The meeting of National Academies of SCIENCES・ENGINEERING・MEDICINE

At General Atomics in San Diego, February 26, 2018

Research and Development Policy on Fusion Energy in Japan

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The University of Tokyo

On behalf of Science and Technology Committee on Fusion Energy
Subdivision on R&D Planning and Evaluation, Council for Science and Technology
In the Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Content

1. **Brief review of Japanese Fusion Energy Policy and Japanese Fusion Activities**

2. **New Policy decided on December 18, 2017**
   - Report on Japan's Policy to promote R&D for a fusion DEMO reactor –
   - Action plan for DEMO R&D -

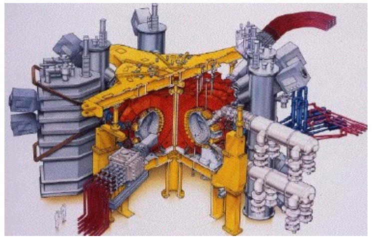
3. **Comments on inquiries from NAS**

Phased Program on Fusion Research and Development in Japan

A phased program : development program proceeds to the next phase on the basis of successful results on the critical path of the present phase concerned.

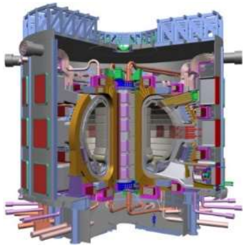
@ 1st Phase Basic Program formulated in 1968
➔ Construction of JFT-2 and -2a devices

@ 2nd Phase Basic Program formulated in 1975
➔ Construction of JT-60 device



@ 3rd Phase Basic Program formulated in 1992
➔ A DT burning experimental reactor

FER has been designed (Domestic Machine)



→ **ITER is assigned to this experimental reactor**

→ **A strategy for DEMO Research and Development has been updated in 2005 and 2017.**

@ 4th Phase Basic Program in 2030s
➔ DEMO

Revised Scenario for Fusion Reactor Development

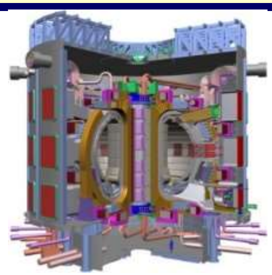
(Atomic Energy Commission in 2005)

The Atomic Energy Commission in 1992 has considered three devices, i.e., Experimental reactor, DEMO and Proto , just similar to Fast Breeding Reactor (FBR) development scenario in Japan.

TFTR/JET/JT-60, JT-60SA,,,

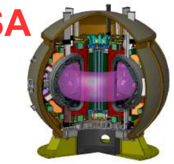
Large Tokamaks

Scientific & Engineering Feasibility



ITER

JT-60SA



high beta, steady-state

Engineering Demonstration & Economical Feasibility

DEMO

Commercialization

Fusion Reactor

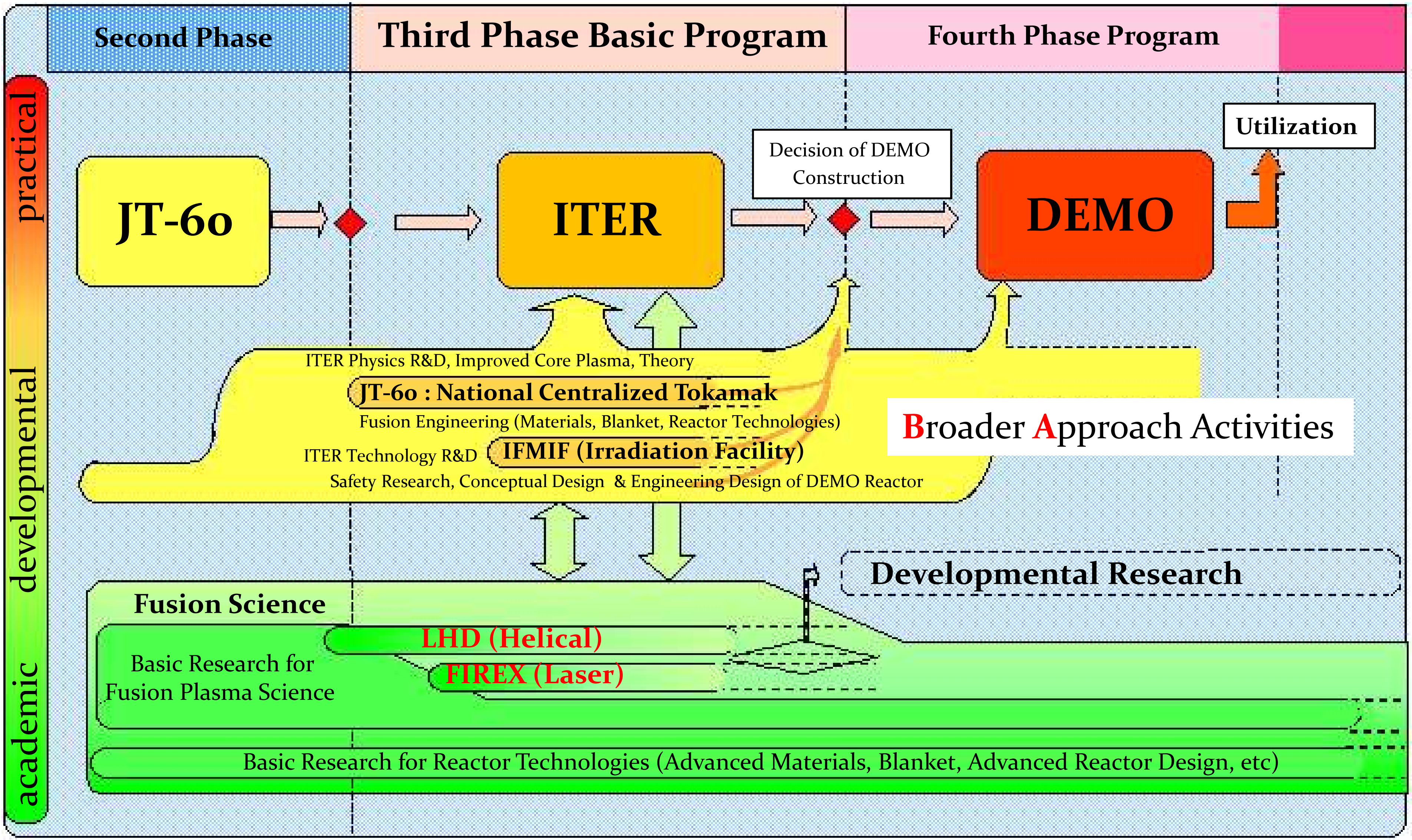
It is appropriate in the DEMO phase to aim at realizing steady-state fusion core plasma with high energy multiplication factor and at the same time demonstrating power generation in a plant scale, taking certain economical performance into account.

➔skip of the Proto type reactor phase.

➔ One integrated device just before commercialization

Promotion of Fusion Research and Development

Strategy for Fusion Development (Atomic Energy Commission, 2005)



Steady promotion of research in the current phase as “Scientific and Technological Feasibility” of the fusion research and development

Scientific Feasibility

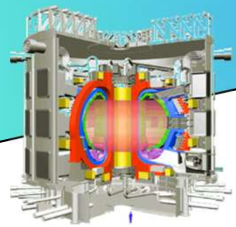
-To achieve break-even plasma condition

JT-60 (QST)

- 7 Members (EU, JA, CN, IN, KO, RF, US) collaboration
- Demonstrate burning plasma (Q>10, 300-500sec)
- ITER Organization assembles components as in-kind contribution by 7 Members (JA: Toroidal Field Coils etc.)

Scientific & Technological Feasibility

-To realize burning plasma and long-duration burning
-To establish physical and technological basis for DEMO



ITER
(Experimental Reactor)

ITER Project

JT-60SA (QST)

BA Activities

IFMIF

- EU – Japan Bilateral Collaboration in Japan supporting ITER and DEMO R&D comprising following activities:
  - IFERC (DEMO design and R&D)
  - IFMIF/EVEDA (Engineering Validation for fusion material irradiation facility)
  - Satellite Tokamak Programme (JT-60SA)
- Discussing activities from 2020 onwards

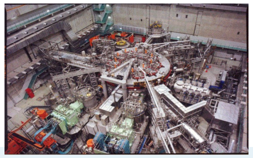
Technological Demonstration & Economic Feasibility

-To demonstrate electric power generation
-To Improve economic efficiency

DEMO Reactor

Academic Research

FIREX
(Osaka Univ.)



LHD(NIFS)

QST: National Institutes for Quantum and Radiological Science and Technology
NIFS: National Institute for Fusion Science

MEXT MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

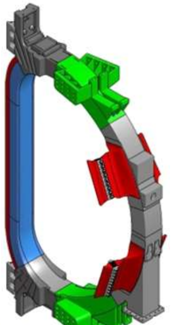
Projects Summary

ITER – Japanese In-kind Contribution

- **Japan procures components which are indispensable for DEMO development and lead to strengthening Japanese international competitiveness.**

CS Coil

- manufacturing of all 49 conductors were completed
- 42 conductors were already shipped to US. (39 arrived at US as of the end of Sep. 2017)

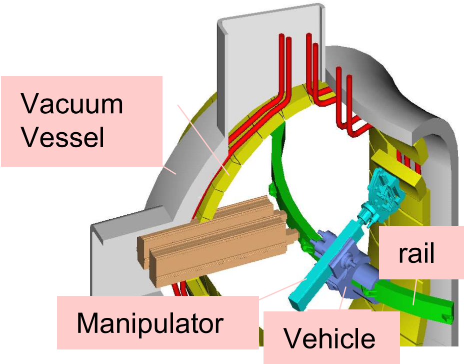


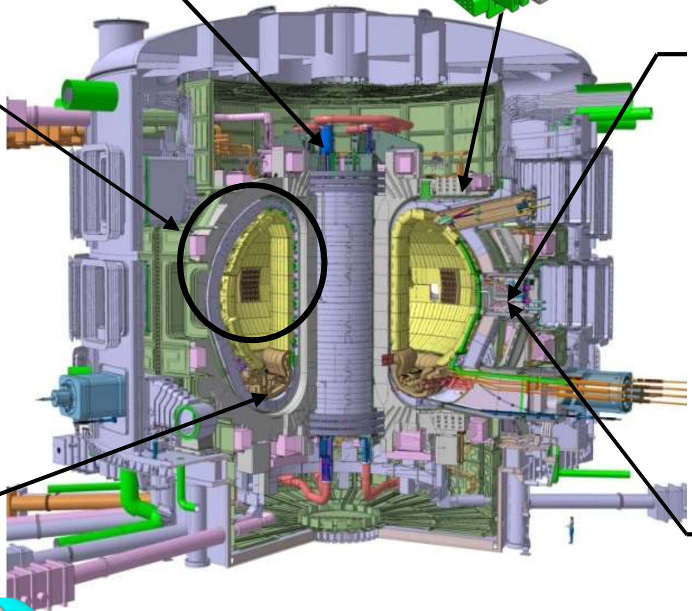
TF Coil

- 9 out of 19 TF Coils and all 19 Coil Structures are procured by JA.
- Completion of WP insulation of the 1st WP was achieved in January 2017.
- First TF coil will be completed in 2018.

Remote Handling

- Manufacturing Review will be held in 2018.





NBI system

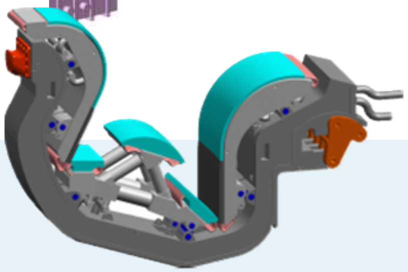
- All 5 DC generators, 1MV insulating transformer and 85 % of the transmission lines are installed on the NBTF site in Italy.
- The final components are manufactured in March/2017.

ECH system

- 8 out of 24 gyrotron are procured by JA.
- First gyrotron was fabricated in 2016.

Divertor (Outer Target)

- Passed the first evaluation test of real scale prototype full tungsten divertor.



Broader Approach Activities

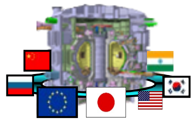
Outline of the Project

A joint JA-EU fusion research and development project to establish a technological basis for DEMO as well as to play supporting and complementary roles for the ITER Project .

Parties: JA, EU
BA Agreement : Effectuated on 1st June, 2007
Site: Rokkasho (Aomori) and Naka (Ibaraki)
Total cost: 92 billion yen, evenly shared by JA and EU
(as of value on 5, May, 2005)
Schedule: Until the end of March 2020

Role of the BA Activities

ITER



DEMO

Commer-cialization

Broader Approach Activities
Development of Key Fusion Technologies for DEMO, etc.

Roadmap for Realization of Fusion Energy

JT-60SA

Activities in sites

【Rokkasho in Aomori 】

（1）Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility（IFMIF/EVEDA）

- Develop prototype accelerator for International Fusion Materials Irradiation Facility (IFMIF)

（2）International Fusion Energy Research Centre (IFERC)

a) DEMO Design and R&D coordination Centre
b) Computational Simulation Centre, etc.

【Naka in Ibaraki】

（3）Satellite Tokamak Programme

- Upgrade of JT-60 Tokamak to JT-60SA with superconducting magnets and its operation.
- Under high pressure plasma environment, supporting/complementary experiment for the ITER and DEMO.
- Operation will start in September 2020.

Discussion for BA Phase-II (beyond Apr. 2020)

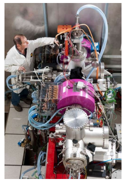
- BA phase-II Task Group established at BASC-20 is discussing scope, schedule, cost and necessary administrative procedure of JA-EU cooperation from April 2020 onward.
- The Task Group submitted an interim report to the BASC-21 in Dec 2017. The Task Group, with government representatives to be newly appointed, will further discuss those issues, and report to the BASC-22 in April 2018.

Progress in BA Activities

IFMIF/EVEDA (Rokkasho, Aomori)

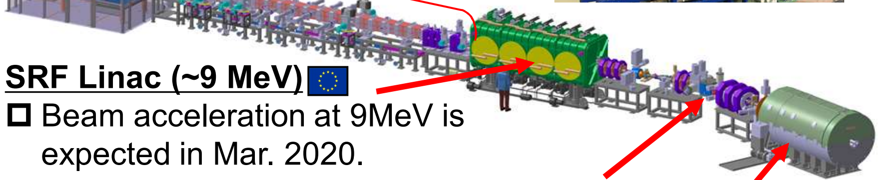
Injector (~0.1 keV)

- ☐ The Injector achieved 135 mA beam with sufficient beam quality in 2016.



RFQ (~5 MeV), RF Power

- ☐ Acceleration by RFQ will start in the beginning of 2018.



SRF Linac (~9 MeV)

- ☐ Beam acceleration at 9MeV is expected in Mar. 2020.

Installation

- ☐ RFQ was installed in July 2017.
- ☐ Assembly of SRF Linac will start in 2018 and installed in 2019.

HEBT

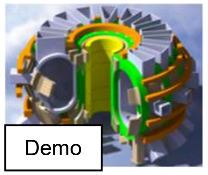
Beam Dump

Building

Auxiary System

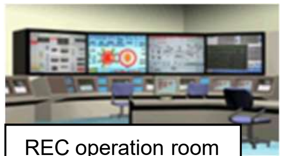
IFERC project (Rokkasho, Aomori)

- ☐ Interim report of DEMO design activity was finalized in 2017.
- ☐ The Helios super computer was shutdown in Dec. 2016 after 5 year's successful operation. More than 600 research papers have been published by this supercomputer so far.
- ☐ The infrastructure of the Remote Experiment Center was completed in Mar. 2017.



Demo

Helios super computer



REC operation room

JT-60SA (Naka, Ibaraki)

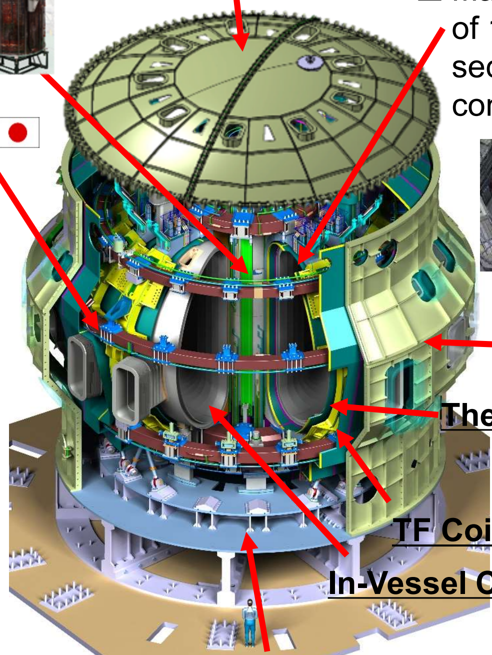
In Satellite Tokamak Project (JT-60SA), Japan procures key components for DEMO ; Vacuum Vessel, CS, PF coil, and Assembly & Installation (those are not procured in ITER Project).

CS Coil

- ☐ Fabrication of 4 CS modules will be completed in Mar. 2018.

PF Coil

- ☐ Fabrication of 6 PF coils were completed in 2016.
- ☐ At present, 3 PF coils were pre-installed.



Vacuum Vessel

- ☐ Manufacturing of 10 VV sectors were completed.

Assembly and Installation

- ☐ Assembly and installation of Vacuum Vessel was completed in Aug. 2015.
- ☐ Installation of Toroidal Field Coil started in Dec.2016 and will be completed in July. 2018.

Deliberation Status of BA phase-Ⅱ

- BA (Broader Approach) Activities were launched under the BA Agreement between Japan and EU in 2007. It consists of (1) (IFMIF/EVEDA, (2) IFERC, and (3) Satellite Tokamak Programme (JT-60SA).
- As activities after the current BA Activities which will be finished in March 2020 have not been decided, Japan and EU are considering scope, schedule, cost and necessary administrative procedure of JA-EU cooperation after April 2020, which is to be positioned as BA phase-Ⅱ.
- BA phase-Ⅱ Task Group established at BASC-20 submitted an interim report to the BASC-21.
- The interim report recommends the following activities in the 5 years of BA phase-Ⅱ by March 2025;

  (1) advancement of Prototype Accelerator produced in the current phase for the long-duration operation (IFMIF/EVEDA).

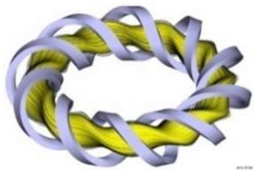
  (2) design of DEMO reactor, necessary R&D, computer simulation and the preparation of remote control experiment (IFERC).

  (3) development of operation scenario for the ITER and DEMO reactor through the operation of JT-60SA, and necessary advancement of its devices (JT-60SA).
- The report also says that further discussion is needed for the whole cost and concrete activities of the phase-Ⅱ, as well as the share of the cost for each party.
- BA phase-Ⅱ Task Group, with government representatives to be newly appointed, will further discuss those issues, and report to the BASC-22.

Outline and current status of Large Helical Device (LHD) Project

Confining the plasma: Twist and Doughnut-shaped magnetic configuration

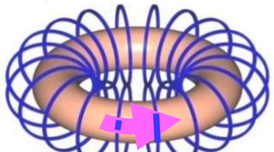
Twisting the external coils : Helical type (LHD)



Allow Steady State Operation for more than one year in principle

Issue : To realize High Performance Plasma capable of ignition
→ Ion temperature of 120 million ℃ (LHD)

High current inside the plasma: Tokamak type (ITER, JT-60SA)



Allow to generate High Performance Plasma

Issue : To realize Steady State Operation
High efficiency drive of electric current inside the plasma

Advantage of Helical type :

The adopted confining configuration "heliotron" for the LHD is the Japanese original idea, and the devices have the advantages of controllability and Steady State Operation in comparison with the devices which rely on the current inside the plasma, such as a tokamak.

Inside the vacuum vessel (LHD)

Summary of Experimental Achievements in the LHD :

- Long pulse operation of 54min. (world record) in 2005
- 12×10^{14}/cc (world record) in 2008
- 120 million℃ of Electron Temperature in 2014
- 120 million ℃ of Ion Temperature in 2017

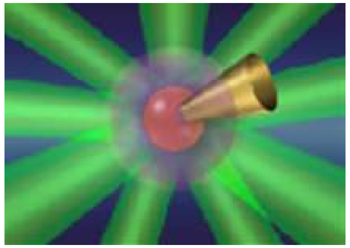
Deuterium Experiment Plan :

Aim for high performance plasma by deuterium experiment which started in March 2017 and obtain prospect for helical type nuclear fusion reactor design.

Outline and current status of Fast Ignition Realization EXperiment (FIREX) Project

Laser fusion research is positioned as one of the prioritized fusion projects in Japan along with Tokamak and Helical types, and is promoted by Institute of Laser Engineering, Osaka University as a central institution.

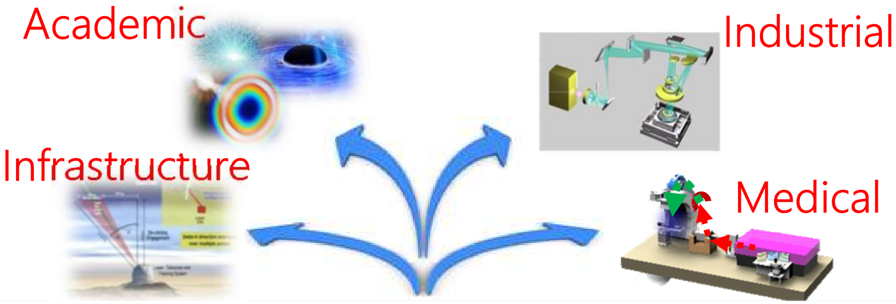
Advantage of Fast ignition type:
Fast ignition type is the method that realizes fusion ignition by compressing the fuel with high energy laser and heat it with High intensity laser. It is expected that Fast ignition may make possible an ignition with one-tenth of the energy compared to central ignition, which realizes ignition only by implosion.



Background and current situation:
- Started FIREX-I Project in 2008 for demonstrating the principle of Fast ignition with implosion laser (Gekko-XII) and Heating laser (LFEX).
- Achieved electron temperature of higher than 22 million degrees.
- Cooperation with the Lawrence Livermore National Laboratory such as exchanging of researchers and collaborative research using large laser devices.

The next steps:
- Aim to demonstrate the ignition temperature as the original goal of FIREX-I Project.
- Strengthen international partnerships in anticipation of FIREX-II Project which will aim to demonstrate self-ignition.
- Promote the research in the field of High Energy Density Science with a view of application to a wide range of fields such as academic, medical, and industrial fields.

Gekko-XII



OSAKA UNIVERSITY ⇔ Lawrence Livermore National Laboratory

Content

1. Brief review of Japanese Fusion Energy Policy and Japanese Fusion Activities

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3. Comments on inquiries from NAS

Fusion Science in National Policy

5th Science and Technology Basic Plan（Cabinet Decision in January 2016）

◇Chapter 3　Addressing economic and social issues

(1) Sustainable growth and self-sustaining regional development

① ｉ）Ensuring stable energy and improving energy efficiency

・・・Furthermore, we will work on R&D aimed at establishing important energy technologies for the future, such as innovative nuclear fusion and nuclear fuel cycle technologies.

◇Chapter 4　Reinforcing the "fundamentals" for science, technology, and innovation

(2) Promoting excellence in knowledge creation

① iii）Promoting joint international research and forming world-class research centers

・・・ As a nation, we are making advances in such areas as planning the use and operation of facilities in Japan and overseas for big science projects such as nuclear fusion, particle acceleration, and space development and utilization, as well as constructing mechanisms to stimulate international joint research with a variety of overseas partners. In addition, in order to strengthen bilateral and multilateral collaboration and build mutually beneficial relationships, we are working to enhance fund-matching partnerships and the operation of jointly managed overseas research centers while cooperating strategically

Strategic Energy Plan（Cabinet Decision in April 2014）

◇Chapter 4. Promotion of strategic technology development (energy-related technologies for which research and development should be intensively conducted in order to implement measures related to energy supply and demand in a comprehensive and systematic manner in the long-term)

2. Technical challenges to be addressed

・・・Besides, GOJ steadily promotes nuclear fusion development activities, including the ITER project, which is being implemented through international cooperation, and the Broader Approach Activities from the long-term viewpoint.

A New Report on Japan's Policy to promote R&D for a fusion DEMO reactor
Science and Technology Committee on Fusion Energy in MEXT

文部科学省 MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN (MEXT): Ministry of Education, Culture, Sports, Science and Technology

核融合原型炉研究開発の推進に向けて

http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu2/074/houkoku/1400117.htm

- 核融合原型炉研究開発の推進に向けて
- 核融合原型炉研究開発の推進に向けて（PDF:369KB）
- 核融合原型炉研究開発の推進に向けて（要旨）
- 核融合原型炉研究開発の推進に向けて（要旨）（PDF:122KB）
- チェック・アンド・レビュー項目（案）（PDF:74KB）
- Japan's Policy to promote R&D for a fusion DEMO reactor
- Japan's Policy to promote R&D for a fusion DEMO reactor (PDF:278KB)
- Executive Summary of Japan's Policy to promote R&D for a fusion DEMO reactor
- Executive Summary of Japan's Policy to promote R&D for a fusion DEMO reactor (PDF:124KB)
- Check and Review Items (plan) (PDF:93KB)

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

http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu2/074/attach/1400127.htm

文部科学省 MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

Japan's Policy to promote R&D for a fusion DEMO reactor (Tentative Translation)

Japan's Policy to promote R&D for a fusion DEMO reactor (Tentative Translation)

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

Introduction

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

1. Background

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

Committee Members

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Norio ATSUMI	General Manager, Nuclear Power Department, The Federation of Electric Power Companies in Japan (FEPC)
Michiko IGARASHI	Scientific Journalist
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Report on "Japan's Policy to promote R&D for a fusion DEMO reactor"
(December 18, 2017)

@Executive Summary

@Main Text

1. Background
2. Changes in the Energy Situation and Societal Demands
3. Strategy for Developing Fusion Technology for Demo Reactors
4. Basic Concept Required for the DEMO Reactor
5. Advancement of Development for Resolution of Technological Issues
6. Approach for Transitioning to the DEMO Phase

@Table of Check and Review Items (Issues and Schedule)

Policy on DEMO Development

New Policy on DEMO Development has just been compiled in Dec. 2017 as the revision of the policy set by Atomic Energy Commission in 2005. Summary of the New Policy is as follows.

Development Strategy

- ✓ Common target for entire community is to achieve technological solution for DEMO with tokamak
- ✓ Promote balanced research on helical and laser fusion as alternative or complimentary option in parallel

Basic Concept Required for DEMO

- ✓ Steady and stable electric output (Hundreds MWe)
- ✓ Availability sufficient for commercialization
- ✓ Tritium breeding that fulfills self-sufficiency in fuel
- ✓ Inherent safety leveraged by merit of fusion (No chain reaction)

Approach for Development for Resolution of Technological Issues

- ✓ Development plan taken into account construction cost, operation scenario etc. as well as technical consistence
- ✓ Technological issues classified under 15 elements as "Action Plan" (see next chart)
- ✓ Building all-Japan framework comprising industry, academia and government
- ✓ Nurturing human resources necessary for long-term R&D
- ✓ "DEMO Reactor Development Roadmap" will be formulated integrating overall development process including priorities, international cooperation.

Timeline for Transition to DEMO Phase

2015- 2020- 2025- 2035-

Demonstrate Scientific and Technological Feasibility (Experimental Reactor) → Technological Validation and Economic Feasibility Demonstration (DEMO)

2020-	2025-	2035-
JT-60SA First Plasma	ITER First Plasma	ITER DT Operation
1st Interim C&R	2nd Interim C&R	Decision on Transition

6. Approach for Transitioning to the DEMO Phase

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

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

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

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

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

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

Check and Review Items

Items

① Validation of burn control in the self-heating area by ITER

② Establishment of an operational technique for stationary high-beta plasma for operation of the DEMO reactor

③ Establishment of integrated technologies by ITER

④ Material development for the DEMO reactor

⑤ Technical development of reactor engineering for DEMO reactor

⑥ Designing the DEMO reactor

⑦ Social relations

Schedule

@ 1st intermediate C&R (~ 2020 : JT-60SA first plasma) => to CDA phase

@ 2nd intermediate C&R (~ 2025 : ITER first plasma) => to EDA phase

@ Transition to the DEMO reactor stage (2030s , ITER DT plasma)

Table of Check and Review Items (Technical Issues and Schedule)

Items	Objectives by the 1st intermediate C&R (~ 2020)	Objectives by the 2nd intermediate C&R (~ 2025)	Judgment criteria for transition to the DEMO reactor stage (2030s)
① V alidation of burn control in the self-heating area by ITER	・Create a technical target achievement plan for ITER.	・Reflect ITER's collaborative research in the ITER technical target achievement plan.	・ITER maintains fusion power of Q=10 or higher (for over several hundred seconds) and validates burn control.
② Establishment of an operational technique for stationary high-beta plasma for operation of the DEMO reactor	・Proceed with ITER collaborative research and preparatory studies on stationary high-beta plasma and start JT-60SA research.	・JT-60SA achieves a high-beta non-inductive current drive. ・Have integrated simulations including the divertor verified by JT-60SA and other projects. ・Create a plan for JT-60SA divertor research compatible with the DEMO reactor's plasma-facing walls.	・Gain prospects for non-inductive steady operation by ITER's achievement of non-inductive current drive plasma and integrated simulations based on ITER's knowledge of burn control. ・JT-60SA validates the stationary operation of a high-beta (bN = 3.5 or higher) collisionless plasma regime compatible with the DEMO reactor's plasma-facing walls.
③ Establishment of integrated technologies by ITER	・Establish ITER's manufacturing technologies for superconductive coils and other key components and build an integrated technological foundation through the construction of JT-60SA.	・Launch ITER operation. ・Acquire integrated technologies to manufacture, install and adjust the ITER apparatus.	・Establish integrated technologies through ITER operation and maintenance and confirm the safety technology.
④ Material development for the DEMO reactor	・Obtain low activation ferrite steel's reactor irradiation data of dosages up to 80 dpa and finalize the materials for testing under a neutron irradiation environment similar to nuclear fusion. ・Complete the concept design of the nuclear fusion neutron source.	・Complete the validation of heavy irradiation data by reactor irradiation of low activation ferrite steel up to 80 dpa. ・Evaluate the initial irradiation behavior of blanket and diverter functional materials by reactor irradiation and validate the principles of lithium-securing technology. ・Start the construction of a nuclear fusion neutron source and create a plan for collecting material irradiation data.	・Draw up the structural design criteria. ・Establish lithium-securing techniques on a pilot-plant scale. ・Collect initial irradiation data on low activation ferrite steel and blanket and divertor functional materials with a nuclear fusion neutron source.

Table of Check and Review Items (Technical Issues and Schedule) (continued)

Items	Objectives by the 1st intermediate C&R (～2020)	Objectives by the 2nd intermediate C&R (～2025)	Judgment criteria for transition to the DEMO reactor stage (2030s)
⑤Technical development of reactor engineering for the DEMO reactor	・Formulate divertor development policies. ・Create technical development plans for reactor engineering requiring early preparation, including superconductive coil technology. ・Collect the necessary data for blanket design from the cold testing facilities.	・JT-60SA, LHD, etc. collect the necessary data relevant to the divertor, including the properties of the plasma-facing materials. ・Create development plans for the superconductive coil, divertor, remote maintenance, heating/current drive, fuel system, measurement/control, etc. for the engineering technology of a medium- or plant-sized reactor, and complete the concept designs of these items for the development test facilities. ・Establish foundation technology for the power generation blanket, build ITER-TBM No. 1, and complete the safety verification tests on the actual device.	・Establish reactor engineering technologies that support DEMO reactor design, including such items as the superconductive coil, divertor, remote maintenance, heating/current drive, fuel system and measurement/ control, based on the outcomes of the development test facilities and the performance results of ITER, JT-60SA, etc. ・ITER collects tritium and validates the evaluation technique for tritium behavior with the nuclear fusion neutron source.
⑥ Designing the DEMO reactor	・Formulate the overall objectives for the DEMO reactor. ・Draw up a basic concept design of the DEMO reactor. ・Submit requests regarding reactor core and reactor engineering developments.	・Complete the DEMO reactor's concept design that ensures high safety standards and economic feasibility by incorporating reactor core and reactor engineering developments. ・Identify issues in developing reactor core and reactor engineering to establish a technological foundation for engineering design and create a development plan.	・Acquire social acceptability, confirm economic feasibility at the stage of practical use, and complete the DEMO reactor engineering design by coordinating reactor core and reactor engineering developments. ・Draw up policies on safety laws and regulations.
⑦ Social relations	・Establish a headquarters for promoting social awareness. ・Draw up an awareness activity promotion plan.	・Promote social awareness initiatives and conduct social relations activities.	・Proceed with social relations activities toward the construction and operation of the DEMO reactor.

② Establishment of an operational technique for stationary high-beta plasma for operation of the DEMO reactor

[Objectives by the 1st intermediate C&R : ~ 2020]

・Proceed with ITER collaborative research and preparatory studies on stationary high-beta plasma and start JT-60SA research.

[Objectives by the 2nd intermediate C&R : ~ 2025]

・JT-60SA achieves a high-beta non-inductive current drive.
・Have integrated simulations including the divertor verified by JT-60SA and other projects.
・Create a plan for JT-60SA divertor research compatible with the DEMO reactor's plasma-facing walls.

[Judgment criteria for transition to the DEMO reactor stage : ~ 2035]

・Gain prospects for non-inductive steady operation by ITER’s achievement of non-inductive current drive plasma and integrated simulations based on ITER's knowledge of burn control.
・JT-60SA validates the stationary operation of a high-beta (β_N = 3.5 or higher) collisionless plasma regime compatible with the DEMO reactor’s plasma-facing walls.

④ Material development for the DEMO Reactor

[Objectives by the 1st intermediate C&R : ~ 2020]

- Obtain low activation ferrite steel's reactor irradiation data of dosages up to 80 dpa and finalize the materials for testing under a neutron irradiation environment similar to nuclear fusion.
- Complete the concept design of the nuclear fusion neutron source (A-FNS).

[Objectives by the 2nd intermediate C&R : ~ 2025]

- Complete the validation of heavy irradiation data by reactor irradiation of low activation ferrite steel up to 80 dpa.
- Evaluate the initial irradiation behavior of blanket and diverter functional materials by reactor irradiation and validate the principles of lithium-securing technology.
- Start the construction of a nuclear fusion neutron source and create a plan for collecting material irradiation data.

[Judgment criteria for transition to the DEMO reactor stage : ~ 2035]

- Draw up the structural design criteria.
- Establish lithium-securing techniques on a pilot-plant scale.
- Collect initial irradiation data on low activation ferrite steel and blanket and divertor functional materials with a nuclear fusion neutron source.

⑤ Technical development of reactor engineering for DEMO reactor

[Objectives by the 1st intermediate C&R : ~ 2020]

- Formulate divertor development policies.
- Create technical development plans for reactor engineering requiring early preparation, including superconductive coil technology.
- Collect the necessary data for blanket design from the cold testing facilities.

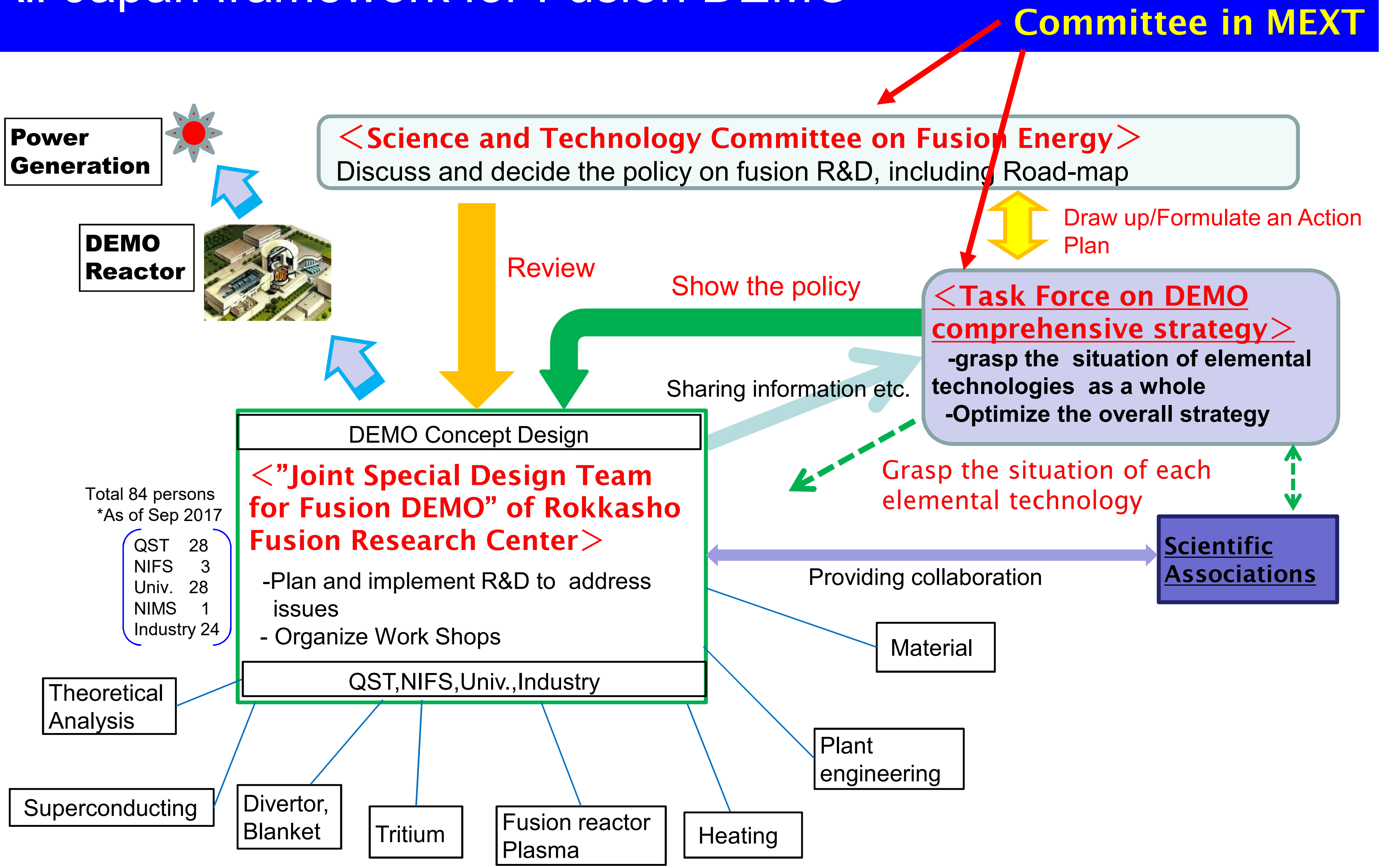
[Objectives by the 2nd intermediate C&R : ~ 2025]

- JT-60SA, LHD, etc. collect the necessary data relevant to the divertor, including the properties of the plasma-facing materials.
- Create development plans for the superconductive coil, divertor, remote maintenance, heating/current drive, fuel system, measurement/control, etc. for the engineering technology of a medium- or plant-sized reactor, and complete the concept designs of these items for the development test facilities.

[Judgment criteria for transition to the DEMO reactor stage : ~ 2035]

- Establish foundation technology for the power generation blanket, build ITER-TBM No. 1, and complete the safety verification tests on the actual device.
- Establish reactor engineering technologies that support DEMO reactor design, including such items as the superconductive coil, divertor, remote maintenance, heating/current drive, fuel system and measurement/ control, based on the outcomes of the development test facilities and the performance results of ITER, JT-60SA, etc.
- ITER collects tritium and validates the evaluation technique for tritium behavior with the nuclear fusion neutron source.

All-Japan framework for Fusion DEMO



MEXT MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

Action Plan

Published by Task-force sub-committee on DEMO Comprehensive Strategy of MEXT in 18 December 2017)

An action plan presented here is the plan toward construction of a Demo reactor in Japan. A Task-force on DEMO Comprehensive Strategy was established in MEXT, and has considered an action plan, so as to provide R&D issues for the decision to DEMO construction in 2030s.

The action plan will lead works in a Joint Special Design Team for Fusion Demo established for design and R&D of the Demo reactor in Japan.

Member s of Task Force sub-committee

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Outline of Action Plan for a DEMO development (rev. 2017.12)

Ⅰ Action Plan for a DEMO development composition table

While viewing the whole, We made a composition table that can list actions at hand for the time being.

【Technical Issue items 】

(0) Reactor Design (1) Superconducting Coils (2) Blanket (3) Divertor (4) Heating and Current Drive Systems
(5) Theory and Numerical Simulation Research (6) Reactor Plasma Research (7) Fuel Systems
(8) Material Development and Establishment of Codes and Standards (9) Safety of DEMO and Safety Research
(10) Availability and Maintainability (11) Diagnostics and Control Systems (12) Cooperation with the Society
(13) Helical (14) Laser

(Image of table)

	Basic design of concept	Conceptual design	Engineering design
2015	2020~	2025~	2035~
# Field of R&D	Action 1	Action 2	
		Action 3	
Issue 1	(17)○○○○	○○○○——>(24)	
Issue 2	(15)○○○○○ ——>(19)		

Ⅱ Explanation by Action plan items

Supplementary explanation of each item is attached to the composition table.

Phases of Action	Basic design of concept	Conceptual design	Engineering Design
Black: Kick off of Year of Items Red : Close of items	2015	2020~	2025~ — 2035~
0.Demo Design			
Concept & Construction plan	(2015)S: Phys.& eng. guideline →(2019) (2015)S: **Basic design of concept** →(2019) (2016)S/TF: Fuel cycle strategy ----------------- (2017)Q/N/U/S: Integrated simulator ------- (2018)S/D: Cost evaluation --------------------	(2020)S/D: Conceptual design →(2026) ---> (2026) ---> (2026) (2023)S/Q/F: Rev. of target plasma →(2026) -->	(2027)D/S: Design of Demo core parts →(2035) --> (2031) (2029)G/TF: Decision of candidate site →(2031) (**2032)G: Site assessment** →(2035)
Equipment Design	(2015)S/Q: Basic design of SC →(2019) (2019)S/Q: Demo TBM targets →(2019) (2017)S/D: Equip. config. w/BOP →(2019)	(2021)S/D: Conceptual Design of BOP →(2026)	**(for site asses.)** (2027)D/S: Design of plant, build..& Equip →(2031) (2027)A/S: Regulation & standard →(2031) **(after decision of standard & site candidates)** (2032)D/S: Design plant/build./equip →(2035)
Safety Policy	(2016)S/D: Draft of safety policy →(2019)	(2020) S/D: Asses. of Safety aspect -------------- (2020)S/D: Asses. of Safety aspect →(2026) (2020)TF/S: Draft for safety regulation →(2026)	--> (2031) (2027)G/TF: Safety regulation →(2035) (2032)G: Safety assessment →(2035)
Database of Physics, Engineering & Materials	(2016)Q/U/F/S: Demo Phys. DB ----------------- (2016)Q/U/F/S: Eng. & Materials DB -----------	--->(2026) --->(2026)	(2027)Q/S: Update Eng.& materials DB→(2031) **w/ results by JT-60SA** (2032)Q/S: Update material DB→(2035) **w/ 14MeV heavy irradiation data**

<u>Organization expected to be in charge</u>
G : Japanese Government
S : Joint Special Design Team for DEMO
Q : QST (Dep. of Fusion)
N : NIFS
U : Universities
D : Industries
F : Fusion Energy Forum

C1～C5 : See the list (right)
A : Academies
I : ITER team in JP
M: National Institute of material Science
Qw: QST(West)
TF: Task Force
HQ: Head Quarter for Outreach

List of Center and Labs

C1 : Ins. of Laser Engineering Osaka University
C2 : Institute of Advanced Energy Kyoto University
C3 : Plasma Research Center. University of Tsukuba
C4 : Res. Ins. for Applied Mechanics Kyushu University
C5 : Hydrogen Isotope Research Center Univ. Toyama

Phases of Action	Basic design of concept	Conceptual design	Engineering Design
Black: Kick off of Items Red : Close of items	2015	2020~	2025~ 2035~

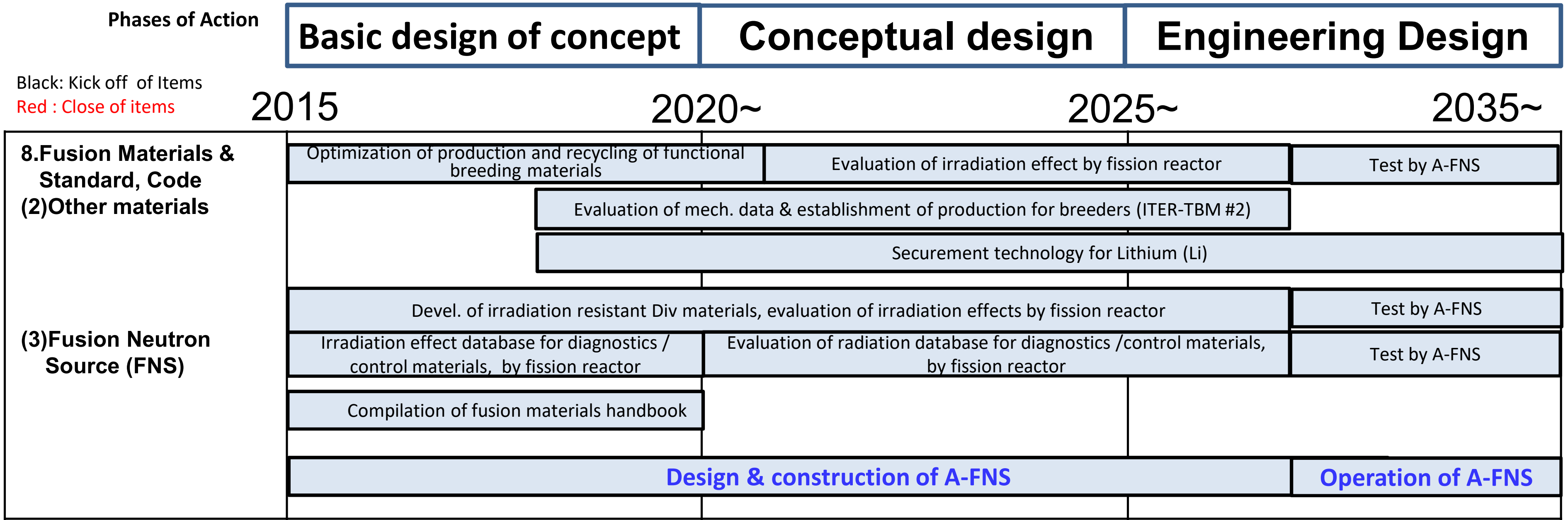
8.Fusion Materials & Standard, Code

(1)Structure Materials for Blanket (Blk)

FNS:Fusion Neutron Source

- Clarification of material spec. for Demo / Proposal of technical spec. for structure material (2015–2025~)
- Mass-production technology / Blk structure production technology (2015–2025~)
- Reliability evaluation & code of small specimen testing technology (2015–2025~)
- Environment data of jointed cover parts (2015–2020~)
- **Irradiation data by fission reactors** (2015–after 2025~)
- **Irradiation test by A-FNS** (after 2025~ to 2035~)
- Evaluation of fusion neutron irradiation effects/irradiation-induced degradation model/Establishment of standards for structure design (2015–2035~)
- Decision for utilization of advanced Blk materials (2015–2025~)
- Expansion of database for advanced Blk materials (2015–2035~)

	2015–	2020~	2025~
Low activation Ferritic Steel	(15)Q/S/U: Clarification of material spec. & technical spec. for Demo ---	----------------------------------> (26)	
	(15)Q/D: Mass-production -------------------	----------------------------------> (26)	
	(15)Q/D: Establishment of Blk structure production technology ----	----------------------------------> (26)	
	(15)Q/D/A: Reliability evaluation & code of small specimen testing technology ----	----------------------------------> (26)	
	(15)Q: Environment data of jointed cover parts by cold test ---	----------> (22)	
	(15)Q: 80dpa data by fission reactor →(19)	(20)Q: **Verification of 80dpa data by Fission reactor** →(26)	
	(15)Q: Environment data of jointed cover parts ----	---------------------------------->	----------------------> (31) (**30)Q: Irradiation test by A-FNS** →(35)
	(15)Q/N/U: Evaluation of effects of He & fusion neutron irradiation, establishment of degradation model ----	---------------------------------->	----------------------------------> (35) (27)Q/D/A: Structural design code based on the irradiation results→(35)
	(15)Q/D/A: Policy towards structural design code based on irradiation results----	----------------------------------> (26)	
	(15)Q/D/A: Academic activity towards material codes ----	---------------------------------->	----------------------------------> (35)
Advanced Blk Materials	(15)S/Q/N/U: Decision for utilization of advanced Blk materials ----	----------------------------------> (26)	
	(15)Q/N/U: Expansion of database for advanced Blk materials ----	---------------------------------->	----------------------------------> (35)



Functional Breeding Materials (Neutron breeder & Tritium Multiplyer)	(15)Q: Optimization of production and recycling of functional breeding materials ----- (18)Q: Evaluation & production of irradiation resistant Div materials ---- (18)Q: Securement technology for lithium -----	------> (22) (23)Q: Irradiation effects by fission reactor ------- --> -->	-----------------> (30) -----------------> (30) (30)Q: Irrad. test by A-FNS →(35) ---> (35)
Divertor Materials	(15)N/U: Irradiation effect by fission reactor - (18)Q/N/U: Development & evaluation of irradiation resistant materials ----	---> (26) -->	---> (35)
Materials for diagnostics & Control	(15) Q/S: Database construction of irradiation effects →(19)	(20)J/N/U: Evaluation of irradiation resistant materials (35) ----	---> (35)
Others	(15) Q/N/U: Compilation of fusion materials handbook →(19)		
Fusion Neutron Source (FNS)	**(15) Q: Design & construction of A-FNS**	-->	-----------------> (30) **(30) Q/U: Operation of A-FNS** →(35)

Content

1. Brief review of Japanese Fusion Energy Policy and Japanese Fusion Activities

2. New Policy decided on December 18, 2017
   - Report on Japan's Policy to promote R&D for a fusion DEMO reactor –
   - Action plan for DEMO R&D -

3. Comments on inquiries from NAS

Inquiries from NAS Committee

(1)the Japanese strategic plan for the development and demonstration of fusion energy,

=> **Report on "Japan's Policy to promote R&D for a fusion DEMO reactor" (December 18, 2017)**

(2) any lessons learned from the formulation of the Japanese strategic plan,

(3) your views of role of international partnership in fusion energy research, including participation in the ITER project and research plans for JT-60SA,

(4) the value of various magnetic confinement concepts in a synergetic scenario for fusion reactor development,

(5) any strategic approaches that might further strengthen or accelerate fusion energy development as an economical energy source of electricity.

(2) any lessons learned from the formulation of the Japanese strategic plan

@ A phased program : development program proceeds to the next phase on the basis of successful results on the critical path of the present phase concerned.

@ International collaboration (bi-lateral, multi-lateral) becomes very important; i.e., US/Japan collaboration program since 1979, ITER project, EU/Japan BA activities.

@ Toward 4th phase (i.e., DEMO phase), the strategy has been intensively discussed at the committee of MEXT including many experts from a wide field, and the R&D program to DEMO has been updated in 2005 and 2017.

@ Toward to the transition to DEMO phase (~ 2030s), the Check and Review will be carried out in ~2020 (JT-60SA First Plasma) and in ~2025 (ITER First Plasma).

(3) Your views of role of international partnership in fusion energy research, including participation in the ITER project and research plans for JT-60SA

@ Long history of US/Japan bi-lateral collaboration since 1979;
(DIII-D, HFIR, JIFT, etc.)
=> A fruitful scientific outcome
=> Contribution to human exchange and young talent training

@ EU/Japan bilateral collaboration has been strongly promoted through BA activities such as JT-60SA, IFMIF/EVEDA and IFERC.

@ multi-lateral cooperation era such as ITER

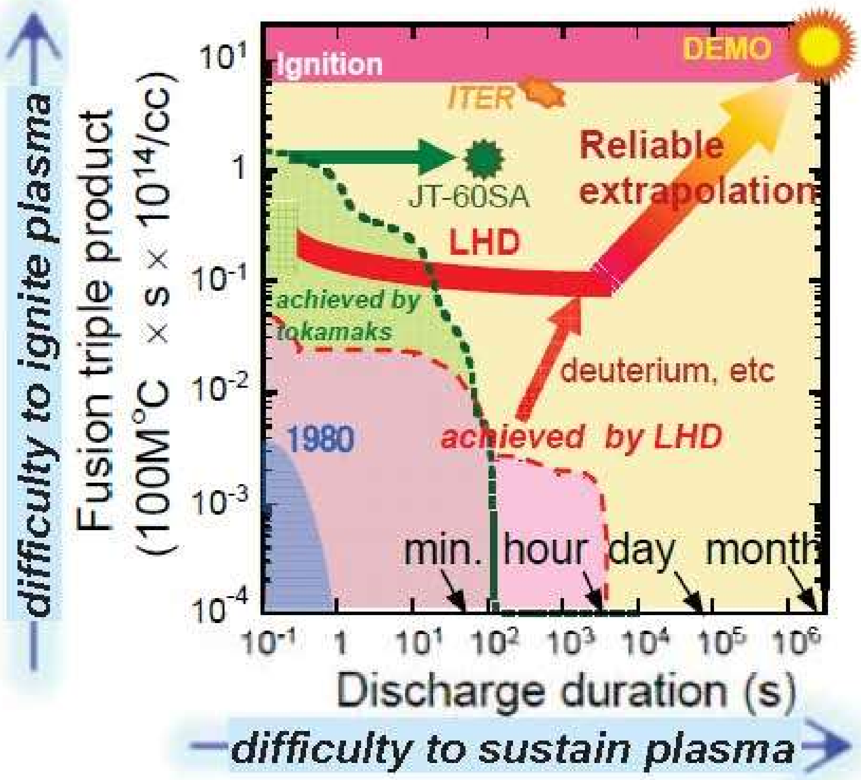
@ Bi-/multi- lateral international cooperation for DEMO R&D, including burning plasma physics in ITER, high-beta study in JT-60SA and material development with IFMIF, might be effective for accelerating fusion reactor development and for saving investment cost.

(4) the value of various magnetic confinement concepts in a synergetic scenario for fusion reactor development

@ Helical system has an advantage for steady-state operation, and LHD has demonstrated a 54 min. operation with a power level of 1 MW. Since 3-D effect such as RMP coil to suppress giant ELMs becomes important in tokamak plasmas, knowledge and experiences in helical plasmas would contribute to these 3-D physics in fusion plasmas.

@ Since many technical issues in action plan are common between tokamak and helical, we have no distinction among various magnetic concepts.

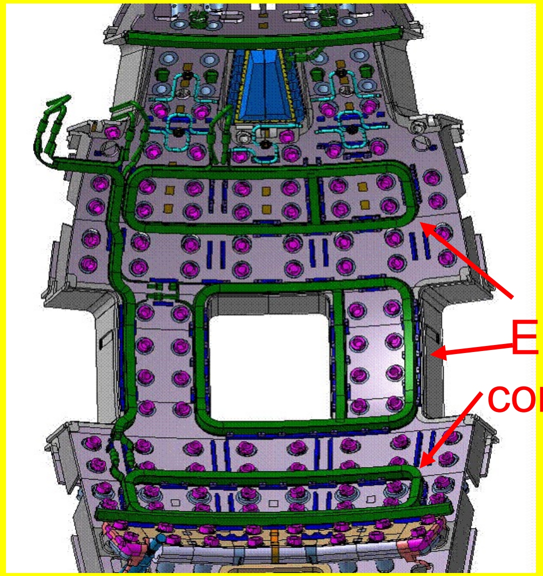
Synergetic development scenario



helical

tokamak

3-D



ITER

In-vessel coil

⇒ Magnetic island,
stochastic field

Synergetic effect between tokamak and helical plasmas on the scenario of fusion reactor

(5) any strategic approaches that might further strengthen or accelerate fusion energy development as an economical energy source of electricity

@ The committee consists of the experts of a wide field; i.e., fusion community, industry, electric utility, technology management specialist and journalist.

@ Comprehensive analysis of introduction of fusion energy into the world electric power market has been carried out.

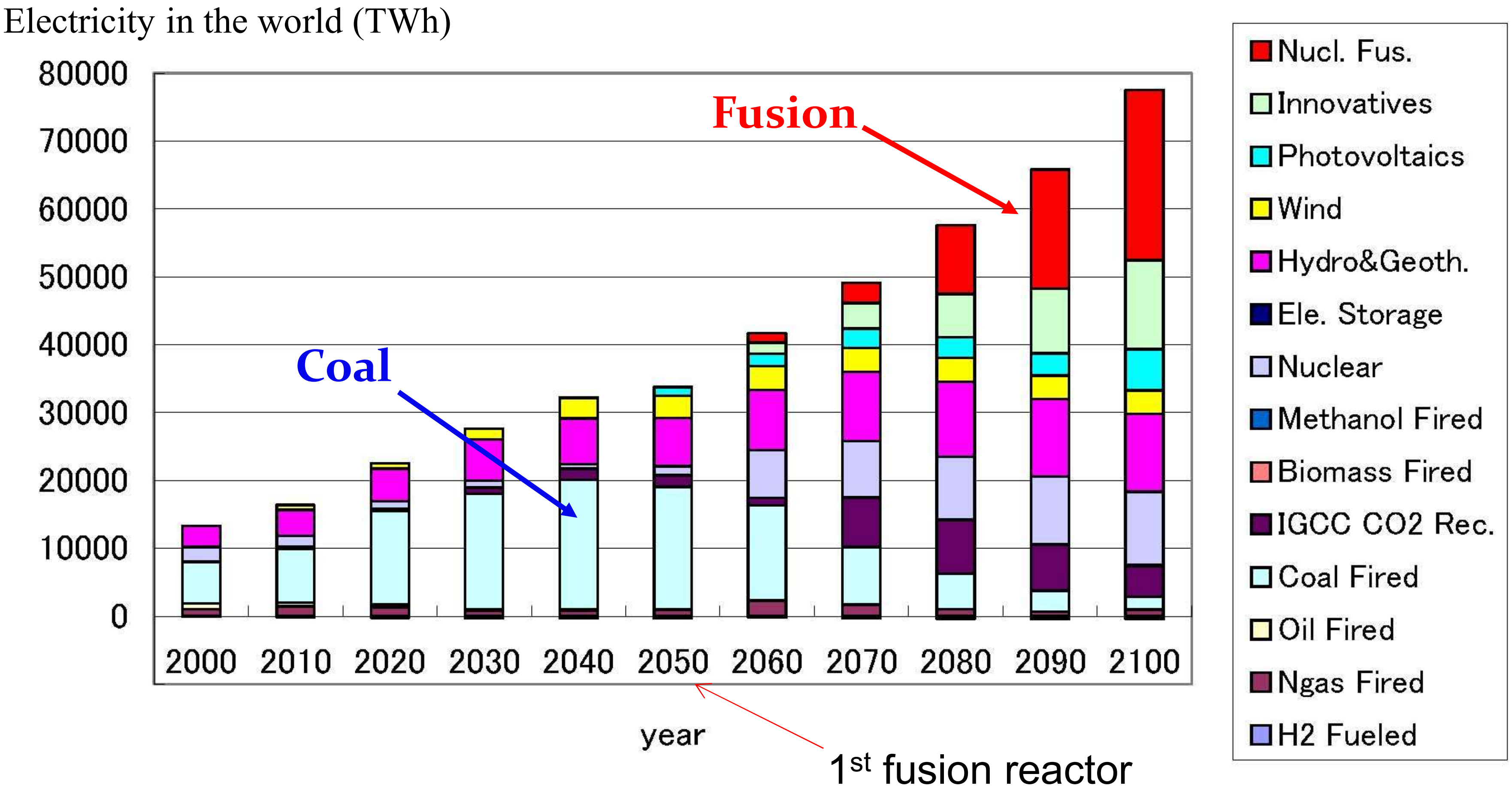
@ A support from public is quite important and indispensable, because fusion energy development needs a relatively large budget and a long development period. An importance of outreach activities for fusion energy development is assessed at the committee, and the performance of outreach activities is included as one of the check & review items.

Committee Members

Yuichi OGAWA (Chair)	Professor, The University of Tokyo
Noriyasu OHNO (Vice Chair)	Professor, Nagoya University
Norio ATSUMI	**General Manager, Nuclear Power Department, The Federation of Electric Power Companies in Japan (FEPC)**
Michiko IGARASHI	**Scientific Journalist**
Kiyoshi EBIZUKA	**President, The Japan Electrical Manufactures' Association (JEMA)**
Kunihiko OKANO (TF leader)	Professor, Keio University
Hiroshi OZAKI	**General Manager, Nuclear Power Engineering Dept., Fuji Electric Co. Ltd.**
Yasuaki KISHIMOTO	Director of Institute of Advanced Energy and Professor, Kyoto University
Ryosuke KODAMA	President of Institute of Laser Engineering (ILE), Osaka University
Katyuka SATO	**Senior Managing Director, Japan Atomic Industrial Forum, Inc. (JAIF)**
Chikako TAKANASHI	**Associate Professor, Graduate School of Technology Management, Ritsumeikan University**
Yasuhiko TAKEIRI	Director-General, National Institute for Fusion Science (NIFS)
Izumi MURAKAMI	Professor, National Institute for Fusion Science (NIFS)
Masahiro MORI	Managing Director, Fusion Energy Research and Development Directorate, National Institutes for Quantum and Radiological Science and Technology (QST)
Yoshio UEDA (Scientific secretary)	Professor, Osaka University
Takeshi AKIYAMA (Scientific secretary)	Associate Professor, National Institute for Fusion Science (NIFS)

Introduction of fusion energy into the world energy market

TOKIMATSU, K., et al., Studies of breakeven prices and electricity supply potentials of nuclear fusion by a long-term world energy and environment model, Nuclear Fusion 42 (2002), 1289.



@ In the case of 550 ppmv CO_2 concentration constraint.
@ Future energy demand is assumed to be the case of IS92a.
@ In nuclear fusion the cost of electricity (COE) in the introduction year (i.e., 2050) is assumed to be 65 mill/kWh,

⑦ Social relations

[Objectives by the 1st intermediate C&R : ~ 2020]

- Establish a headquarter for promoting social awareness.
- Draw up an awareness activity promotion plan.

[Objectives by the 2nd intermediate C&R : ~ 2025]

- Promote social awareness initiatives and conduct social relations activities.

[Judgment criteria for transition to the DEMO reactor stage : ~ 2035]

- Proceed with social relations activities toward the construction and operation of the DEMO reactor.

Thank you for your attention !

Appendix
(Executive Summary)

1. Background

○ Over 10 years have passed since the formulation of the "Future Fusion Research and Development Strategy" (formulated by the Japan Atomic Energy Commission's Advisory Committee on Nuclear Fusion in October 2005, hereinafter referred to as Fusion R&D Strategy).

Amid various changes over the years, the Science and Technology Committee on Fusion Energy of MEXT believed it necessary to prepare a new report on the course of research and development of the DEMO reactor, considering the internal and external factors surrounding fusion research and development.

2. Changes in the Energy Situation and Societal Demands

○ Since the accident at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Plant, people have been losing confidence in nuclear power. The principle of nuclear fusion differs from that of nuclear fission and can be said to be intrinsically safe. However, the accident mentioned above should be a lesson for those who are involved in nuclear fusion since it deals with neutron and radioactive substances as is the case with nuclear fission.

It should be understood while establishing the fusion DEMO reactor that the reactor is expected to have an even higher level of safety than the current level of nuclear safety technology because it would not be possible to introduce a fusion DEMO reactor in Japan without first obtaining the confidence of the public.

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

3. Strategy for Developing Fusion Technology for Demo Reactors

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

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

○ Comprehensive activities characterized by a degree of diversity should be advanced to promote the acceleration of research and development and to resolve various issues. While striving for steady progress on the tokamak reactor, research on helical and laser systems which are complementary and alternative to tokamak as well as other innovative concepts should also be conducted in parallel.

4. Basic Concept Required for the DEMO Reactor

○For commercialization of fusion energy, the objective of the DEMO reactor is to

(1) realize a steady and stable electric output of over several hundred thousand kilowatts,

(2) availability sufficient for commercialization,

(3) overall tritium breeding that fulfills self-sufficiency in fuel.

○ To achieve the basic concepts mentioned above, it is necessary to

(1) ensure safety base on ALARA,

(2) achieve an acceptable level of construction costs,

(3) design a flexible blanket and divertor.

○ Additionally, during the operational development phase of the DEMO reactor, it is also important to realize

(1) particle control and plasma control,

(2) a practical maintenance scenario and availability,

(3) high performance of the blanket and divertor.

5. Advancement of Development for Resolution of Technological Issues

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

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

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

5. Advancement of Development for Resolution of Technological Issues(continued)

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

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

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

6. Approach for Transitioning to the DEMO Phase

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

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

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

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

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

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