large experimental devices in the institutes such as JAERI and through the development of forefront devices in cooperation with industries. These human resources play central role in other advanced scientific and technological fields than fusion as well.

5) In the course of advancing the above R&D, our country has made world-leading research accomplishments, for instance in experimental reactor program, and in the wide range of fields on fusion core plasma and reactor technology.

Looking over these achievements, it can be concluded that, regarding tokamak system, we have now a basis that can embody the R&D plan leading to the next Phase toward the early realization of fusion energy. In the following sections, we will describe in detail the present status of researches on major issues from a viewpoint of achieved level of necessary bases to execute experimental reactor program and necessary works to be attained toward the Next Phase.

2.2 Experimental Reactor Program

In 1996, the Atomic Energy Commission expressed a view that it is appropriate to develop ITER through international cooperation as an experimental reactor in the Third Phase Program of our country. Since then, the ITER Project has been regarded as an experimental reactor program of fusion R&D in our country.

2.2.1 Progress of ITER Project

Based on the results of the three years of Conceptual Design Activities (CDA) since 1988, the ITER Project started Engineering Design Activities (EDA) in 1992 as an international collaborative project among Japan, US, EU and Russia under the auspices of International Atomic Energy Agency (IAEA) with the objective of providing detail design and technical data necessary to judge the start of its construction.

During EDA (1992-2001), a joint central team directed by ITER director has been formed with researchers and engineers from each party and conducted international cooperative design works and completed an ITER design in July 2001. At the same time, each party organized home team and shared engineering R&D and design works under the task agreements between the home team leader and ITER director. In our country, JAERI was appointed as an implementing agency and accomplished the role of home team in cooperation with industries, NIFS and universities.

At present, inter-governmental negotiation is progressing to conclude a joint implementing agreement on ITER construction, operation, utilization and decommissioning among six parties: Japan, EU, Russia, US being withdrawn from EDA for a while, China and Korea.

At the time of 1992, the experimental rector was expected to start its operation around 2005, but the schedule has been delayed substantially due to long process to establish agreement on international cooperation and to redesign more suitable machine and demonstrate its validity. Some people pointed out the delay of ITER construction

schedule affected seriously on smooth inheritance and development of fusion related technology in research institutes and industries.

2.2.2 ITER Engineering Design

The ITER engineering design completed by EDA after six years of initially slated period was considered to be difficult to proceed into construction due to its size and cost. Parties then reconsidered the technical objectives.

On reconsideration, new technical objectives were set under the leadership of our country while keeping the programmatic objectives of ITER as shown in Attachment 5, placing more emphasis on developing fusion reactor in non-intermittent operation (steady-state fusion reactor[*18]) by taking into account of the new results in core plasma research in JT-60, etc. and fusion technology. The term of EDA was extended by three years to complete the detailed design of the device satisfying new technical objectives.

ITER designed under new technical objectives is a tokamak device with major radius[*19] of 6.2 m, minor radius[*19] of 2 m, plasma current[*19] of 15 MA and nominal fusion output of 500 MW (Attachment 5). The device can achieve energy multiplication factor[*19] $Q \geq 10$ with sufficient margin and also has a possibility of achieving $Q \sim$ infinity with restricted nuclear burning[*20] time as well. Thus the device enables us to study plasma confinement dominated by self-heating by alpha particles[*21]. The feasibility of achieving such plasma performances has been confirmed by the ITER physics R&D activities using tokamak devices of participating parties.

It was also confirmed by ITER engineering R&D (full scale trial manufacture of major components of ITER machine such as large scale superconducting magnet[*22], vacuum vessel[*23], plasma facing component[*24], remote maintenance device[*25] and so on) implemented under cooperation among participating parties that the construction of ITER machine is basically possible. And the necessary preparations for the transition to the construction phase have been completed.

2.3 Fusion Plasma Research

2.3.1 Tokamak Device

(1) Research and Development Necessary for Construction and Operation of Experimental Reactor

Regarding the R&D on core plasma, database in various physics area (energy confinement[*26], plasma stability[*27], non-inductive current drive[*28], behavior of high energy particles, heat and particle control[*29]) necessary for design and construction of experimental reactor has been prepared through international cooperation of ITER physics R&D activity. This database becomes a basis of ITER engineering design. The International Tokamak Physics Activity (ITPA)[*30] have succeeded the above activity and been further accumulating data necessary for the experiment and operation of ITER. During this process, researches using tokamak devices in our country have accomplished major contributions in various fields described below (Attachment 6).

- **Energy Confinement:** A scaling law[*33] of energy confinement time[*26] in H-mode (high confinement mode)[*32] as a standard operation mode of ITER is established based on confinement database from worldwide tokamak devices including JT-60 and JFT-2M[*31] (JAERI). ITER was designed based on this scaling law.
- **Plasma stability:** Research on suppression and mitigation of disruptions[*34] and

investigation on instabilities preventing the attainment of high-pressure plasma have been advanced, led by JT-60. ITER was designed taking into account of these results.

- **Non-inductive current drive:** Non-inductive current drive is indispensable for steady state operation of future tokamak reactor. WT-3 (Kyoto Univ.) and JIPPT-IIU (NIFS) made pioneering research on RF-current drive. JT-60 demonstrated non-inductive current drive in plasmas with temperature higher than one hundred million degrees centigrade by negative-ion-based[*36] neutral beam injector[*37] and electron cyclotron wave injector[*38] in addition to the demonstration of current drive by lower hybrid wave[*35].
- **Heat and Particle Control:** In JT-60, a simulation experiment on whether or no we can exhaust helium, which is so to say burning ash[*39] in ITER, has been carried out and successfully demonstrated that we can exhaust helium effectively. The results were reflected in the design of ITER. Also, studies of plasma-wall interaction[*40] including metal and carbon walls were progressed.

Tokamak experiment with tritium (T)[*41] has not been carried out in our country. However, JET tokamak[*42] in Europe and TFTR tokamak[*43] in US confirmed the effective plasma heating by alpha particles produced in tritium and deuterium (D) fusion reaction, and obtained DT fusion power outputs of 16 MW and 10 MW, respectively.

(2) Research on Tokamak Improvement (Advanced and Complementary Research)

On tokamak devices JT-60, TRIAM-1M[*44] (Kyushu Univ.), JFT-2M and JIPP-IIU, researches such as on plasma confinement, long duration plasma discharge, efficient steady-state plasma operation method, plasma compatibility test of first-wall structural material have been conducted aiming at improving the performance of tokamak. And our country has attained world-leading research achievements. However, there still remain important subjects to be solved such as the research on increasing plasma pressure (Attachment 7).

- **Energy multiplication factor[*45] and plasma temperature:** By negative shear operation[*46], which is a newly proposed operation method of tokamak, DT equivalent energy multiplication factor Q_{DT}[*47], the ratio of energy produced by the fusion reaction to energy necessary to heat plasma, has reached the world record Q_{DT} of 1.25. And by improved core plasma confinement through optimizing current and heating profiles, the world highest ion temperature of 520 million degrees centigrade has been achieved, which well covers the operational space of ITER and fusion reactors.
- **Long pulse discharge and highly efficient steady state operation:** TRIAM-1M has succeeded in sustaining plasma for more than 5 hours by injecting RF (lower hybrid wave) externally and driving the current non-inductively. Furthermore, as a method of reducing the external electric power necessary for non-inductive current drive, in JT-60's negative shear operation, they have succeeded in producing non-inductive current driven plasmas by increasing the fraction of bootstrap current[*48], which needs no auxiliary electric power, up to 70-80% and driving the remaining plasma current by particle beam[*49] injection. By demonstrating the principle of such method for efficient steady state plasma operation, we have come to a stage where we can foresee the realization of long pulse operation in an experimental reactor by a steady state operation (a method sustaining plasma current only by non-inductive

current).

- **Research on producing higher beta[*50] plasma:** Beta value is an index of how efficiently we can confine high-temperature and high-density plasmas by magnetic fields, and economically competitive fusion reactors require the realization of high beta value. In DIII-D tokamak (US), beta value of more than 10% has been obtained.
- **Compatibility of the first wall[*51] structural materials:** Since low activation ferritic steel[*52], the most promising candidate for the first wall structural material, is a ferromagnetic material[*53], there was a concern about its influence on plasma performance. On HT-2 (Hitachi, Ltd.) and JFT-2M, experiments have been conducted by covering the whole inner surface of the vacuum vessel with low activation ferritic steel, and it has been confirmed that this has no effect on plasma build up and plasma control. Moreover, JFT-2M has attained moderately high beta plasma (normalized beta value[*54] of more than 3) and given the prospect of using ferritic steel in DEMO reactor.

2.3.2 Helical, Laser and Other Devices

Concerning devices other than tokamaks, large helical device LHD[*55] (NIFS) started its experiments and confirmed good plasma confinement capability next to tokamaks. In laser fusion devices, by employing a novel concept of Fast Ignition method[*56], plasma heating up to 10 million degrees centigrade has been successfully achieved, and FIREX-I Project[*57] (Osaka Univ.) aiming at the realization of ignition temperature has started. In other plasma confinement devices, many academic achievements contributing to plasma confinement and control have been attained.

(1) Helical Device

Ahead of EU that was constructing its large helical device, and US that started the construction of its own small-scale helical device, the construction of the world largest helical type device LHD was completed in 1997, and up to now, the following research results have been obtained through its experimental studies.

It has been experimentally confirmed that the scaling law of energy confinement time deduced from relatively low temperature plasma in small to medium size devices (CHS[*58] (NIFS) and Heliotron-E (Kyoto Univ.)) still holds in the plasma of large device (LHD) with high electron temperature (100 million degrees centigrade) close to fusion core plasma condition. And this has significantly improved the reliability of the existing energy confinement time scaling law. Also, a long time operation sustaining its confinement performance has been demonstrated. Furthermore, high electron temperature plasma is realized in LHD by forming high electric potential and transport barrier related with turbulence suppression by plasma flow shear. It has been pointed out that suppressing the orbit loss of high-energy particles[*60] caused by the magnetic field ripple[*59] specific to helical devices might be hard to be compatible with MHD stability. However, by the progress in research on the control of magnetic field configuration in LHD, the good confinement of high-energy particles has been obtained with good plasma confinement even in a linearly unstable region, and the high beta plasma of 4% has been achieved.

In LHD and Heliotron-J[*61] (Kyoto Univ.), researches on optimization of magnetic field configuration, further improvement of plasma confinement and study in an attempt to get a common understanding of toroidal plasma are still ongoing.

(2) Laser Device

For energy driver of inertial fusion[*62], there are methods using laser, heavy ion beam and Z-pinch. But in our country, researches have been conducted with a central focus on laser fusion[*63]. Laser fusion research in Japan has been playing a leading role in world laser fusion research, for example by achieving compression to 600 times the solid density (up to 600 g/cc, compared with solar core density 150 g/cc) in implosion[*65] experiment on GEKKO XII Laser facility[*64] (Osaka Univ.) in 1989 (Attachment 9). This has moved the world laser fusion research to the demonstration of ignition and burning. In case of conventional "central ignition"[*66] method in which fuel core is heated by the work of imploding fuel pressure, megajoule-class input energy is needed to realize ignition and burning required for a fusion reactor. In Europe and US, construction of NIF[*67] (US) and LMJ[*68] (France) having this class of laser energy is under way and the demonstration of fusion ignition and burning is expected around 2013.

Meanwhile in the laser fusion research of our country, "fast ignition" method is proposed and promoted in which required laser input energy for ignition and burning is expected to be lowered substantially by one order of magnitude. In this method, ignition will be realized by heating ultra high-density plasma[*69] produced by implosion further by other ultra short pulse laser[*70]. As a step of proof of principle experiment, heating of implosion plasma up to 10 million degrees centigrade has been successfully demonstrated in an experiment using a petawatt-class laser[*71]. With this success, FIREX Project aiming at ignition and burning by "fast ignition" method is proposed and started its first stage (goal: realization of 50-100 degrees centigrade).

(3) Other Confinement Devices

In researches on reversed field pinch[*72] plasma, TPE-RX device[*73] (National Institute of Advanced Industrial Science and Technology, hereafter AIST) has succeeded in improving energy confinement by several times and achieved the energy confinement time of 10 ms by current profile control via poloidal current drive[*74]. In REPUTE device (Univ. Tokyo), a quasi-stable configuration in an ultra low q (ULQ) region has been discovered experimentally and understanding on relaxation phenomena has been advanced.

In research on mirror-confinement plasma[*75], GAMMA-10 device[*76] (Tsukuba Univ.) has made progress in experimental researches such as on physical mechanism of electrical potential formation[*77] and effects of electric field on plasma.

In research on compact torus[*78], study on sustaining high beta plasma has been advanced in FIX device (Osaka Univ.). Also, physical understanding on magnetic field reconnection[*79] phenomena associated with structure formation of confinement magnetic field has been progressed and as an expansion of research commonality with the magnetosphere and space solar plasma has been explored.

In research on spherical torus[*80], pioneering studies on plasma current build up by RF wave without ohmic coil system have been explored in TST-2[*81] (Univ. Tokyo) and LATE[*82] (Kyoto Univ.). And in TS-3/4 devices[*83] (Univ. Tokyo), research on the formation and heating of spherical tokamak by plasma merging has been advanced.

In research on confinement devices with internal conductors[*84], Proto-RT/Mini-RT[*86] (Univ. Tokyo) have been proposed based on a newly developed relaxation theory[*85] and constructed. Research aiming at sustaining high beta plasma has been started.

Also, basic researches on high performance divertor have been conducted in CSTN-IV[*87], HYBTOK-II (Nagoya Univ.). Research on plasma wall interaction (detachment phenomena[*89], etc.) has been carried out in NAGDIS-II[*88] (Nagoya Univ.).

2.4 Fusion Technology Research

2.4.1 Research and Development for Experimental Reactor (ITER)

As for the fusion technology research for ITER, fabrication technologies of main components have been established and as a single component they have exhibited performances that meet or outperform the requirement for ITER. Development of technical basis toward ITER construction has thus progressed (Attachment 10).

[Reactor Components]

- **Superconducting Magnet**[*90]: ITER requires large-scaled, high-field superconducting magnets. Required high current and high field (40 kA and 13 T, respectively) have been achieved in a large-scaled magnet, which was developed based on newly developed high-performance Nb_3Sn[*91] superconducting strands for this magnet. Also, the soundness of pulse performance under the conditions of transient magnetic field (1.2 T/s) exceeding the design requirement of ITER has been verified.
- **Reactor Structure and Remote Maintenance**[*92]: A sector model of the vacuum vessel, which has double-walled structure of inner and outer skins, has been fabricated, and fabrication technologies to satisfy high geometrical accuracy have been demonstrated. In-vessel remote maintenance system has been developed, based on a self-deploying rail and a vehicle concept[*94], for the maintenance of the blanket[*93] with a weight of four tons each. Also, highly accurate positioning (setting accuracy within ±2 mm), attachment, detachment and inspection technologies have been demonstrated.
- **Plasma Facing Components**: High performance surface armors and cooling channels with internal heat removal promoters and their joining technology[*95] have been developed. Based on these achievements, the divertor plate[*96], capable of withstanding high surface heat flux (20 MW/m^2 as maximum) has been successfully developed.

[**Ancillary Components**]

- **Heating and Current Drive Components**: Regarding the systems for plasma heating and current drive, there are achievements in increasing the beam energy of negative-ion-based neutral beam injector (1 MeV) and increasing the frequency and power of electron cyclotron heating systems (170 GHz, 1 MW, respectively), etc. Thus the development of these systems has progressed steadily.
- **Tritium Handling Technology**: Basic technologies of tritium fuel cycle system has been established through component developments and testing at Tritium Processing Laboratory (TPL[*97] at JAERI) and their integrated testing in a fuel cycle model loop at TSTA (Tritium Systems Test Assembly, one-sixth scale model of the ITER fuel cycle system) and one-month continuous operation under US-Japan collaboration. ITER technology R&D during the EDA Phase facilitated to refurbish these technologies.
- **Diagnostics and Control Equipments**: Elementary R&D for the ITER basic diagnostics components brought a good prospect for their performances under radiation environments and long-pulse operation anticipated in ITER.

- **System Integration Technologies**[*98]: Through construction, operation and upgrading of JT-60, LHD, TRIAM-1M, and other facilities, important experiences and know-how have been accumulated on system integration technologies of magnetically-confined fusion devices. ITER shielding design has been validated by shielding experiments on Fusion Neutron Source (FNS)[*99] at JAEA and by the evaluation on the radiation environments during operation and maintenance.

Based on the above-mentioned achievements, future R&D issues can be identified as follows: demonstration of full-power performances of plasma heating and current drive systems; further development of diagnostic components for higher performance; and demonstration of performances of the reactor and ancillary components, as an integrated system, including maintainability, through ITER construction and operation.

2.4.2 Formation of Fusion Technology Basis for DEMO Development

With regard to research and development on fusion technologies for DEMO, strategic programs had been established by the Fusion Council on the roadmaps of R&D on the blanket and structural materials for the first wall on the basis of mid-term perspective ([8], [9]). Based on these programs, R&D on the breeding and power-generating blanket, which has functions of energy conversion and tritium production, and on structural materials for the first wall had been conducted (Attachment 11).

- **Development of breeding and power-generating blanket**: By advancing the elemental technological R&D on the pebble-bed-type solid breeding blanket[*101] made of lithium compounds[*100], technical basis for foreseeing the feasibility of the design concept has been established and the preparation for deploying engineering-stage R&D has been almost completed.
- **Structural materials**: In the development of high radiation[*102] resistant (100~150 dpa) and low induced-activation[*103] structural materials, irradiation tests using such as fission reactors have been carried out (to the level of 20~40 dpa) with a central focus on a prime candidate material – low activation ferritic steel, and a good prospect for high radiation resistance has been obtained.
- **Materials irradiation test facility**[*104]: As a facility to accumulate materials irradiation data under neutron[*105] environments similar to those of fusion reactors, design studies on the International Fusion Materials Irradiation Facility (IFMIF)[*107] were carried out under the international cooperation of International Energy Agency (IEA)[*106]. Based on the conceptual design and R&D on key technologies conducted up to now, a technical basis sufficient for proceeding to engineering design phase has been established.

In addition to this, development of superconducting magnet for even higher magnetic field and advancement of technologies on heating and current drive systems are issues to be tackled. As for the former issue, the development of large-scale superconducting magnet for high magnetic field has been conducted based on Nb_3Al[*108] strands, which have less degradation in superconducting property due to strain and a better characteristic in high magnetic field, compared to the Nb_3Sn strands used in ITER. The development has progressed so far to the level of 13 T, the minimum level of the magnetic field deemed necessary for the DEMO.

2.4.3 Other Researches on Fusion Technology

(1) Technology Development on Laser Fusion

The most important issue in the R&D on laser-driven inertial fusion is the development of high-power laser system with high energy-conversion efficiency[*109] from electrical to laser energy and high repetition rate. As the laser system in the reactor can be realized by integrating a number of small-sized modules, the target of R&D is to develop a unit module (output energy of 100 J to 1 kJ, repetition rate of 5 to 10 Hz) and technology to integrate the modules into a single system.

In this respect, R&D on Diode-Pumped Solid-State Laser (DPSSL)[*110] has been conducted, and steady progress in the development of laser technologies for fusion reactors and academic researches has been obtained, such as the success in the development of the HALNA laser[*111] (Osaka Univ.) with an output energy of 10 J and a repetition rate of 10 Hz, and an excimer (KrF) laser[*112] (Super-ASHURA, AIST) with an output energy of 20 J and a repetition rate of 1 Hz.

(2) Fundamental and Basic Researches on Fusion Technology

Substantial progress has been achieved as follows: Enrichment of fusion materials database (structural, breeding, and functional materials) including the effects of neutron irradiation[*113] and the development of advanced materials; Formulation of material irradiation damage modeling[*114] and its theoretical and experimental treatments; Establishment of electromagnetic-thermal-structural analysis[*115] methods; Development of neutron transport[*116] calculation methods and the accumulation of relevant database; Theoretical and experimental researches on plasma-wall interactions; Tritium science and engineering, including safety handling, environmental behavior, and biological effects. In particular, as basic researches to realize advanced blankets such as a liquid metal blanket and a high-temperature gas-cooled blanket, the following researches have been advanced: Improvements of Vanadium-alloy fabrication technologies and the technological development of SiC-series composite materials; Development of oxide dispersion strengthened steels; Basic scientific studies on liquid breeding materials such as molten salt or liquid metal; Particle-irradiation simulation experiments on structural materials by means of accelerators; Researches on irradiation effects on electrical insulating materials. Some of them were effectively conducted through the US-Japan collaborative programs (FFTF-MOTA, JUPITER).

2.5 Fusion Reactor System Design

Researches on fusion reactor system have made progress especially on study of tokamak type fusion reactor design aiming at improvement of economical competitiveness and environmental acceptability. Improvement design study and evaluation of environmental safety of fusion reactor SSTR[*117] originally designed in 1990 made progress. Highly economical reactor CREST[*118] has been designed at Central Research Institute of Electric Power Industry (CRIEPI) (Attachment 12). Based on these progresses, system comparison studies between tokamak-type fusion reactors and various energy sources were performed in Subcommittee of the Fusion Council for the Fusion Development Strategy [5].

Significant progresses on expansion of database of various related fields and establishment of method for nuclear fusion reactor design have made it possible to start the conceptual design study of demonstration fusion reactor.

2.6 Safety Research [Attachment 13]

In researches on safety, evaluation of the soundness of radioactive materials confinement capability, studies on tritium plant, and the development of tritium removal facility have proceeded.

Moreover, as ITER in scope, progress has been made in accumulation, improvement of analysis and evaluation method of various engineering safety data on distribution, characteristics, ensuring of whose confinement, and soundness of radioactive materials such as tritium. In this way, the basic policy on safety ensuring and the necessary technological basis for safety toward the construction of ITER in our country have been established.

Also, progress has been made in research on environmental migration behavior of tritium, tritium monitoring technique, biological influence of tritium, measurement and control technique of tritium in the vacuum vessels of JT-60 and other machines, and the accumulation of experience on safety handling including decontamination and maintenance of tritium handling devices.

Based on this, Ministry of Education, Culture, Sports, Science and Technology and Nuclear Safety Commission organized and discussed critical issues on ITER safety and specified a guideline on security and regulation of safety. [10], [11], [12]

2.7 Achievement in Academic Fields

2.7.1 Academic Achievements in Plasma Confinement

Scientific research on plasma confinement has contributed to development of basic science especially plasma physics. Through studies on various magnetically confined plasmas, plasma transport phenomena, behavior of plasma turbulence, structure formation, and transition phenomena[*119] have been recognized as common plasma physics. Generalization of plasma physics including relations to other scientific fields has strengthened academic basis of plasma research.

For instance, in fluid, turbulence generation by spatial gradient of laminar flow in space (shear) is a commonly observed phenomenon. But the turbulence suppression by shear of laminar flow has first been observed in plasma. The laminar flow, which suppresses turbulence, is produced by turbulence wavelength transformation. It causes strong nonlinearity in transport and autonomous structure formation of plasma. Studies of turbulence and transport in confined plasma bring new insight on nonlinearity and self-organization in fluid mechanics.

Transition phenomena in plasma have been studied in various devices including tokamak, helical and mirror machines, and limit cycle[*120] (repetition of transition and reverse transition) has been observed. Limit cycle is a self-stabilizing state commonly observed in open nonequilibrium matters such as lives. Studies on self-stabilizing state in plasma with strong nonlinearity have contributed to the progress of physics in open nonequilibrium system.

Magnetic reconnection studied in magnetically confined plasmas in tokamak, helical and pinch devices has closely related to phenomenon observed in sunspots and studies on these topics have contributed to the progress of plasma physics as basic science having common basis with space plasma physics.

On the other hand, implosion experiment in laser fusion research enables us to produce extreme state existing only in stellar interior, and has created novel science

fields so to say high energy density science[*122] represented by laboratory astrophysics and laser nuclear physics[*121].

Medium and small size devices have contributed to develop measurement technique. New heat and particle control method has been developed aiming at strengthening academic basis for fusion science. Basic process in plasma including atomic and molecular process has been studied as well.

2.7.2 Theory and Simulation Research on Fusion Plasmas

In the area of fusion plasma theory, theory and simulation studies based on first principle[*123] and nonlinear plasma theory have progressed through the advancement of numerical calculation method.

In the field of tokamak, large-scale simulation has brought about a better understanding of transport phenomena, magnetohydrodynamic stability[*124], current drive and divertor. In particular, progress has been made in the development of gyro-kinetic[*126] linear and nonlinear turbulent transport code package solving about 100 million particles orbit and electrostatic fluctuation[*125] self-consistently.

Various non-linear MHD dynamics[*127], which limit extension of high performance plasma, are clarified such as new magnetic reconnection having unique structure not foreseen in previous classical theoretical models. Understanding of control and sustainment of high performance plasma with internal transport barrier[*128] is progressed.

Proposal of physical models, development of numerical codes and systematic comparison with experimental results lead to the development of models qualitatively explaining experimental results. Theoretical model, analysis code and experimental database necessary for integrated burning plasma simulation code[*129] have been prepared aiming at simulation of burning plasma.

In the area of laser fusion research, systematic development of the theory of high energy density plasma physics has been progressed concerning ultra high pressure and density plasma including equation of state and theory of X-ray energy transport. This progress has made it possible to simulate and to predict theoretically the behavior of ultra high-density plasma such as implosion plasma or stellar interior.

2.8 Spin-off Effects on Industry [Attachment 14]

Fusion technology has been developed based on unexplored innovative technologies of various engineering fields. Fusion technology provides spin-off effects on various industrial fields such as nanotechnology, material science, life science, information and communication technology and environment.

Technology of positive ion beam developed for fusion plasma heating has been applied to manufacture hard-disc and large liquid crystal displays and has contributed to the significant improvement of manufacturing technology. Application of negative ion beam technology to the manufacturing technology of next-generation semiconductor substrate is also considered.

Vacuum technology developed in fusion research has been applied widely to production of ultra-high vacuum environment necessary for nanotechnology and semiconductor manufacture, taking advantage of its ultra-high vacuum and large volume pumping features. Surface processing technology has been widely applied to hard metal tool for milling.

In an area of environmental protection, selective pumping technology[*130] developed for fusion has been applied to separation and recovery of perfluorocarbon (PFC), a kind of greenhouse-gas, used in semiconductor production process. The practical application is also planned.

Also in superconductor technology, area of fusion has been major driving force such as for improvement of superconductor wire rod performance and manufacturing infrastructure, and has contributed to the development of superconducting application to medical diagnosis by magnetic resonance imaging (MRI) and structural analysis of protein by nuclear magnetic resonance (NMR).

High frequency radio wave technology developed for plasma heating has been applied to ceramic sintering technique.

Utilizing atomic process simulation codes, diagnostic methods and pellet technology[*131] developed in laser fusion research, development of ultra-violet light source[*132] for next generation semiconductor has been advanced and the necessary laser technology is being developed.

2.9 Training and Education

Providing attractive and challenging research environment is essential for fostering young excellent talents. Many researchers and engineers have been fostered through graduate course education and research guidance in universities and Graduate University for Advanced Studies. In the past fusion research, cutting-edge and innovative studies using medium to small-scale devices in universities has worked effectively in fostering young researchers and engineers. Collaborative research centralized on the inter-university research institute NIFS and international collaboration such as US-Japan science and technology cooperation program have been meaningful in providing the arena for young researchers and engineers. Moreover, international research using large-scale experiment devices at institutes such as JAERI and the development of state-of-the-art devices in collaboration with industries have greatly contributed to fostering many talented young researchers and engineers.

As for systems to support these, utilization of Collaborative Graduate Studies Program, and increase in the fixed number of postdoctoral fellowships of Japan Society for the Promotion of Science (hereafter, JSPS) and JAERI have worked effectively to ensure the research opportunities for young researchers and engineers. On the other hand, decline in fusion related order causes transferring majority of engineers in industry from fusion section to other sections and it becomes difficult to preserve and succeed related technologies.

2.10 International Collaboration

International collaboration is quite effective to promote fusion research efficiently and effectively, considering increase in manpower and program-cost accompanying the expansion of research development. International collaboration programs promoted by our country are shown in Attachment 15.

In OECD/IEA collaboration programs under International Energy Agency (IEA), various collaboration research activities have been performed such as Cooperative Programs on Three Large Tokamak Facilities, Stellarator, Reverse Field Pinch, and in fusion technologies, Fusion Materials (including IFMIF), joint international

collaboration experiments at world top class experimental facility Fusion Neutron Source (FNS, JAERI), at the high heat load test stand (JEBIS, JAERI), and at the blanket test stand (JAERI), and Cooperative Program on Environmental, Safety and Economic Aspects of Fusion Power.

In collaboration programs under the International Atomic Energy Agency (IAEA), International Fusion Energy Conference, Technical Meetings and ITER Project have been promoted as multilateral cooperation. Especially in the ITER Project, Japan (JAERI) as a leading party contributed to establishing the technical basis for construction by providing model coil test facility for central solenoid coil and completing test program that is most important research and development item in ITER engineering R&D conducted for nine years since 1992.

Bilateral cooperation programs have been also promoted with US, EU, Canada, Australia, Russia, China, South Korea and so on. Especially between Japan and US, US-Japan Coordinating Committee on Fusion Energy has been established under "Agreement between the Governments of Japan and the Government of Unites States of America on Cooperation in Research and Development in Energy and Related Fields". Wide range of cooperation has been promoted in five programs such as Exchange Program, Joint Planning, Joint Projects, Collaborative Program on the Data-Link and Joint Institute for Fusion Theory.

As for the participation of Japanese researchers in foreign research programs, participation in advanced plasma confinement research at tokamak facility DIII-D in US, joint material irradiation experiment at nuclear reactors FFTF and HFIR, joint experiments on fusion fuel circulating system and safety on tritium handling at tritium system test facility TSTA, and the Data-Link cooperation has been conducted. Also, the participation in Program on Environmental, Safety and Economical Aspects of Fusion Power, experiment of tritium release conducted under the Agreement between Canada and Japan, and the participation in DT experiments at TFTR and JET could have been achieved only by international collaboration. Many researchers from institutes such as JAERI and AIST, NIFS and various universities and engineers from industries have participated in these international collaboration programs.

As for the participation of foreign researchers in Japanese research programs, many foreign researchers have participated in the research programs at JT-60 facility leading the world in research on steady state plasma operation and negative-ion-based NBI facility, under the IEA Cooperative Program on Three Large Tokamak Facilities. Also, researchers from UA, EU and Russia have participated in central solenoid coil test in which our country has played major role in ITER engineering R&D. Many researchers from all over the world have also participated under IEA Collaboration Agreement and US-Japan Cooperation in the experiments of the world's largest superconducting helical device LHD, superconducting tokamak TRIAM, and high performance fast ignition petawatt laser at GEKKO laser facility. Furthermore under the LHD International Mutual Experiment Program (LIME), collaborative research on plasma confinement and fusion technology are actively promoted centering in LHD device among various world-wide research groups on helical system in EU (especially Germany and Spain), US, Australia, Russia and Ukraine.

Chapter 3 Basic Approach of Fusion Research and Development

As described in Chapter 1, realization of the fusion energy in use is important from the viewpoint of the contribution to the resolution of global environmental problem, expected to become serious in future, and of the energy security. Therefore, the scenario must be established for its realization.

For this purpose, considering the past progress, the development strategy foreseeing the next stage of the fusion research is investigated from the viewpoint of the early realization of the fusion energy in the R&D of tokamak system.

In this regard, it should be promoted such that national and international programs linked to the ITER Project should be established while having the ITER Project as a core program. And in promoting the research and development, it is necessary to pursue always the economic rationality so that it can lead to the utilization of the fusion energy, and the high safety and the minimization of the environment load in its life cycle from the construction to the decommissioning.

In the fusion research and development, the synergy effects between developmental and academic researches is remarkable from the past examples such that the result of the developmental research raises a problem for the academic research and the results of the academic research, especially the discovery of the wisdom leads to the acceleration of the developmental research. Thus, it is inevitable to respect the results of the academic research for a progress of the future research and development. Therefore, it is very important to keep and maintain the basis for academic research and education.

For the future fusion research and development, in view of promoting further active participation by industry, broad deployment of its research regarding not only the improvement and advancement of the basic technology of the fusion energy but also the application of the products of research and development is important.

3.1 Strategy for Early Realization of Fusion Energy

In order to put fusion power into practical use, it is necessary to make fusion system technically practical as a power generation system, and to have economical competitiveness against abundant energy sources. To this end, it is necessary to have economical prospect and to demonstrate safety and operation reliability as a major premise for the future assessment of the commercialization of the fusion energy.

Considering that the ITER Project is now moving to the construction stage, that the proof of principle of the steady-state operation in the tokamak system has been done, and that the fusion technology basis toward the power generation has been developed, it is adequate to proceed developmental research in the tokamak system in parallel with ITER, toward DEMO taking certain economy into account.

It is desired to realize steady-state operation in the tokamak type fusion reactor from the viewpoints of an economy and a technology such as thermal fatigue, although there are inductive pulsed operation[*133] and non-inductive steady-state operation for the tokamak system.

In order to make the most rational plan toward the practical use of the fusion energy, it is important to select what can be realized only with an integrated device like ITER and what can be realized with an element technology and to limit the number of integrated devices.

So, the Annex to the Third Phase Program, "On the promotion of the fusion research and development" in 1992 is reviewed based on the progress of the research until now, toward the early realization of the fusion energy. And clarification of the technical specifications of DEMO and clarification of the policy at the experimental reactor phase taking the development of DEMO into account have been done.

3.1.1 Consideration of Development Phases

In "On the promotion of the fusion research and development" in 1992, it is defined that three phases should be taken in the experimental reactor stage and in the following development stages such as (1) achievement of ignition condition, realization of fusion long-duration burning, and formation of fusion engineering basis necessary for development of DEMO, (2) realization of a steady-state fusion core plasma[*134] and technical demonstration of power generation in a plant scale, and (3) demonstration of economical feasibility as a power generation plant. It is concluded that as central devices for this purpose, experimental reactor, DEMO and Proto should be necessary. And, it is also decided that the development of the structural material to withstand neutron irradiation of the fusion reactor should be started in the experimental reactor stage from the long-term viewpoint.

Considering that the stage has come, where the realization of the steady-state operation in ITER can be foreseen through the research progress of the tokamak system as described in Chap. 2, it is judged that the realization of the steady-state core plasma can be built into the experimental reactor phase expected at the DEMO phase except simultaneous realization with high energy multiplication factor (roughly more than Q~30). Based on this, it was also examined in the committee whether the technical demonstration of the power generation at the plant scale could be performed in ITER ahead of DEMO phase. It is concluded that it is possible in principle, but also requires big design change, reconsideration on the safety, and formation of international consensus. So, it is judged that for the moment it is appropriate to aim at functional demonstration and small-scale power generation by using the power generation blanket test module.

As for the technical subject on economical feasibility defined in (3), on the other hand, suppression of total capital cost is most important to reduce cost of electricity. In other words, it is most important to realize high power density with the core dimension similar to ITER. For this purpose, it is effective to raise the beta value, which is the ratio of the plasma pressure to the magnetic field pressure, and to reduce heat flux by control of the boundary plasma. It was recognized that these technical subjects on economical feasibility could be implemented in the DEMO reactor phase, and that the development of the material, which withstands the neutron irradiation of the power generating plant, and development of other technologies concerning economical feasibility could be implemented as element development.

As mentioned above, based on clarification of what needs to be realized with an integrated device and what can be realized as element development without integrated device, it was concluded that it is appropriate in the DEMO phase to aim at realizing steady-state fusion core plasma with high energy multiplication factor and at the same time demonstrating power generation in a plant scale taking certain economical performance into account, from the viewpoint of the early realization of the fusion energy. So, the research and development in the experimental reactor phase shall

cover all necessary elements to realize this objective. As for the promotion after the DEMO stage, it is desirable to promote the industrial leadership for commercialization. The way of promotion at the moment, however, will be examined in future, taking into account the research progress on the ITER Project and the materialization of the DEMO program.

3.1.2 Phase Changeover and Utilization of Fusion Energy

In the ITER Project, technical objectives are centered on establishment of the control technique of fusion burning plasma. And according to the ITER final design report, achievement of the major basic performance is expected at shortest in about 7 years after the startup of ITER operation (in the early 2020s). For the early realization of the fusion energy, it is desirable to proceed to the construction of DEMO after the achievement of the basic performance of ITER.

Therefore, for the tokamak system, an integrated research and development necessary for the construction of tokamak type DEMO should be implemented in order to judge the soundness of the changeover to the DEMO phase by the time when the main basic performance of ITER is achieved. If a switchover to the DEMO phase is done in the early 2020s followed by prompt construction of DEMO, it will be foreseeable to start test program and improvement using DEMO from 2030s with the objective of demonstrating continuous power generation, safety, economical viability and operational reliability. If so, it is foreseeable to get prospect for commercialization by the mid-21st century.

3.1.3 Tokamak type DEMO Reactor

Tokamak type DEMO is supposed to have the core dimension similar to that of ITER and the power generation capability of the gigawatt level. This DEMO needs to operate continuously for about one year and with high plant efficiency[*135], high output stability at transmission end and the overall tritium breeding ratio (TBR)[*136] exceeding unity. The technical specifications required by such DEMO are shown in the following.

As for the fusion core plasma, high plasma pressure operation is required to increase fusion power density several times higher than that of ITER to realize 3-4GW level of thermal output. It also requires the non-inductive steady-state operation and the control of heat and particle to enable continuous operation of year level. These requirements significantly exceed that of the ITER standard operation.

As for the structure material of blanket first wall with strong candidates such as reduced activation ferritic steel, final target of development is to withstand about 3-6 years neutrons (as the neutron fluence[*137] of about 10-20 MW year /m^2) and heat flux[*138] (about 1 MW/m^2) under high power density operation.

As for the breeding and power generation blanket composed of many modules, which fulfills an essential function of the self-production and self-supply of tritium fuel in the plant, it must realize the breeding and recovery of the tritium with high reliability securing tolerance against the disruption.

As for the divertor components, which removes the heat and particles from the high-temperature plasma, they are exposed to higher heat and particle fluxes than the blanket first wall and must be the high heat flux components[*138] having tolerance to

neutron irradiation and high particle flux for several years level.

As for the maintenance period of the first wall and the divertor plate, whose periodic exchange is scheduled once in several years, it should be sufficiently short not to affect plant availability very much. Furthermore, reliability of continuous operation of the heating and current drive system up to one year should be established as well.

Here, in view of the economic rationality of the development strategy leading to the commercialization of the fusion energy, construction cost of DEMO should be controlled to an acceptable level taking the future commercialization into account.

3.1.4 Research and Development in Experimental Reactor Phase

An integrated developmental research to realize DEMO shall be implemented in the experimental reactor phase to aim at early realization of the fusion energy.

The research and development shall consist of, 1) establishment of the control technique of the burning plasma[*139] dominated by the self-heating, 2) realization of the steady-state fusion core plasma, 3) establishment of the integrated system technology and the test of the power generation blanket, 4) establishment of the high beta steady-state operation method to gain prospects toward economical feasibility, 5) development of the material and fusion technologies related to DEMO, and 6) conceptual design of DEMO. It is also important to extend 7) theoretical and simulation research, and 8) the research on social and environmental safety.

In order to proceed with the above developmental research in the experimental reactor phase, it is important to take full advantage of an integrated device ITER. But it is valuable to make use of the flexible JT-60 facility without DT burning for doing what is difficult to be carried out in ITER and what needs proof of principle before applying to ITER. The design of DEMO should be made by reflecting other developmental research results and by considering technical consistency. As for the development of material and fusion technology, developmental research should be carried out steadily as element-technology development through preparation of various test facilities to carry out 5) as mentioned above.

(1) Research and Development using ITER

Establishment of the burning plasma control technology

Energy multiplication factor of about 30 is necessary in tokamak-type DEMO. It is necessary in ITER to realize burning plasma of the self-ignition regime (energy multiplication factor of more than 20), where self-heating by the alpha particle becomes dominant, and to understand its physics and to obtain prospects for the burning plasma control.

Realization of the steady-state fusion core plasma

Because in tokamaks, plasma is confined by generated plasma current, it is necessary to establish the non-inductive steady-state operation method and to realize steady-state burning in ITER. Here, energy multiplication factor Q of more than 5 should be attained. And, it is required to sustain such plasma more than about 1000 seconds exceeding physical time constants, such as current diffusion time[*140], to prove its effectiveness.

On the other hand, divertor heat flux reduction method and low sputtering[*141] and low tritium inventory plasma facing components should be developed using ITER and

other devices toward DEMO whose continuous operation time extends to one year.

Establishment of integrated system technology and power generation blanket test

The integrated system technology including superconducting magnet technology and the nuclear technology should be established through the construction and operation of ITER. At the same time, safety will be demonstrated in ITER as a fusion-burning device. And, in principle as an individual activity of each party, it is necessary to obtain basic technology on power generation blanket through the functional demonstration of tritium breeding and power generation blanket using test modules.

(2) Proof of Principle of High Beta Steady State Operation Method

In the tokamak-type DEMO, it is necessary to realize high power density by increasing plasma pressure by 2-3 times that of ITER with the core dimension similar to ITER to gain economical prospect of fusion power. For this objective, it is most effective to realize steady-state operation with high beta value, which is defined as a ratio of the plasma pressure to the magnetic pressure.

Achievable beta value of a tokamak is known to depend on aspect ratio[*142], plasma shape[*143], and feedback control[*144]. It is valuable to utilize JT-60 facility, which can realize plasma condition close to fusion reactor, to implement research on tokamak improvement toward DEMO. It is important to reflect its results as much as possible to ITER. On the other hand, some results of research on tokamak improvement are required to be reflected on the design of DEMO directly since the heat removal capability, the aspect ratio and the plasma shape of ITER are mostly fixed.

(3) Development on Material and Fusion Technologies for DEMO

Development on materials and fusion technologies, to be steadily implemented as elementary R&D issues for DEMO, includes: 1) development of breeding and power-generating blankets; 2) development of structural materials; 3) materials test using the fusion materials irradiation facility; 4) improvement of superconducting magnet and heating and current drive technologies; and 5) development of tritium and engineering safety technologies.

Development of breeding and power-generating blankets is an essential R&D for self-sufficiency of tritium fuel[*145] and demonstration of power generation in DEMO, and is also an important R&D concerning economic prospect.

As for the structural materials, we have to develop structural material that can withstand high neutron irradiation and high heat flux anticipated in DEMO.

In reactor irradiation, we can conduct an experiment on material irradiation damage (dpa) at fusion-reactor-level, but cannot simulate the effect of gaseous transmutation products such as hydrogen and helium, which are the consequence characteristic of high-energy (14 MeV) neutron produced in a fusion reactor. Therefore, it is necessary to make neutron field similar to the neutron irradiation environment in a fusion reactor, and to conduct material tests for understanding the characteristic change of fusion reactor materials and clarifying the condition of their applicability to breeding and power-generating blankets.

As for the superconducting magnet technology, further upgrading is necessary in view of achieving high power density in DEMO through high field (more than about 16 T) complementary to high beta operation in view of aiming at improving economical performance. As for the heating and current drive system, reliability and economic

performances should be improved under the DEMO design specification.

Considering that ITER will demonstrate the safety of a burning plasma facility and a tritium plant, and that DEMO will be the first facility with full breeding blankets and power generation plant system, R&D on the tritium technologies and related engineering safety should be conducted to solve the DEMO-specific safety issues.

(4) Conceptual Design of DEMO

The concept of DEMO shown in 3.1.3 should be further clarified in order to implement integrated R&D to realize tokamak type DEMO. Therefore, it is necessary to develop the conceptual design study of the tokamak-type DEMO taking into account of economical prospect toward a commercial reactor, enhanced safety and environmental acceptability, and also decommissioning. Also, participation of utility company in the conceptual design of DEMO is necessary in view of commercial plant.

(5) Tokamak Theory and Simulation Research

During the above research and development, predictive capability on plasma performance of DEMO should be enhanced by progress in understanding of the turbulent transport, the plasma stability, the high-energy particle behavior, the heating and current drive characteristics and the divertor characteristics, of the ITER burning plasma and the steady-state high beta plasma. Therefore, it is important to advance the tokamak theory and simulation research.

(6) Social and Environmental Safety Research

DEMO should establish the safety of the fusion energy in the social system, including the licensing and the social acceptance. Social and environmental compatibility must be secured by expanding the framework of present nuclear fusion research. For this objective, fusion safety must be evaluated with respect to the society and the environment in order to make fusion intrinsic safety to be "easier for the public to understand" and to be "easier technology for the society to handle". And we should examine the way of disposing the radioactive waste and deploy the safety research from a broader perspective to get social cognition.

3.2 Meaning and Positioning of Academic Research for Fusion

Thus far, the fusion research at the universities and NIFS has been exploiting unique ideas, challenging research on their various confinement systems, and attaining good results.

As indicated in the report [13] of Working Group on Fusion Research of the Special Committee on Basic Issues of the Subdivision on Science under Council for Science and Technology (hereinafter, the Fusion WG)[*146], future fusion research shall be promoted with research efficiency and centralization, putting JT-60, LHD and GEKKO-XII on the center.

Considering that the helical system and the laser system have confinement performance next to the tokamak and have characteristics different from the tokamaks, they should remain promoted at the universities and NIFS with emphasis on the academic research from the viewpoint of expanding choices of the fusion reactor. In the academic fusion research, a systematized scientific principle is required to be built by accumulating new knowledge through the research on ITER, tokamak, helical, laser,

and reactor engineering, and through the quest for new possibility based on original ideas. In the course of these activities, efforts are required to contribute to ITER and foster human resources. Also, these research results should be reflected properly on the design of DEMO.

3.2.1 Centralized Projects other than Tokamak

Helical system: The helical system has demonstrated confinement performance next to the tokamak in the magnetic field confinement system, and its confinement scaling law has been mostly established. By comparison of the attainable confinement performance (such as the energy multiplication factor) with the tokamak based on this scaling, it becomes clear that further improvement in confinement is necessary for the helical system to have its confinement exceed that of the tokamak system (Attachment 4). In the helical system, there is room for further optimization in view of variety in the magnetic configuration originating from its three-dimensional structure. Giving emphasis to the research on LHD, the performance improvement of the helical plasma and the optimization research on the magnetic configuration should be advanced through cooperation with world helical research. And it is necessary to identify the direction of helical-type reactor core plasma from the various helical magnetic configurations, and to advance research toward the comprehensive understanding of torus plasma by learning similarities and differences with the tokamak.

Laser system: The laser system has significance as a subject of fusion research and development fundamentally different from magnetic confinement system. In the fast ignition laser fusion concept, a part of the fuel compressed to high density is heated with laser initiating fusion ignition. Then alpha particles generated in the ignited region sequentially heat the fuel till the whole fuel is burned. The objective is to get the prospect for high energy multiplication factor more than 100, which is necessary for the eventual laser fusion reactor. In order to prove the fast ignition concept, the following step-by-step process is necessary: (1) Demonstrate the heating of fuel to the ignition temperature using a relatively small-scale device; (2) Demonstrate ignition and burning by heating a fuel larger in size than the range of alpha particles using a large-scale device.

Considering as above the change in the evaluation and the promoting status of the tokamak and other systems, regarding research on systems other than tokamak, it is necessary to promote the research suitable for these systems independently of the tokamak research.

The ongoing LHD Program and FIREX Program shall be continued with emphasis on the academic research at universities and NIFS. And based on their progress, the evaluation of their potential to become a fusion reactor shall be carried out at an appropriate time, and the plan of the Programs thereafter shall be considered.

3.2.2 Enrichment of Fundamental and Basic Research on Fusion

Academic research on nuclear fusion deploys researches widely in diversified fields and progresses through the systematization and generalization of their achievement. It is needless to say that acquiring new knowledge through the research

on ITER and other large devices such as tokamak, helical and laser is important. But regarding the basic experiments on fusion plasma science in universities, etc., we need to continue the researches on small-to-medium-sized experimental plasma devices based on novel ideas, which can realize plasma regimes unobtainable in large devices. For example, researches on a spherical torus or a new type of inner conductor system, development of new diagnostics, researches on the control of plasma, heat and particles, and so on.

Also, theoretical and simulation studies, which make full use of the large-scale simulation technology and the information technology, shall be promoted to enrich the basic science on the nuclear fusion plasma.

In the field of fusion technology as well, it is necessary to advance researches in accordance with the international joint research program, etc. aiming at the development of material. Also, basic researches on material and reactor engineering based on novel ideas using unique small-to-medium-sized engineering research device remains important and should be enriched.

3.2.3 Generalization as Academic Research

In the developmental research on fusion reactor, where various elements are integrated in a complicated manner, it is important to reduce research achievements to elements, and systematize and generalize them as academic entities. On the other hand, we can expect a creation of new academic field by synthesis of the reduced basic academic elements.

To be more specific, various research achievements of ITER, the centralized joint research devices of tokamak, helical and laser, unique small-to-medium-sized plasma devices, theoretical researches using large-scale simulation, etc., and the developmental and basic research on material and reactor engineering, can contribute through the establishment of systematized scientific principle in nuclear fusion research to the science, technology, and academic research of many fields, such as plasma physics, space/cosmic plasma physics, applied plasma science, computational science, material science, nuclear engineering, electric engineering, high energy density science in extreme state, and the most-advanced ultra high intensity laser technology. And, the understanding of the characteristics of fusion plasmas as a complex system, can make substantial contribution to the complexity science[*147] whose importance is growing recently. The academic research at universities, etc. directed toward the establishment of such systematized scientific principle should further be promoted.

3.3 Education and Training, and Sustainable Development of Fusion Base Technology

3.3.1 Education and Training

In fusion research, which requires long periods of time before realization, continuous development of human resources under advanced professional education and the world cutting-edge research environment is a requisite for the success of large international projects such as ITER Project, and for our country for playing a leading role in it.

As stated in the Fusion Research WG report in January, 2004, in the education and training, it is necessary to provide various attractive research opportunities for excellent

young researchers, and to design organizations and systems, which make active use of shared facilities and collaborative researches, and allow the active exchange and mobilization of research and researchers. In universities and so forth, more expansion of the bidirectional joint research is needed. And in non-university research institutes, taking into account their efforts to provide high-level professional training and education, it is necessary to consider a new framework for professional training and education based on the strengthened collaboration and cooperation with universities and NIFS.

Furthermore, it is necessary to seek ways of securing human resources that underpin the development of the base technology centered on the industrial world, and to produce excellent talented people from the fusion community who support the nation built on the platform of scientific and technological creativity with broader perspective.

3.3.2 Sustainable Development of Fusion Basic Technology

The fusion energy technology will be able to become one of the basic industries of our country, if it is put into practical use in the future. Especially, it is important to succeed and develop technologies accumulated in the industrial world. For this objective, continuous design and manufacturing of experiment devices that require leading-edge technological development are indispensable. Furthermore, it is necessary to make active application of the high technologies developed in the nuclear fusion research to other fields.

3.4 Promotion of International Collaboration

In the future fusion research and development, it is important to promote the existing multi-lateral cooperation, such as IEA and IAEA, and bi-lateral cooperation, such as Japan-US, more actively from the viewpoint of international contribution and reduction of development risk and cost. Since the request for our country's leadership in the science and technology area is growing, it is desired to make effective use of our potential to research and develop on the nuclear fusion and to promote international cooperation on our own initiative. In particular, we shall take an active part in the International Tokamak Physics Activities (ITPA), which support the physical aspect of ITER, in addition to the participation in ITER, aiming at making leading contribution to the support research for the ITER Project.

Furthermore, it is important to strengthen international cooperation as a member of Asia with South Korea and China, who are recently making remarkable progress in the field of nuclear fusion in the construction of the superconducting tokamaks KSTAR and EAST, and with other countries.

3.5 Balance among various Projects and Check and Review

3.5.1 Balance in Project Implementation

As stated in Section 3.1.4, in the Third Phase Program, broad range of programs, including the ITER Project as the central device, should be implemented in a balanced manner. In promoting the Program, efficient and effective allocation of research and development resources should be made based on "Selection and Concentration" strategy, and the following points should be considered.

The central device of the Third Phase Basic Program, ITER, is expected to start its operation around 2015 and achieve its technological objective in the beginning of 2020s. For the firm achievement of the objective, our country should carry out the duty it bears.

From the viewpoint of realizing the fusion energy, by the time the technological objective of the experimental reactor is expected to be achieved, we need to carry out in parallel, the conceptual design of DEMO, developmental research on fusion core plasma, material and fusion technology toward the development of DEMO, research on social and environmental safety, and theoretical and simulation research, and make appropriate allocation of resources.

It is important to maintain close cooperation between the different hierarchies of academic research and developmental research, and make appropriate allocation of research resources between the developmental research, which aims at the early realization of fusion, and the academic research, which forms a principal pillar of the nuclear fusion research.

3.5.2 Check and Review

Comprehensive check and review on the progress of whole fusion research and development is to be carried out in every about 5 years with the participation of members from other fields, such as energy, environment, nuclear energy, and from private-sector businesses.

As for the developmental research aiming at the early realization of the fusion energy, the Atomic Energy Commission must judge the propriety of switchover to the DEMO stage before the termination of the Third Phase Program, based on the check and review on the progress of necessary developmental research. And in the course of this judgment on the propriety of switchover to the DEMO stage, it is important to perceive the progress of fusion research and development comprehensively including other systems. And it is also important to give serious consideration to commercialization of fusion and to get the participation of private-sector business.

As for the academic research on the nuclear fusion, check and review shall be carried out with central focus on the helical system and the laser system, which are its centralized programs, and the direction of the research development shall be determined at an appropriate time.

In order to carry out these various researches and developments in an organized and effective manner, appropriate action shall be investigated as necessary, apart from the comprehensive check and review, based on the proposals of the Council for Science and Technology or a wide range of opinions from scientists of academic societies, public, and industries, with full grasp of the progress.

Chapter 4 Promotion of Fusion Research and Development

Based on the basic approach described in Chapter 3, developmental research toward a fusion DEMO reactor and fusion relevant academic research should be advanced in order to aim at the early realization of fusion energy. For this purpose, the policies in the Third Phase Program are clarified as follows:

4.1 Developmental Research in Tokamak

In order to establish a technical basis for a tokamak-type DEMO reactor, promote developmental research on the experimental reactor ITER, research on the improvement of tokamak, research on fusion technology, research on fusion reactor system, tokamak theory and simulation research, and the research on social and environmental safety.

4.1.1 Developmental Research using ITER

Through the participation in the ITER Project, advance the technological development on fusion burning plasma control and fusion technology, and achieve the following technological development objectives. Also, observing that ITER has advanced functionality as a fusion energy system, carry out research and development for the establishment of technical basis for fusion core and fusion technology toward the realization of DEMO reactor, by the effective use of ITER facility.

(1) Fusion Burning Plasma Control

As for fusion burning plasma control, aim at the realization of following goals. To achieve these goals, get a better understanding on physical processes such as, confinement of ITER burning plasma, stability, current drive, and heat and particle control by divertor. To carry out these research and development, advance plasma diagnostics and develop feedback control technology using these diagnostics. Also, based on these, promote researches relevant to the burning control and particle control technologies for DEMO reactor.

Burning plasma control in the self-ignition region: The goal is to sustain the energy multiplication factor exceeding about 20, which corresponds to the self-ignition region, and aim at demonstrating the controllability of fusion burning plasma using ITER. Thereby fusion output power should be less than about 500 MW, and the duration of inductive operation should be longer than several 100 seconds.

Burning plasma control in a long-duration steady state plasma: In order to establish a basis for continuous burning plasma anticipated in DEMO reactor, sustain burning plasma for a long period (more than about 1000 seconds) with a steady state operation method combining bootstrap current and non-inductive current drive. The goal is to sustain the energy multiplication factor of more than about 5 with fusion output power of less than about 500 MW.

(2) Development of Fusion Technology

Elemental technologies: Establish a technological basis for manufacturing major components and systems, by sharing the device manufacturing of the experimental reactor (ITER). Also, demonstrate the overall performance of heating and current drive systems and basic diagnostic systems, and develop advanced diagnostic systems.

System Integration technology: Establish technological basis for fusion a reactor as well as its safety and reliability, through the construction and operation of ITER, by confirming and validating step-by-step its performance as an integrated system in the following aspects: i) Performance demonstration of superconducting coil under plasma discharge and radiation conditions; ii) Establishment and advancement of remote maintenance technology for components which undergo radiation environment and operating history; iii) Demonstration of treatment technology and safety handling technology of tritium fuel; iv) Operation control technology of tokamak components and plant system conform to plasma operation; v) Performance demonstration of in-vessel components conform to heat, particle and electromagnetic loads, and of fuel injection, evacuation and heat removal systems.

Demonstration of small-scale power generation technology: Considering that the test of power generating blanket in ITER is in principle an individual activity of each party, based on our country's proposal, etc., install test power generating blanket, conduct tritium production and recovery tests, perform breeding, multiplier, and structural material tests, and extract high-temperature heat. Also aim at realizing a proof of principle test of small-scale power generation in cooperation with ITER parties.

(3) Promotion of ITER Project

In carrying out the research and development of the international collaboration, the ITER Project, as our country's experimental reactor project, establish a framework for its implementation under international agreements and a framework for its domestic support.

Implementing framework for ITER Project: Although it is under negotiation with the countries concerned at present, the framework is expected as follows:

The entity established under a Joint Implementation Agreement is an international organization qualified as a legal personality (tentative name: ITER International Fusion Energy Organization (ITER Organization)), and implements the construction for about 10 years, the operation and utilization research for 20 years, and the removal of radioactive materials for about 5 years after decommissioning. Thereafter, ITER facilities are transferred to an organization of a host party and undergo dismantlement, disposition, and reposition. ITER Organization is composed of a Council as the highest legislative organ which consists of representatives of participating parties, a number of Advisory Committees and Auditors supporting the Council, the Director-General responsible to the Council for its execution of the ITER Project, and the Staff under the command of the Director-General. Each participating party will establish a Domestic Agency, which delivers party's in-kind contribution. Also a staff will be dispatched to ITER Organization through the Domestic Agency.

Our nation will achieve the technical objectives of the experimental reactor project of its own through ITER, as a participating party of ITER Organization that is the

implementing organization of ITER Project. During the construction phase of ITER, our Domestic Agency delivers components as in-kind contribution to ITER Organization. Furthermore, contribute to construction of ITER through the dispatch of staff to ITER Organization and aim at obtaining system integration technology. In the experiment/operation phase, secure opportunities for domestic researchers to participate in ITER Project so that the maximum outcomes are returned and accumulated in our country.

Cooperation of ITER and domestic research: In order to lead ITER Project to a success and to make best use of its achievement in the fusion research and development of our country, establish following organized framework for cooperating with the following domestic fusion research.

In promoting ITER Project, carry out the construction and experimental operation under the mutual cooperation between Domestic Agency, universities and NIFS, and industries. Moreover, reinforce and extend the Fusion Forum[*149], etc., and promote broad understanding of ITER Project and fusion research by scientists and public, so as to gain their cooperation and support.

Furthermore, make effort to run ITER so that the research achievements in our country are reflected appropriately in ITER Project, and establish a framework for the researchers of universities, etc. to participate in ITER Project.

The research environment for bring up young people continuously, who take an active part in ITER and support ITER, has been developed by the centralization of the domestic research facilities. Through the achievements of advanced research by utilizing these, make efforts to take a lead in international activities such as International Tokamak Physics Activity (ITPA) and ITER research. Make an arrangement so that ITER support researches at the facilities devoted to these collaborative projects and collaborative researches can be conducted more effectively by mobilizing the human resources of JAEA and universities and NIFS.

4.1.2 Research on Tokamak Improvement

Toward the early realization of fusion energy, promote the national centralized tokamak facilities program for the development of high-beta steady state operation method and ITER support research, aiming at advancing the improvement of tokamak system with national standpoint and making contribution to ITER Project. Thereby, establish scientific basis of fusion core plasma necessary to decide the construction of DEMO reactor (Attachment 16)

(1) Development of High-Beta Steady State Operation Method

In order to establish scientific basis of DEMO reactor for which high output power density is required, perform the research and development focused on long-duration stable maintenance of high-beta (β_N=3.5-5.5) plasma. Its issues are the control of high-beta steady state operation and the control of divertor heat and particles by means of plasma shape control, feedback control, and profile control. In addition, demonstrate long-duration stable maintenance of high-beta steady state plasma aiming to improve the operational reliability while mitigating and avoiding disruptions.

(2) ITER Support Research

Contribute to ITER-relevant international physics activities so as to improve further the ITER performance and expand the operational margin of ITER. To be more specific, conduct researches on plasma confinement, plasma stability, plasma current drive and steady state operation method, divertor heat and particle control, and the confinement of high-energy particles, in a long-duration regime exceeding various physical time constants.

(3) National Centralized Tokamak Project

While conducting preparatory researches in (1) and (2) using JT-60, convert JT-60 to the following national centralized tokamak and contribute to the early realization of fusion energy.

The national centralized tokamak is a superconducting device with break-even-class plasma performance, ensuring the maximal maneuverability and flexibility in plasma aspect ratio, plasma shape controllability, and feedback controllability. Its goal is to establish basic technologies on power ascension and operational reliability necessary in the later half of DEMO reactor operation period. More precisely, aim at sustaining a high-beta (normalized beta value: β_N=3.5-5.5) non-inductive-current-driven plasma required in the later half of DEMO reactor operation period for more than about 100 seconds. Also, advance the improvement of heating and current drive devices in order to establish a basis for reactor operational reliability, and aim at a stable operation of high-beta steady state plasma for duration longer than several hours.

4.1.3 Development of Fusion Technologies for DEMO

Regarding technological development toward DEMO reactor, advance technological development of breeding and power generating blanket, development of structural materials, the International Fusion Materials Irradiation Facility project, improvement of superconducting and heating devices, etc., and safety research are improved. Thereby, establish technological basis necessary to decide the construction of DEMO reactor.

(1) Technological Development of Breeding and Power-Generating Blanket

As for power-generating blanket, its function test conducted on ITER is positioned as an important milestone. Therefore, in order that the function test be available from early stage of ITER operation, launch in-pile test[*150] in fission reactor and ex-core engineering test. Also, carry out irradiation test of blanket materials, neutronics test[*151], and develop tritium recovery and processing technologies, etc. During low-fluence DT experiment phase of ITER, acquire engineering data useful to decide the construction of DEMO reactor through the demonstration of tritium breeding and recovery functions and heat removal and power generating functions. Moreover, carry out steady research and development targeting more efficient power-generating blanket.

(2) Development of Structural Materials

Regarding structural materials, continue the development of low activation ferritic steel, which is a principal candidate material. Acquire its heavy irradiation data[*152] through irradiation test using fission reactor, etc. (As a level to gain an understanding of irradiation effects, and to evaluate a life time of about 2 years in DEMO reactor, irradiation damage of larger than about 80 dpa is required), and determine the material to be used in the irradiation test at high energy neutron irradiation facility. Moreover, make steady efforts in the development of advanced structural materials maintaining consistency with the development of high-performance power-generating blanket.

An accelerator neutron source employing d-Li stripping reaction[*153] is deemed to be the most suitable neutron source that has a potential of reproducing a neutron irradiation environment similar to fusion reactor without difficulty. The International Fusion Materials Irradiation Facility (IFMIF) (Attachment 17) is a high-energy neutron irradiation facility based on this concept. Regarding the engineering design activity of IFMIF, if there is sufficient prospect that other entity will construct the main body of the facility and that a certain amount of our participation in the irradiation test at IFMIF main body is ensured by our country's contribution to the engineering design activity, then start the activity under international collaboration and contribute to the establishment of technological basis.

(3) Development of High Performance Superconducting and Heating Devices, etc.

Toward the DEMO reactor, increase the magnetic field of superconducting magnets, improve heating and current drive systems (increase beam energy of neutral beam injection system, increase frequency of electron cyclotron heating system) and so forth.

(4) Technological Development Research on Safety

The DEMO reactor is a system which self-supplies tritium fuel by means of its breeding blanket and drives a high-temperature and high-pressure medium containing tritium. It involves a lot of future technological development issues such as: development of tritium processing intended for a large volume medium[*155], safety management technology of tritium[*156] inside and outside the plant, and improvement of measuring technology. On the other hand, in addition to the development of engineering safety technology, safety securing requires the establishment of engineering technological basis for the standardization of inspection system, etc. to ensure technical standards and soundness. To this end, establish technological basis of tritium and engineering safety researches.

(5) Technological Development on Radioactive Waste Reduction and Processing

Although a fusion reactor does not produce high-level radioactive waste, it produces a relatively large amount of radioactive materials resulting from the replacement of components and the decommissioning of the reactor. Therefore, targeting the DEMO reactor and beyond, explore methods to reduce low-level radioactive materials originating from the reactor main body (vacuum vessel, shield, and superconducting coils, etc.) and conduct technological development for them.

And hereafter conduct steady technological development on the efficient use of resources in a fusion energy system and on dismantling waste disposition, such as: the reprocessing technology of blanket material including reuse of lithium, decontamination technology, recycling technology of various materials, dismantling technology, and reduction of radioactive waste and its disposal cost.

4.1.4. Research on Fusion Reactor System

(1) Conceptual Design of DEMO

Conduct conceptual consideration on a tokamak-type DEMO reactor that has economical prospect for the commercial use of fusion energy and has enhanced safety and environmental acceptability. Reflect it in the engineering development program of fusion core and fusion technology. Carry out conceptual design based on the progress in the engineering development of fusion core and fusion technology.

In the course of conceptual consideration of the DEMO reactor, examine the overall target performance of the plant (construction cost, output scale, operation characteristics, operating rate, safety characteristics, fuel breeding performance, waste processing, etc.). And to realize it, conduct conceptual design of total plant, taking into account safety equipment, construction schedule, maintenance technology, and processing and disposition of waste. In the course of conceptual design, reflect the results obtained in other research and development in it as necessary, and promote the participation of private sector aiming at commercial plant.

(2) Overall Assessment of Fusion Energy System

From the viewpoint of maximizing the contribution of fusion energy to the energy and environmental issues on a global scale, we need to establish a concept of more attractive and marketable commercial reactor and its energy system, reflect it in the research and development in the DEMO reactor phase, and lead to the commercial viability of fusion energy. For this purpose, evaluate the acceptability of nuclear fusion to society and energy system from a broader perspective, and based on this, conduct design study on fusion plant and energy system, and develop design evaluation methodology. As a part of this study, carry out a system research on multi-purpose utilization of energy, etc.

4.1.5 Tokamak Theory and Simulation Research

Develop simulation technique based on the leading-edge computational science technology and advance theoretical research on nonlinearity and open system plasma[*156], in order to understand the dynamic characteristics and to take control of the ITER burning plasma which has characteristics of multi-hierarchical, complex, and compound system, and of a high-beta high-bootstrap-current plasma which accompanies structure formation.

Develop an integrated simulation code as a tool for integrating experiment data of ITER and its supporting devices and for designing the fusion core plasma of tokamak-type DEMO reactor. Also, carry out researches on tokamak theory and simulation, focusing on the research and development that can realize the numerical experiment of tokamak[*157] based on their underlying first principle technique.

4.1.6 Social and Environmental Safety Research

Conduct basic researches necessary to ensure the safety of fusion energy and its acceptability to environment and society, from the viewpoint of environment, society and public, in case of building the DEMO reactor in our country. Specifically, establish methodology and databases on manufacturing fusion plant, technical standards for inspection, and safety assurance and evaluation. Moreover along with this, investigate on the explanation to public of potential risk that fusion has, and on the social system that accepts fusion energy and handles it. Also, launch comprehensive researches on fusion safety in collaboration not only with the conventional fusion researchers who study on such as dynamic behavior, biological influence, and medical epidemiology of tritium released from the fusion plant, in the environment and ecosystem, but also with various broader fields such as nuclear power, energy, environment, biology, medicine, and society. In addition, investigate on disposal methods of radioactive wastes and establish the concept of overall safety assurance system inclusive of life cycle.

4.2 Academic Researches in Fusion

For academic research relevant to fusion, advance the centralized large-scale project research, and enrich fusion basic research by ensuring various studies based on pioneering and germinating researches in the field of plasma experiment, theory and fusion technology. Also systematize fusion science and technology as an academic entity.

4.2.1 Research in Helical Device

Promote research on LHD aimed at gaining a prospect for fusion reactor and universal knowledge of turbulence transport and confinement improvement, etc. Also, obtain knowledge necessary for steady maintenance of high-beta plasma, study on the divertor, and demonstrate steady-state operation. The knowledge of fusion core plasma and fusion technology of a helical device has a lot in common with that of tokamak. Thus, gain systematic understanding of its similarity and difference with tokamak.

By exploiting the merit of helical plasma that electric/magnetic structure in plasma can be externally controlled, conduct detailed studies on the relation between the electric/magnetic structure and transport/MHD stability. Establish academic basis related to the confinement of fusion core plasma.

Considering the diversity of magnetic configuration originating from its three-dimensional structure, carry out research on the optimization of helical magnetic configuration by comparison with domestic and foreign helical devices from the aspects of confinement, MHD stability and steady-state maintenance.

Furthermore, carry out design study on helical-type steady-state fusion reactor in order to clarify the prospect of helical device for fusion reactor.

Based on the evaluation of these research achievements, etc., made by the Council for Science and Technology, determine the direction of research by helical devices.

4.2.2 Research in Laser Device

Promote research aimed at the realization of ignition and burning plasma by a laser fusion system. For this purpose, carry out the FIREX first-phase program with Osaka University as its center. The objective of this program is to heat fusion fuel compressed by the existing GEKKO-XII laser up to the ignition temperature of 50 to 100 million degrees centigrade, by a newly equipped ultra-intense short-pulse laser. The issue in the first phase is whether or not the highly efficient heating necessary to achieve the ignition temperature is possible (Attachment 18).

Based on its achievement, decide whether it should be advanced to the second-phase program aiming at the realization of ignition and burning, or not, taking into account the assessment of the Council for Science and Technology, etc. The objective of the second-phase is to demonstrate ignition and burning with the fuel whose size is larger than the range of an alpha particle, and to get a prospect for the realization of high energy-multiplication factor required for a laser fusion reactor. The FIREX program is to be promoted in enhanced cooperation with NIFS.

Moreover, carry out the design studies of fast ignition laser fusion reactor, in order to clarify the prospect of fast ignition method for a laser fusion reactor.

4.2.3 Fundamental and Basic Fusion Research

(1) Basic Experiments of Fusion Plasma Science

Utilize and improve small-to-medium-sized devices developed thus far. Promote elemental researches common to plasma confining systems such as on plasma stability, transport physics, interaction between wave and particle, plasma-wall interaction, and atomic and molecular process, and researches on high energy density science such as relativistic and quantum plasma physics.

Moreover, in view of promoting the establishment of systematized academic science, reinforce the basic research on fusion science conducted on small-to-medium-sized devices exploring new possibility based on original ideas. Also, promote fundamental researches related to plasma diagnostics.

(2) Theory and Simulation Research

Fusion plasma exhibits diverse complex phenomena as nonlinear and far-nonequilibrium medium[*158]. For example, autonomous structural formation[*159] results from the nonlinear and far-nonequilibrium processes of dissipation that occurs in the turbulence of various temporal and spatial scales. By maintaining close cooperation with academic fields in which the similar physical process plays an essential role, such as cosmological and astronomical fields, condensed matter physics and life science, advance theory relevant to fusion plasmas and develop simulation technique based on the leading-edge computational science technology, and promote the development of plasma physics. Take an active role in leading the material science of the 21st century in which plasma, covering from basic science to industrial application, plays an essential role.

(3) Fusion Technology Development for Laser System

For realizing laser fusion, it is necessary to establish elemental technology of laser

for fusion reactor and to make the reactor design viable, in addition to establish the fusion core plasma physics performed in FIREX project. Regarding the laser for fusion reactor, develop a high-power semiconductor-pumped solid-state laser whose laser output is close to that of a planned single module. Develop also the wave front combining technology to integrate multiple modules. Regarding the design of laser fusion reactor, conduct it in cooperation with researchers in magnetic confinement fusion and fusion technology.

(4) Basic Research on Materials and Fusion Technologies

Regarding advanced and basic researches on fusion technology in universities and NIFS, promote exhaustively and comprehensively the research and development on advanced neutron irradiation resistant structural materials, plasma facing materials, highly-functional tritium breeding materials, and various high-performance functional materials, fusion technological development specific to helical systems, conceptual design and system research of advanced fusion reactor system, and basic research in a broad area of fusion technology including the relevant elemental engineering research. Moreover, enrich the database and systematize the design method for the design of fusion reactor, examine the research and development issues of new blanket concept for fusion reactor, and generalize and universalize these achievements.

4.3 Sharing of Fusion Research and Development

Atomic Energy Commission (AEC): The fusion research and development in our country is promoted as a part of the Nuclear Energy Policy under the basic policy (the Third Phase Basic Program of Fusion Research and Development) laid down by the Atomic Energy Commission. The Atomic Energy Commission will continue to investigate and deliberate the basic policy relevant to fusion research and development such as the revision of the basic policy for transition to the fourth phase, and verification of the check and review carried out by the Ministry of Education, Culture, Sports, Science and Technology, etc.

Ministry of Education, Culture, Sports, Science and Technology (MEXT): The MEXT plans and implements policies and measures relevant to fusion research and development, based on the basic policy laid down by the AEC, and conducts check and review on the fusion research and development at the Council for Science and Technology, etc.

Japan Atomic Energy Agency (JAEA): The independent administrative agency, JAEA, is in charge of playing the role of central institute for the developmental research on tokamak system. More specifically, it is assumed to take the role of core institute for conducting active cooperation with ITER Project, and promoting domestic tokamak fusion core plasma research, fusion technology, theory, simulation study, conceptual design of DEMO reactor, and elemental technological development, in collaboration with universities, NIFS and industries. Also, it bears the role of offering its research facilities for the cooperative projects and collaborative researches with researchers of universities and NIFS.

National Institute for Fusion Science (NIFS): As an institute of Inter-university

Research Institute–National Institutes of Nature Sciences, NIFS is expected to play the role of promoting the science of fusion plasma and its applied research, conducting academic research using LHD, theoretical and simulation researches, collaborating with the laser fast ignition program centered at Osaka University, and coordinating fusion technological studies at universities.

Universities, etc.: Regarding universities, even after their turning into independent administrative entities, promotion of academic research and education of students are positioned as their main pillar. They are expected to carry out the establishment of diverse academic research bases, using small-to-medium-sized devices, under their independence and autonomy. Moreover, they are expected to strengthen the cooperation with NIFS and JAEA, take an active part in the research using the centralized joint devices, contribute to fusion research and development by reinforcing the academic research basis of fusion science and technology and by educating students, through investigation and evaluation of a wide range of fusion reactor systems including tokamak and through basic research on fusion technology. Furthermore, contribution to the conceptual design of DEMO reactor is expected in the investigation of a broad range of fusion reactor system conducted at universities, etc. Other research and development organizations are expected to contribute to basic research and development of fusion.

Industries: In order to establish manufacturing technology for DEMO reactor and to pursue the economic rationality, industries are expected to strive for accumulating and improving the manufacturing technology of fusion devices with its focus on ITER. Considering the importance of utilizing, maintaining and developing the knowledge and technology of industries in future research and development, it is necessary to promote research and development so that we can get active participation by industries in a long-term research and development program. Regarding the design of DEMO reactor and investigation on the commercialization of fusion reactor, participation by industry-related organizations, manufacturers, and power industry is anticipated.

International Cooperation: Although the above sharing of roles in research and development is described with domestic activities in mind, it is needless to say that international cooperation is necessary and important. It is important to continue the active planning of programs to promote multi- or bi-lateral cooperation and their effective utilization.

Shared use of facilities, collaborative researches, and cooperation: In fusion research and development, whose promotion has been led by universities, institutes, research organizations, and industries, with the understanding of shared role of each, mutual collaboration and cooperation is indispensable. Therefore, it is necessary to further reinforce the shared use of facilities and collaborative researches. In universities and NIFS, a new type of bidirectional collaborative research has been developed principally by an inter-university research institute, NIFS, in which researchers of universities, etc. can conduct collaborative research relatively freely using devices of universities, etc. or carry out an exchange of researchers. We need to continue further reinforcement of such bidirectional collaborative research.

On the other hand, research organizations such as JAEA are required strongly to promote new cooperation and collaboration including the improvement of frameworks

for joint planning and collaborative research.

Furthermore, regarding research for ITER and the DEMO reactor, a whole national cooperative framework including industries is needed. We also have to consider the way of collaboration and cooperation from such overall perspective.

4.4 Assignment of Talented Persons and Message to Society

Although fusion research population was increasing gradually in the past 20 years, it starts to be on a downward trend recently. Similarly, although the number of graduated students increases, the ratio of those remaining in the fusion field is diminishing (exemplified in Attachment 19).

It is imperative to carry out balanced cultivation of human resources who are to lead fusion research and development in future. For that purpose, in addition to research education in educational institutions such as universities, it is extremely important for institutes and industries to conduct practical education. Therefore, we have to build a framework for realizing this into the fusion research and development system of our country.

Reinforcement of Research Personnel: In order to make a large-scaled international project such as ITER Project a success and for our country to take a leading role in it, it is crucial to foster constantly talented young scientists who can take international leadership. In particular, programs such as the fellowship of Japan Society for the Promotion of Science and the postdoctoral fellowship of JAEA have been improved and expanded in recent years, and functioning effectively in ensuring opportunities for many young researchers to make an active role. Further expansion of such frameworks is required in the future. However, it's hard to say that the opportunities for continuing activities in the field of fusion are sufficiently ensured. Therefore we have to secure the opportunities for enabling continuous researches.

Improvement of Research Environment: In order to promote fostering of human resources based on advanced professional education, it is necessary to arrange environment in which a young researcher capable of taking leadership can conduct cutting-edge research. More specifically, we can take as an example of such environment, direct involvement of worldwide scale large experiment devices, and participation in germinating/innovative researches on flexible small-scale devices that universities, etc. are good at. In fostering human resources, it is important to provide this kind of various research opportunities to talented young researchers.

Efficient Utilization of Shared Facilities and Research Collaboration: In future human resource development, we have to set up proper competitive environment so that research and education are optimized, and need to arrange organizations and systems that enable active exchange and mobilization of researches and researchers, by efficient utilization of shared facilities and research collaboration. Moreover, in order to promote fostering of human resources through advanced professional researches conducted in research institutes such as JAEA, the expansion of collaborative graduate studies program and the reinforcement of visiting researchers are required.

Massage to Society: For the continuous evolution of fusion research and development,

it is important to gain public understanding of the meaning and safety of fusion energy. And in the training of successors, we need to make the field of fusion such an attractive field that students can accept it continuously in future. Also from now on, it is imperative to devise countermeasures to issues such as declining birth rate, and declining popularity of science. Fusion participants should never neglect efforts for that. In view of enhancing understanding of the long-lasting fusion research, it is also important to promote broad participation of scientists and public in ITER Project and fusion research at Fusion Forum, etc.

4.5 Global Structure of Research and Development and the Road to Utilization

A development strategic map of the above described contents of the Third Phase Program, which aims at the demonstration of the scientific and technological feasibility, is shown in Attachment 20, in relation to the research and development of the Second Phase Program, which aimed at the demonstration of the scientific feasibility of fusion, and the Fourth Phase Program, which aims at the demonstration of the practicality of fusion energy by DEMO reactor.

4.6 Check and Review Items and Transition Condition to the Next Phase

Summarizing Section 3.1, the transition condition to DEMO reactor phase is that the followings are completed: 1) demonstration of burning control in self-heating regime on the experimental reactor; 2) realization of non-inductive steady state operation with $Q \geq 5$ on the experimental reactor; 3) establishment of integration technology on the experimental reactor; 4) establishment of high-beta steady state operation method to get a perspective of economic viability; 5) development of materials and fusion technology relevant to DEMO reactor; 6) conceptual design of DEMO reactor. Moreover, in deciding the changeover to DEMO phase, it is important to gain the prospect for its commercialization and to get the participation by private sectors, as well as to understand the overall progress of fusion research and development including other methods.

For early realization of fusion energy, it is necessary to advance research and development on fusion core, fusion technology, and reactor design, in parallel with the experimental reactor project. Attachment 21 shows the performance goal in the interim phase (about 10 years after) and the technical requirements (draft) for changeover to the following final phase (DEMO reactor phase), aiming at the early realization. In promoting the program, it is preferable to refer to this table and implement policies. In that event, it is indispensable to make effective and efficient allocation of resources based on the policy of "selection and concentration".

Reference

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[6] Report on Long-Term Energy Supply and of Demand and Feasibility Study of Alternative Energy Sources
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[10] On Safety for ITER, (November 28, 2003, Nuclear Safety Division, Science and Technology Policy Bureau, Ministry of Education, Culture, Sports, Science and Technology)
http://www.mext.go.jp/b_menu/public/2003/03111001/001.htm
[11] On Safety for ITER (August 6, 2001, Nuclear Safety Commission)
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[12] On Safety Regulation for ITER (June 3, 2002, Nuclear Safety Commission)
http://www.nsc.go.jp/anzen/sonota/kettei/20020603.pdf
[13] Future Direction of the National Fusion Research, (January 8, 2003, Working Group on Fusion Research, Council for Science and Technology, Ministry of Education, Culture, Sports, Science and Technology)
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Appendix 1. Characteristics of Fusion as the Energy Sources [5]

Fusion energy has a lot of merits from the viewpoints of resource abundance, supply stability, environmental acceptability, safety, nuclear proliferation resistance, and processing and disposal of radioactive wastes. It has also possibility of getting high social acceptability as humankind's limitless energy source.

Resource abundance and supply stability: Because deuterium and lithium, which are feedstock and fuel of deuterium-tritium fusion reaction, exist abundantly in seawater, and there already exist productive facilities capable of producing several hundreds tons of deuterium a year by means of the isotope exchange method, and because the technology for collecting lithium from seawater is already developed, they can be supplied stably as energy sources of our country surrounded by sea. As for materials such as niobium and beryllium that constitute a fusion reactor, we can secure sufficient amount of resources, and their distributions are not localized. Moreover, unlike renewable energy, fusion has few issues of geographical requirements and output stability, and is excellent in supply stability.

Environmental acceptability: It is expected that a fusion reactor plays an important role in the view of preserving global environment, since, like a fission reactor, it does not emit carbon dioxide and nitrogen oxide, etc., which are regarded as causative substances of global environmental problems such as global warming, and acid rain, in the course of power generation.

Safety: In a fusion reactor, the total amount of fuel that exists in reaction area is quite small. Therefore, even when some trouble occurs, we can stop fusion reaction promptly by stopping fuel supplies. Also, since there is no reaction accelerating mechanism that goes out of control, it can be said that a fusion reactor has in principle high intrinsic safety. Moreover, it has a feature that its potential radiation risk index (the ratio of mobile radioactive material quantity to the legal concentration limit) is as low as about one thousandth of that of a fission reactor.

Nuclear proliferation resistance: The property of having resistance to the spread of nuclear weapons. Since no uranium/plutonium is used in a fusion reactor, there is no chance of inducing the spread of these feedstocks for nuclear weapons. Moreover, since nuclear fusion requires a temperature of several hundreds of million degrees and is a reaction hard to occur, even if you have deuterium and tritium, you cannot initiate fusion reaction only with them.

Nuclear waste processing and disposal: Since the products of fusion reaction are neutron and helium, a fusion reactor has a feature that it does not produce high-level radioactive wastes that a fission reactor produces. The long-term radiation risk index of low-level radioactive wastes generated by the reaction of feedstocks with high-energy neutrons is lower than that of the ash from coal power plants.

Reference Material 1

Members of the Advisory Committee on Nuclear Fusion (as of October 26, 2005)

Chair:	
Tetsuya Endo	former Vice-Chairman of Atomic Energy Commission (until January 2004)
Masami Fujiwara	former Director General of National Institute of Fusion Science (since September 2005, member before that)
Members:	
Teruo Tamano	former Councilor of Atomic Energy Commission
Tetsuhiko Ikegami	President, University of Aizu
Yuji Ikeda	Director of United Nations Institute for Training and Research (UNITAR)
Sanae Itoh	Professor, the Research Institute for Applied Mechanics, Kyushu University
Masao Ito	Special Counsel of RIKEN Brain Science Institute
Nobuyuki Inoue	Professor emeritus, the University of Tokyo
Makoto Katsurai	Professor emeritus, the University of Tokyo
Hiroshi Kishimoto	former Chief Director of Research Organization for Information Science & Technology (until September 2005)
Masahiro Kuroda	former Regular Director of Keio University
Tomifumi Godai	Councilor of Space Activities Commission in MEXT
Yasuo Shimomura	ITER International Team Leader
Seishi Suzuki	former Director of the PFI Promotion Division in the Committee on Land Development & Housing Policies in Nippon Keidanren
Shuichi Takamura	Professor, Nagoya University Engineering Graduate Course
Masahiro Nishikawa	Professor, Osaka University Graduate School Engineering Graduate Course
Shinzaburo Matsuda	Director General of the ITER management, Japan Atomic Energy Agency
Kunioki Mima	Professor, Director General of Institute of Laser Engineering, Osaka University
Kenzo Miya	Professor, Keio University Graduate School of Science and Technology
Osamu Motojima	Director General of National Institute for Fusion Science, Vice President and Executive Director of National Institutes of Natural Sciences

Reference Material 2

Members of the Technical Working Group of the Advisory Committee on Nuclear Fusion (as of September 2, 2005)

Chair:

Teruo Tamano	former Councilor of Atomic Energy Commission (until July, 2005)
Masami Fujiwara	former Director General of National Institute of Fusion Science (since August 2005, member before that)

Members

Sanae Itoh	Professor, the Research Institute for Applied Mechanics, Kyushu University
Nobuyuki Inoue	Professor emeritus, the University of Tokyo
Makoto Katsurai	Professor emeritus, the University of Tokyo
Hiroshi Kishimoto	Chief Director of Research Organization for Information Science & Technology
Yasuo Shimomura	ITER International Team Leader
Shuichi Takamura	Professor, Nagoya University Engineering Graduate Course
Masahiro Nishikawa	Professor, Osaka University Graduate School Engineering Graduate Course
Shinzaburo Matsuda	Director General of the ITER management, Japan Atomic Energy Agency
Kunioki Mima	Professor, Director General Institute of Laser Engineering, Osaka University
Kenzo Miya	Professor, Keio University Graduate School of Science and Technology
Osamu Motojima	Director General of National Institute for Fusion Science, Vice President and Executive Director of National Institutes of Natural Sciences

Reference Material 3

On the Establishment of Committee on Basic Issue on Fusion Research

April 28, 2003

Technical WG, Advisory Committee on Nuclear Fusion

1. Establishment objective

In June 1992, the Atomic Energy Commission laid down “The Third Phase Basic Program of Fusion Research and Development”, the main objective of which is “the achievement of the self-ignition condition, the realization of the long-duration burning and the foundation of fusion technological basis necessary for the development of DEMO reactor”. Along with this, the Atomic Energy Commission decided to “conduct check and review from a comprehensive viewpoint as appropriate”. Since then, some 10 years have passed. As there is a big change in the status concerning the fusion research and development, such as the progress of the International Thermonuclear Experimental Reactor (ITER) Program, growing social recognition of solutions for global environmental problems and so forth, Committee on Basic Issue on Fusion Research (hereafter, “the Committee”) is established under the Technical WG of the Advisory Committee on Nuclear Fusion, in order to consider the way of carrying out fusion research and development based on this situation.

2. Subjects of investigation and deliberation

Clarify the meaning, necessity and basic form of fusion research and development under the Nuclear Energy Policy, deliberate a basic program of fusion research and development consistent with these, and make a draft report on that.

3. Points of concern

In the course of investigation and deliberation, take note of the following aspects.

(1) Before deliberating the basic program of fusion research and development, conduct check and review on "On the Promotion of the Fusion Research and Development" (May 18, 1992, Council for Fusion).

(2) Clarify the positioning, such as meaning and necessity, of fusion research and development under the Nuclear Energy Policy, by considering the role of nuclear fusion in the solution for energy and environmental problems, and by illuminating its relation to other solutions, etc.

(3) On deliberating the basic program of fusion research and development, present a comprehensive basic program making use of international cooperation such as ITER. Also, give due consideration as well to the basic research which is necessary for the development of nuclear fusion, tactics to foster researchers, and the aspect of cost effectiveness.

(4) On the deliberation of the above subjects, refer to the following materials:

• “Report on Technical Feasibility of Fusion Energy and Extension of the Fusion Program and Basic Supporting Researches” (May 17, 2000, The Subcommittee of the Fusion Council for Fusion Development Strategy)

• Report of Special Committee on ITER Project (May 18, 2001, Special Committee on ITER Project)

• Report on Long-Term Energy Supply and of Demand and Feasibility Study of Alternative Energy Sources (June, 2000, the Committee for Long-Term Energy

Supply and of Demand and Feasibility Study of Alternative Energy Sources)
• Report on Survey of Distribution of Resources for Research and Liability for International Cooperation (June, 2000, the Committee for Survey of Distribution of Resources for Research and Liability for International Cooperation)
• “Future Direction of the National Fusion Research” (January 8, 2003, Working Group on Fusion Research, Council for Science and Technology, Ministry of Education, Culture, Sports, Science and Technology)
• "Deliberation Materials for the Acceleration Plan for the Realization of Nuclear Fusion” (December 5, 2002, Working Group on the Acceleration Plan for the Realization of Nuclear Fusion)

4. Term of establishment

The Committee shall be dissolved, when a draft report on the deliberation results is approved by the Advisory Committee on Nuclear Fusion.

5. Others

(1) Head of the Committee shall be nominated by the chairperson of the Technical WG.
(2) The Committee meeting shall be held in principle open to public.

Other subjects necessary for the management of the Committee will be determined in the Committee meeting.

Reference Material 4

Members of Committee on Basic Issue on Fusion Research (as of August 16, 2005)

Chief examiner:

Masami Fujiwara	former Director General, National Institute for Fusion Science

Members:

Teruo Tamano	former Councilor, Atomic Energy Commission (until July, 2005)
Hiroshi Azechi	Professor, Laser Energy Research Center, Osaka University
Shinsaku Imagawa	Professor, Department of LHD Project, National Institute for Fusion Science
Hisashi Ishitani	Professor, Keio University, Graduate School of Media and Governance
Katsumi Ida	Professor, Department of LHD Project, National Institute for Fusion Science
Takatsugu Uehiro	Supreme Researcher, Head of International Affairs, National Institute for Environmental Studies (from January, 2004)
Yuichi Ogawa	Professor, High Temperature Plasma Center, the University of Tokyo
Michio Otsuka	Chief Engineer, Fusion and Accelerators Department, Hitachi Works, Hitachi,Ltd.
Kunihiko Okano	Supreme Researcher, Central Research Institute of Electric Power Industry
Yoshio Kani	Vice Director General, Oarai Engineering Center, Japan Nuclear Cycle Development Institute
Mitsuru Kikuchi	Deputy Director, Department of Fusion Plasma Research, Assistant Director of Naka Fusion Research Establishment for ITER Planning, Japan Atomic Energy Research Institute
Hideyuki Takatsu	Supreme Researcher, Deputy Director, Department of Fusion Engineering, Japan Atomic Energy Research Institute
Takayuki Terai	Professor, Graduate School of Engineering, the University of Tokyo
Shinya Nagasaki	Professor, Graduate School of Engineering, the University of Tokyo
Tsuneyuki Morita	Director, Social and Environmental Systems Division, National Institute for Environmental Studies (until August, 2003)

Reference Material 5

Progress of Deliberations in the Committee on Basic Issue on Fusion Research

Meeting Ordinal	Date	Agenda
1st meeting	June 25 (Wed), 2003 13:30~15:30	1. On the establishment of the Committee on Basic Issue on Fusion Research 2. On the process of deliberation 3. Others
2nd meeting	July 1 (Tue), 2003 15:30~17:30	1. On the present status of fusion research and development 2. On the basic approach of fusion research and development 3. Others
3rd meeting	July 10 (Thu), 2003 10:00~12:30	1. On the meaning of fusion research and development 2. On the present status of fusion research and development 3. Others
4th meeting	July 16 (Wed), 2003 10:00~13:00	1. On the meaning of fusion research and development 2. On the basic approach of fusion research and development 3. Others
5th meeting	July 25 (Fri), 2003 15:30~18:00	1. On the basic approach of fusion research and development 2. On the present status of fusion research and development 3. Others
6th meeting	July 30 (Wed), 2003 13:30~16:30	1. On the meaning of fusion research and development 2. On the basic approach of fusion research and development 3. Others
7th meeting	August 12 (Tue), 2003 14:00~ 17:00	1. On the meaning of fusion research and development 2. On the basic approach of fusion research and development 3. Others
8th meeting	August 21 (Thu), 2003 14:00~17:00	1. On the basic approach of fusion research and development 2. Others
9th meeting	September 10 (Wed), 2003 13:30~16:30	1. On the meaning of fusion research and development 2. On the basic approach of fusion research and development 3. Others

10th meeting	September 19 (Fri), 2003 14:30~17:30	1. On the basic approach of fusion research and development 2. Others
11th meeting	September 29 (Mon), 2003 14:00~16:00	1. On the basic approach of fusion research and development 2. Others
12th meeting	October 7 (Tue), 2003 14:30~16:30	1. On the basic approach of fusion research and development 2. Others
13th meeting	October 24 (Fri), 2003 14:30~16:30	1. On the meaning of fusion research and development 2. Others
14th meeting	November 12 (Wed), 2003 10:00~12:00	1. On the basic approach of fusion research and development 2. Others
15th meeting	December 9 (Tue), 2003 15:00~18:00	1. On the basic approach of fusion research and development 2. Others
16th meeting	December 16 (Tue), 2003 15:00~17:00	1. On the basic approach of fusion research and development 2. Others
17th meeting	January 6 (Tue), 2004 14:30~16:30	1. On the basic approach of fusion research and development 2. Others
18th meeting	January 27 (Tue), 2004 14:30~16:30	1. On the basic approach of fusion research and development 2. Others
19th meeting	February 24 (Tue), 2004 14:30~16:30	1. On the basic approach of fusion research and development 2. Others
20th meeting	March 23 (Tue), 2004 13:30~15:30	1. On the basic approach of fusion research and development 2. Others
21st meeting	August 16 (Tue), 2004 13:35~15:59	1. On the draft report of the Committee on Basic Issue on Fusion Research 2. Others