JAPANESE JOINT CORE TEAM REPORT
FOR THE ESTABLISHMENT OF TECHNOLOGY BASES REQUIRED FOR THE DEVELOPMENT OF A DEMONSTRATION FUSION REACTOR


*On behalf of the Joint-Core Team
About Joint-Core Team

Background and its mission
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The joint core team itself does not design a DEMO.
The joint core team designs planning and road-map.
The joint core team works together with related sectors.
National Policy of the “Future Fusion R&D” in 2005

26 October 2005, Atomic Energy Commission, Advisory Committee on Nuclear Fusion

Evolution of Development Research

- JT-60
- ITER
- DEMO

Fusion Science

- Basic Research on Fusion Plasma Science (Medium and Small Sized Plasma Devices, Theory)
- Basic Research on Fusion Technology (Advanced materials, Blankets, Design Research of Advanced Reactor, etc.)

Evolution of Development Research

- JT-60
- ITER
- DEMO

Judgment of construction of DEMO based on the comprehensive understanding of progress in fusion research and development

Practical Use Phase

Academic Research

- Development Research

Second Phase

| (Scientific Feasibility) |

Third Phase

| (Scientific and Technical Feasibility) |

Fourth Phase

| (Technical Demonstration and Economical Feasibility) |
Background: Change of Energy Situation and Social Requirement in Japan

• Since 2005 when the AEC issued the “Future Fusion R&D”, there have been 3 major epochs that have affected fusion research and development significantly.
  • Economic downturn precipitated by the Lehman Brothers bankruptcy in 2008
  • Experience of the shortage of electric power after the Great East Japan Earthquake
  • Collapse of the nuclear safety myth due to the accident at the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station
    ➢ What Fusion DEMO reactor should be?

• ITER construction has been progressed.
  ➢ Feedback to the research and development strategy towards next step DEMO should be considered.

The W.G. for Fusion Research, MEXT has requested JAEA and NIFS to take the leading role in forming the joint-core team for the establishment of technology bases required for the development of DEMO.
Mission of joint-core team and issues

• Mission
  • To develop strategy for the establishment of technology bases required for the development of DEMO by taking into account the progress of the ITER project, the BA activities and academic researches such as the Large Helical Device (LHD), and standing on the consensus in the Japanese fusion community.
    ➢ Projecting the goal of DEMO, we have reviewed the technological issues to fulfil the Transition Conditions towards the Fourth Phase Program first by a tokamak, which exhibits the most advanced development, and to approach defined issues by the organized framework for implementation throughout Japan in parallel with the ITER project.

• Issues
  1. Concept of DEMO premised for investigation
  2. Activities requiring commitment and their goals (research activities, investigation activities)
  3. Scientific and technological review works for the above mentioned activities
On the Concept of DEMO
Premised for Investigation
Fundamental Strategy towards DEMO

- Pre-conceptual design activity (pre-CDA)
- Conceptual design activity (CDA)
- Assessment of transition condition (around 2027)
- Engineering design activity (EDA)
- Decision of construction
- Construction and manufacturing design activity

 ITER project is a ticking clock.

✔ Launching of a full-scale engineering R&D towards construction of DEMO should be promoted immediately after the Intermediate C&R.
Basic Concept Required for DEMO (1)

• The “Future Fusion R&D” in 2005 stated that a tokamak DEMO is presumed to have dimensions similar to ITER and a generating capacity of 1 million kilowatts.

• From the view of the presently available technology bases and their future prospects, this definition should be revisited in the planning of the roadmap with defined milestones aimed at 1) steady and stable power generation beyond several hundred thousand kilowatts, 2) availability reachable for commercialization, and 3) overall tritium breeding to fulfil self-sufficiency of fuels.

• The operational development phase of DEMO before reaching the targets should be planned by classifying the commissioning phase, the power-generation demonstration phase, and the demonstration of economic feasibility phase, and defining milestones at each phase.

• And targets, such as demonstration of power generation by the system equivalent to a commercial reactor, demonstration of high energy gain factor, long-pulse and long-term operation which can be extrapolated to a commercial reactor, and development and demonstration of advanced technology to improve economic performance, should be achieved in each corresponding.

Milestones

- Completion of DEMO construction
- Commissioning phase
  - Preliminary step
- Power-generation phase
  - T-breeding & power generation
- Economic feasibility phase
  - Availability
  - Maintenance of internal component
- (Preparation of DEMO-TBM)
  - commercialization technologies
- Construction of commercial reactor
Basic Concept Required for DEMO (2)

- **TBR**: The target of “overall tritium breeding ratio (TBR) beyond 1 is required” documented in the “Future Fusion R&D” must be achieved.
  - What “overall” means here should be discussed in detail and clarified.

- **Plasma**: Controllability of plasma, such as heat and particle control, and disruption avoidance should be established in order to reduce excessive load on plasma facing components and to enable stable burning in the long term.

- **Maintenance scenario**: By realizing a maintenance scenario which can be extended to a commercial reactor, DEMO should be aimed at demonstration of availability enough for commercialization at its final phase.

- **Divertor and Blanket**: Flexible design of reactor-core components is required in order to resolve issues such as the high-performance blanket and the improvement of divertor capability towards commercialization.

- **Safety issues**: Security of safety to suppress exposure of the public as well as the workers in a DEMO plant to as low as possible (ALARA) rationally is necessary.

- **Cost**: The construction cost of DEMO should be at the acceptable level from the view of subsequent commercialization.
Technological Issues of Elements of DEMO
Technological Issues of Elements of DEMO

Completion of the design and R&D to support the design is needed for the following technological issues.

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
Material Development and Establishment of Codes and Standards

- Standardization of structural material for DEMO blanket
- Validation of reliability under high dose irradiation
- Availability rate and maintainability

**Assessment of the Transition Condition (2027)**
- To present technical specifications of blanket structural materials for DEMO fusion reactor

**DEMO conceptual design**
- Basic requirement for structural design
- Initial design for structural design

**ITER-TBM**
- No user specification except for DEMO fusion reactor materials

**DEMO conceptual design**
- Baseline of DEMO design
- Intermediate C & R (2020)

**Progress since 2005**
- “Future Fusion R&D”
  - Experience in advance meeting
  - Progress in joining technologies and welding
  - Successful connecting activities for material characterization
  - Development of magnetic materials
  - Development of magnetic materials and progress in understanding of material damage

**Progrss in R&D of reduced-activation ferritic steel**

Ex.) Fig. 9. Structure of issues in “Material Development and Establishment of Codes and Standards”
Chart of Establishment of Technology Bases for DEMO. Ex) Materials
Highlighted Remarks in Establishment of Technology Bases for DEMO
Principal matters recognized in Chart

Principal matters of weight which have been recognized in formulating Chart of Establishment of Technological Bases for DEMO are remarked upon below. These matters are summarized into the following 4 points.

1. The ITER project is the definite critical path and its steady accomplishment is indispensable.
2. Besides the ITER project, they are “reinforcement of DEMO design activity” and “strategic acceleration of research and development of divertor” that are the present critical paths and should be grappled with most urgently with more investment of resources than at present.
3. From the prospect around the Assessment of Transition Conditions, “Test Blanket Module (TBM)” and “fusion neutron source” are cited for critical paths to determine the complete timeline.
4. A framework for implementation throughout industrial, governmental and academic sectors in Japan is necessary for establishment of technological bases for DEMO and actions to make this framework effective, in particular, making the best use of human resources, should be taken.
Newly Required Facilities and Platforms

• Test facility of large-scale superconducting coils which fulfils the specification of DEMO (Test facility of superconducting conductor and coils with around 16 T)
• Facility related to blanket (development of ITER-TBM, post irradiation examination, development of waste disposal technology)
• Test facility of real-scale performance of NBI (including expansion of ITER NBTF)
• Supercomputer resource
• Handling facility for large quantities of tritium
• Lithium plant (collection and purification facility)
• Intensive fusion neutron source, fusion neutron source (including expansion of IFMIF/EVEDA)
• Facility for development of large-scale component maintenance
International Cooperation and Collaboration
Present and possible future international cooperation

- ITER, BA (JT60SA, IFMIF-EVEDA, Helios etc.)
- Fusion neutron source and intensive fusion neutron source for material development
- Large-real-scale test facility for development of heating and current-drive system
- Fission neutron irradiation facility such as HFIR in the United States
- Cooperation with tokamak experiments abroad and simulation, specifically regarding the detachment operating scenario and the tungsten issue, which are related to development of the divertor
- A variety of concepts of TBM in ITER depending on contributing countries and party
Special issue: (Intensive) fusion neutron source

• With regard to the fusion neutron irradiation effect, alternative and compound approaches such as the construction of a new fusion neutron source which is able to verify effects of the helium transmutation and the effective utilization of the existing fission reactors should be examined and undertaken not relying solely upon the IFMIF or the early realization of an intensive fusion neutron source with neutron spectrum and flux equivalent for the IFMIF.

➢ Before the assessment of transition condition, experimental verification using the fusion neutron source is needed for the prediction models that based on provisional knowledge related to the materials.
  ➢ Fusion neutron irradiation up to about 20 dpa is expected.
Summary and future: Organizational change concerning DEMO R&D
Conclusion (1/2)

The joint-core team has worked on strategy for establishment of technology bases required for development of DEMO. In particular, the concept of DEMO premised for investigation and activities to ensure the feasibility of this DEMO concept have been examined. The following examinations were summarized in our reports:

- Based upon the analysis of the structure of technological issues, aligned R&D programs with defined milestones, and plans of research bodies grappling issues and required facilities, the following are identified.

  2. What is required after the Intermediate C&R and before the assessment of the Transition Conditions around 2027 (driving the content mentioned as “Promotion to start the enterprise of engineering R&D in accordance of the assessment at the Intermediate C&R”).
  3. Urgent issues
  4. Points of note
Conclusion (2/2) and Residual important issues:

- Along with the methodology of back-casting, the joint-core team has formulated *Chart of Establishment of Technological Bases for DEMO* which visualizes an overview picture with paying attention to definition of plans based upon evidence and precise understanding of the current status and realistic prospect of research and development, and to consistency between global strategy and individual implementation in the workplace.

- The joint-core team sincerely hopes that development of concrete actions and programs as well as policy are earnestly promoted so as to lead to implementation of the plan documented in *Chart of Establishment of Technological Bases for DEMO* and to enable effective PDCA cycle.

- Residual important issues:
  - Socio-economical investigation of fusion energy
  - Investigation of the helical system and laser system
Framework for the establishment of technology bases required for the development of DEMO (draft)

Fusion Science and Technology Committee
Subdivision on R&D Planning and Evaluation, the Council for Science and Technology, MEXT
To discuss and decide promotion policy for fusion research, and to develop roadmap.

Conceptual design activity of DEMO
Joint-special team for DEMO @ Rokkasho, JAEA
- To make plan and implement it for solving issues.
- To convene related WS.

General coordination group
for coordinating JS team as well as TF and academic societies, etc.

Info.-exchange, development of new participation fields.

Comprehensive DEMO Strategy Task Force
- To take and adjust comprehensive, panoramic view of elemental technologies.
- To optimize comprehensive strategy.
  (To propose action plan, etc.)

Formulation and approval of the action plan draft.

Academic societies, associations

DEMO

Theory
B Univ.
S.C. Magnet
A Univ.
Divertor Blanket
A Univ.
Heavy electric machinery manufacturer
JAEA
NIFS
Manufacturer
Plant Eng.
NIMS

C Univ.
C Univ.
Core plasma
Tritium chem.

NIFS
A Univ.
Heavy electric machinery manufacturer

A Univ.

C Univ.

NIFS

Comprehensive, multi-disciplinary approach.

Commercial reactor = Electricity
Thank you for your attention!

I have 7 sets of Joint-core team reports. And also you can download English-language version here. 
http://www.jspf.or.jp/2015/genkeiro/index.html
Appendix
The way towards Joint core-team reports

Mar. 2013 to Feb. 2015: 7th Term Working Group for Fusion Research, MEXT

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Activities</th>
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<tbody>
<tr>
<td>2013</td>
<td>July</td>
<td>The W.G. has requested the Fusion Research and Development Directorate of JAEA and NIFS, which are implementing bodies of large projects, to take the leading role in forming the joint-core team for the establishment of technology bases required for the development of DEMO.</td>
</tr>
<tr>
<td>2014</td>
<td>Feb</td>
<td>release an interim report as summary of issues for the establishment of technology bases required for the development of a fusion DEMO reactor.</td>
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<tr>
<td></td>
<td>Jun</td>
<td>release a report on a basic concept of DEMO and structure of technological Issues.</td>
</tr>
<tr>
<td>2015</td>
<td>Jan</td>
<td>Release an additional report on the CHART of establishment of technology bases for DEMO.</td>
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Fig. 1. Operational phase of DEMO reactor and its target
Fig. 3. Structure of issues in “Blanket”
Fig. 4. Structure of issues in “Divertor”
# Reactor system design

## Reactor System Design

### 0.1 Conceptual design
- 0.1.1 Design guidelines and requirements
- 0.1.2 Reactor concept
- 0.1.3 Maintenance and torus configuration
- 0.1.4 Component and equipment design
- 0.1.5 Plasma physics design
- 0.1.6 Plant and auxiliary systems concept
- 0.1.7 Safety guidelines
- 0.1.8 Physics, engineering and materials DB
- 0.1.9 Initial cost estimate

### 0.2 Engineering design
- 0.2.1 Plasma physics design: Diagnostics and control
- 0.2.2 Reactor design
- 0.2.3 Component and equipment design
- 0.2.4 Plant and building design
- 0.2.5 Power generation system design
- 0.2.6 Physics, engineering and materials DB
- 0.2.7 Secondary cost estimate
- 0.2.8 Design rules, codes and standards
- 0.2.9 Safety requirements: Analysis, Assessment
- 0.2.10 Safety regulations

### 0.3 Construction and manufacturing design

## Link to other task

<table>
<thead>
<tr>
<th>2010s</th>
<th>2020s</th>
<th>2030s</th>
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**Diagram**

- Pre-CIA
- CIA
- EDA
- Detailed conceptual design
- Other terms: Start UK-scale R&D
## Blanket

### 2 Blanket

#### 2.1 Design of DEMO blanket system
- 2.1.1 Compatibility, vapor pressure, water/steam, chemical reaction rates, etc.
- 2.1.2 Compile data base for use in the design activities (properties of packed pebbles, etc.)

#### 2.2 Expansion of basic/reference data

#### 2.3 Validation of reference data base

#### 2.4 Demonstration of integrated functions of blanket system in fusion environment
- 2.4.1 Pre-conceptual design of DEMO blanket and tritium system
- 2.4.2 Conceptual design of blanket system
- 2.4.3 Test plans for TBM system and additional test facilities
- 2.4.4 Confirmation of material to heat and pressure loads, and of response to EM loads
- 2.4.5 Proven manufacturing technology for blanket system
- 2.4.6 Complete technological bases of blanket system including design and manufacturing technology

#### 2.5 Demonstration of tritium breeding and recovery
- 2.5.1 Design and schedule of irradiation and tritium experiments
- 2.5.2 Understandings of tritium behavior, establishment of tritium technology

#### 2.6 Development of advanced blanket system
- 2.6.1 Examination on blanket functions and properties with small test devices
- 2.6.2 Development of concepts for blanket design
- 2.6.3 Development of heat exchange technologies and technological investigation on power generation system
- 2.6.4 Investigation of DEMO-TBM design, offering of preliminary design and their comparison
- 2.6.5 Expansion of fundamental and standardized data
- 2.6.6 Integrated demonstration under reactor conditions with small scale-up

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### Timeline

- **2010s**
  - Reactor design 3.1.3
  - Safety 3.2.3
  - Reactor design 3.1.8
  - Safety 3.2.3
  - Reactor design 5.1.9
  - Code & standards 8.1.5

- **2020s**
  - Feedback from TBM
  - Engineering design
  - Reactor design 5.1.4
  - Reactor design 5.1.5
  - Reactor design 5.1.6
  - Reactor design 5.1.7

- **2030s**
  - Demonstration of electric power generation
  - System design
  - Demonstration of tritium breeding and recovery
  - Demonstration of advanced blanket system

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### Additional Notes

- Demonstration of electric power generation
- System design
- Demonstration of tritium breeding and recovery
- Demonstration of advanced blanket system

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### References

- Tritium facility in ITER
- Tritium breeding and recovery test facilities
- Reactor fabrication technology, blanket materials, welding, heat flow through connecting systems, tritium release measurements, etc.
Divertor

3 Divertor

3.1 Plasma operation scenario
3.1.1 Understanding of physical mechanism which dominate divertor operation
3.1.2 Verification and validation of detachment plasma
3.1.3 Development of theoretical modeling for detachment plasma
3.1.4 Understanding of impurity effects on fusion output
3.1.5 Demonstration of plasma operation scenario
3.1.6 Development of theoretical simulation for burning plasma

3.2 Development of theoretical simulation for burning plasma
3.2.1 Decision of consistent fusion output with divertor heat flux
3.2.2 Understanding of heat removal property of divertor components (steady & transient)
3.2.3 Classification of heat removal property of low activation material
3.2.4 Demonstration of heat removal property of W & C divertor under actual condition
3.2.5 Development of innovative cooling system

3.3 Material development
3.3.1 Understanding of material property of plasma facing components
3.3.2 Improvement of resistance to neutron irradiation of copper alloy
3.3.3 Clarification of neutron irradiation effects on divertor materials

3.4 Particle exhaust
3.4.1 Understanding of hydrogens behavior on plasma facing components
3.4.2 Understanding of hydrogens behavior under actual condition
3.4.3 Development of feasible vacuum pump under DEMO reactor conditions
3.4.4 Establishment of consistent particle exhaust scenario with heat removal
Points of View for Changeover to DEMO Phase and Assessment of Transition Conditions

- It is relevant to elaborate the plan of technological development with the presumption of the review of Transition Conditions around 2027 when the fusion burning with deuterium and tritium (DT burning) fuels will be demonstrated in ITER. Here, it is necessary to embody the contents and criteria of judgement by close examination of C&R items (planned) indicated in “Future Fusion R&D” (see Table 1).

- The “6th Term Report” stated, “The Working Group on Fusion Research continues to revise the report by deepening discussion about the Transition Conditions to the DEMO phase.” In particular, when and how much the results of energy gain, long-pulse operation, and demonstration of blanket function, etc. will be obtained in the ITER project are critical elements directly connected to the assessment at the Transition Conditions to the DEMO phase. Therefore, it is necessary to investigate the appropriateness and the timeline of these critical elements by revisiting the original point of these 10 criteria.

- Above all, “demonstration of maintenance of plasma with Q 20 (for duration longer than about several 100 s) and burn control in ITER” (here, Q is the fusion energy gain and defined by the ratio of energy released by fusion reaction to externally applied energy to reactor-core plasma) and “demonstration of non-inductive current drive plasma with Q 5 (for duration longer than about 1,000 s) in ITER” in the C&R items (planned) of the Transition Conditions to the DEMO phase are requested to be discussed in the Working Group on Fusion Research and in other councils. In order to address re-definition of the C&R items, the fusion community should form common recognition so as to provide rational answers to these questions. For the former item, the goal of ITER is defined as Q=10 and a pulse length is linked with not only validation of performance of reactor-core plasma but also demonstration of functions of breeding and collection of tritium, heat removal, and power generation** in ITER-TBM. Since the latter item is planned in the later phase of the ITER project, should these specific Transition Conditions be replaced by integration of results from achievements ITER, JT-60SA (Japan Atomic Energy Agency: JAEA) and numerical simulation instead earlier than its full demonstration in ITER?

- Full-scale engineering R&D towards construction of DEMO will be launched by the success in the Changeover to the Fourth Phase Program. On the other hand, in case commercialization of fusion energy in the middle of the 21st century is aimed at, the start of engineering R&D at the proper level in the preparation term before the assessment of the Transition Conditions should be promoted for early realization of DEMO.

- The significance of the statement “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” in the “Future Fusion R&D” should be explored and embodied in succession.

** Basically ITER-TBM’s are aimed at tritium breeding, and not at power generation. Nonetheless, the Japanese TBM plans to generate power even though it is a limited level since it can generate steam because of the employment of water as coolant.

In that case, the Intermediate C&R, which is the milestone before the assessment of Transition Conditions for the Phase Changeover, becomes more important than before. The “Future Fusion R&D” stated, “This milestone is presumed around ten years after the establishment of the ITER Organization.” While the examination in this present report endorses that the draft targets at the Intermediate C&R described in the “Future Fusion R&D” are appropriate, the time should be presumed to be around 2020, when the first plasma of ITER is expected, since the assessment of achievements of construction and development in the ITER project is crucial at the Intermediate C&R. Further embodiment of targets and their assessment should then be prepared.
Summary

- In accordance with the request of the Working Group on Fusion Research, MEXT, the joint-core team has worked on strategy for establishment of technology bases required for development of DEMO by taking into account the progress of the ITER project, the BA activities, and academic researches such as the Large Helical Device (LHD). In particular, the concept of DEMO premised for investigation and activities to ensure the feasibility of this DEMO concept have been examined.

- The purpose of DEMO is to indicate the prospect to achieve economic and social rationality of fusion energy competitive with other energy resources. In order to prepare for commercialization, DEMO should be aimed at steady and stable power generation beyond several hundred thousand kilowatts, availability which must be extended to commercialization, and overall tritium breeding to fulfill self-sufficiency of fuels. And the roadmap towards DEMO with defined milestones should be elaborated. In DEMO itself, the operational development phase of DEMO before reaching the targets should be planned by classifying the commissioning phase, the power-generation-demonstration phase, and the demonstration of economic feasibility phase, and defining a milestone at each phase. And targets such as demonstration of power generation by the system equivalent to a commercial reactor, demonstration of high energy gain factor, long-pulse and long-term operation which can be extrapolated to a commercial reactor, and development and demonstration of advanced technology to improve economic performance should be achieved in each phase.

- In accordance with the "6th Term Report", required technological activities of 11 elements of DEMO have been sorted out in looking forward to the roadmap from the summary of issues in the "Interim Report".

- Then, each element has been analyzed in order to clarify the procedure to demonstrate the technological feasibility of DEMO, which is the most fundamental mission, and to develop the roadmap with the timeline and implementing bodies. Here Intermediate C&R and the assessment of Transition Conditions, which have been defined in the "Future Fusion R&D", are presumed around 2020 and 2027, respectively. Then, in view of the timeline, the structure (tree) of technological issues in each element and approach to resolve these issues are shown. While some issues can be dealt with by the presently ongoing projects and existing implementing bodies/platforms or their expansion/reinforcement, there still remain issues which are not yet dealt with because of the lack of corresponding projects and implementing bodies. These two classes are distinguished in Tables 2 - 12.

- Based upon the analysis of the structure of technological issues, aligned R&D programs with defined milestones, and plans of research bodies grappling issues and required facilities, the following are identified.

  1) What is required before the Intermediate C&R
  2) What is required after the Intermediate C&R and before the assessment of the Transition Conditions (driving the content mentioned as "Promotion to start the enterprise of engineering R&D in accordance of the assessment at the Intermediate C&R" in Section 2.5).
  3) Urgent issues
  4) Points of note

- While the investigation in this present report endorses the view that the draft targets at the Intermediate C&R described in the "Future Fusion R&D" are appropriate, the progress of the ITER project will have a great impact on time and criteria at the Transition Conditions. In particular, based upon common recognition about when and how much the results of energy gain, long-pulse operation, and demonstration of blanket function, etc. will be obtained in the ITER project, time and criteria at the Transition Conditions should be discussed in a council such as Working Group on Fusion Research at an appropriate time.

- The problem recognition common in all 11 elements is the dilemma between design of DEMO and R&D for each technological issue. In short, it is nothing but changing the situation from an unfavourable situation in which a target of technological R&D cannot be defined because the design is not fixed and that the design cannot be fixed because the prospect of technological R&D is unclear, to a favourable situation in which the progress of both sides accelerates each other synergistically.

- Development of DEMO is arranged so as to bring together all related technology from a position of integration. Therefore, the DEMO design activity in wide definition is requested to manage the overall development plan by the definition of the target of each technology and assessment of technological maturity, to promote secure progress of the main stream, and to pronounce innovative technological developments for breakthrough. In the DEMO design activity, a structural mechanism to grapple strategically should be arranged in the organized a framework for implementation throughout Japan promptly in order not only to reinforce the present DEMO design activity but also to make the function of the so-called PDCA cycle, in particular, Check and Action, work effectively in planning, management, and coordination of the R&D plan required for engineering development for DEMO, and to organize activity including coordination with other fields and academic societies to resolve issues. This report here requests the Working Group on Fusion Research to discuss this mechanism to plot a comprehensive strategy of establishment of technological base for DEMO.

- At the end, although the joint-core team is responsible only for scientific and technological analysis, it would like to express expectations to governmental administration. Since the appropriateness of DEMO is judged by society, the joint-core team expects leadership by governmental administration to define the responsibility of the implementing body as it should be, to create a mechanism to involve stakeholders and the public in technological assessment to prevent self-centered planning, and to define locational conditions and environmental assessments as they should be based upon the intrinsic safety features of fusion.

- This report is founded on intensive discussions and upon opinions received from the Japanese fusion community at a variety of opportunities. This report was intended to have been based upon a consensus in the fusion community in Japan, and a shared understanding is emerging in the fusion community. We will continue to strive to collect opinions and work toward a broad consensus. The joint-core team is deeply grateful to all contributors for their important communications.
Summary

• The joint-core team has progressed with examinations of planning for the development of DEMO since the team’s formation in July, 2013 along with the term of reference defined by the Working Group on Fusion Research, which are the Interim Report on summary of issues (the 38th meeting of the Working Group on Fusion Research, 24 February 2014) and the report on Basic Concept of DEMO and Structure of Technological Issues (the 41st meeting of the Working Group on Fusion Research, 24 June 2014). And the present report introduces a chart which visualizes development of all of the related programs in a timeline and provides an overview picture of all related processes. It is expected that the fusion-related community of industry, education and research, and government will closely examine this chart, and share recognition of perspectives on issues and future direction in common, which will lead to joint activity and accomplishment throughout Japan. In particular, definition of the roadmap of the development of DEMO, planning of research and development programs after the BA activities which will end in 2017, and reinforcement of joint usage and collaborating research systems and role-sharing with NIFS and universities are anticipated as a consequence.

• The planning of research and development programs after the completion of the BA activities should not be limited only to the present framework of Japan-EU cooperation, but also should be considered with determining what program is appropriate in sequential cooperation with EU, what program should be undertaken only by Japan, and what programs are appropriate in other international frameworks through revisiting the original concept of “broader approach”.

• In order to define the roadmap of development of DEMO in future, there remain two important tasks which the joint-team has not completed. These are socio-economic examination of fusion energy and review of alternative approaches of helical magnetic fusion system and laser fusion system. With regard to the former task, those who are engaged in research and development of fusion energy should recognize correctly the contemporary trend that implementing bodies are requested to be accountable to society regarding the outcome from large-scale projects and outreach activities. With regard to the latter task, it should be noted that the important decisions are made based upon comprehensive assessment of overall progress of fusion research and development, and that the review of alternative approaches is primarily important to form significant solidarity to grapple with development of DEMO by the Japanese fusion community. The joint-core team hopes that these two tasks will be addressed in the Working Group on Fusion Research in the next term.

• Along with the methodology of back-casting, the joint-core team has formulated Chart of Establishment of Technological Bases for DEMO which visualizes an overview picture with paying attention to definition of plans based upon evidence and precise understanding of the current status and realistic prospect of research and development, and to consistency between global strategy and individual implementation in the workplace. The joint-core team sincerely hopes that development of concrete actions and programs as well as policy are earnestly promoted so as to lead to implementation of the plan documented in Chart of Establishment of Technological Bases for DEMO and to enable effective PDCA cycle.
Structure of decision making and execution

Cabinet Office

Japan Atomic Energy Commission (JAEC)

Promotion plan of fusion R&D issued in 2005

Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Council for Science and Technology
- Working Group for Fusion Research

Japan Atomic Energy Agency (JAEA)

National Institute for Fusion Science (NIFS)

Universities

programmatic approach under governmental decision

academic approach integration of bottom-up commitment from universities
Japan Atomic Energy Commission

• Promotion plan of fusion R&D was issued by Japan Atomic Energy Commission at 2005.

• In the development of fusion energy, we should promote its R&D, 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.

• It is necessary to have economical prospect and demonstration of safety and operation reliability as a major premise for the future assessment of the commercialization of the fusion energy.
Council for Science and Technology

• Report
  • “Toward Establishment of Technological Basis for DEMO Reactor” by the Council for Science and Technology, MEXT, Jan. 2013

• Conclusion (extracted)
  • “Establishment of function to investigate the way of development of DEMO (road map) from integrated viewpoint is critical.”

• “It is expected that young researchers (~40’s) in JAEA, NIFS, Universities and Industrials play important role in this function.”
Working Group for Fusion Research

• Then, the WG of Fusion Research under the Council for Science and Technology requested fusion community to launch a core team in July, 2013.

• Under the name of the heads of two leading institutes for fusion R&D, JAEA and NIFS, a joint core team has been formed with participation from a university and industry.
The joint core team towards research and development for DEMO

Revisit and confirm what the goal of DEMO is, what the role of DEMO is, and what specification is requested for DEMO

✓ TRL (Technological Readiness Level) and gap analysis
✓ to narrow options and to define criteria for choice/decision
✓ should pay attention to a remark that lack of social attractiveness due to technological compromise leads to loss of persuasiveness
  ➡ back-cast from what DEMO should be

Define activities which should be implemented and their goal, and make plans from integrated viewpoint

✓ analysis of linkage of issues and risk factors
✓ definition of resources to resolve issues
# Meetings and reports

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 Jun. 2013</td>
<td>1st preparation meeting @ Tokyo</td>
</tr>
<tr>
<td>27 Jun. 2013</td>
<td>2nd preparation meeting @ Tokyo</td>
</tr>
<tr>
<td>22-26 Jul. 2013</td>
<td>1st meeting @ Rokkasho (BA activities)</td>
</tr>
<tr>
<td>7-9 Aug. 2013</td>
<td>2nd meeting @ Naka (ITER, JT-60SA)</td>
</tr>
<tr>
<td>28-30 Aug. 2013</td>
<td>3rd meeting @ Toki (LHD, Fusion Tech. in Helical)</td>
</tr>
<tr>
<td>31 Oct. 2013</td>
<td>4th meeting @ Tokyo</td>
</tr>
<tr>
<td>13 Nov. 2013</td>
<td>5th meeting @ Toki (Promotion plan in 2005)</td>
</tr>
<tr>
<td>10 Dec. 2013</td>
<td>6th meeting @ Tokyo (Blanket)</td>
</tr>
<tr>
<td>25 Dec. 2013</td>
<td>7th meeting @ Tokyo (Divertor)</td>
</tr>
<tr>
<td>17 Jun. 2013</td>
<td>8th meeting @ Tokyo</td>
</tr>
<tr>
<td>3 Feb. 2013</td>
<td>9th meeting @ Tokyo</td>
</tr>
<tr>
<td>17 Feb. 2013</td>
<td>10th meeting @ Naka</td>
</tr>
<tr>
<td>24 Feb. 2014</td>
<td>Interim report to WG for fusion research</td>
</tr>
</tbody>
</table>

in 2014          | Final report                                           |

(Hearing from 55 experts)
## Technology issues: ex) blanket structural materials

<table>
<thead>
<tr>
<th>No.</th>
<th>Decision required</th>
<th>Possible assignees</th>
<th>Facility needed (International or new)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>Irradiation experiments using existing facilities in order to establish structural material design standard. By interaction with related academic societies and design team, clarification of neutron irradiation data is necessary to develop material's design standard. • (Targets) In addition to the basic data required in the step of material development, it is believed that more data will be needed. Which irradiation data, such as dynamic fracture toughness, fatigue, creep, and electromagnetic force test, are additionally needed? Data for joining/welding is needed or not. • (Facility) To solve these problems, additional large-scale irradiation plans using existing irradiation facilities are required or not.</td>
<td>JAEA: Fusion reactor structural materials group and blanket group NIFS: Fusion engineering project Universities: Material scientists Academia: JSME etc.</td>
<td>Fission testing reactors: JOYO, JMTR Hot lab: BA-rokkasho, Tohoku Univ. IMR-Oarai</td>
</tr>
<tr>
<td>3)</td>
<td>To state the role of IFMIF or its alternative in order to solve the above issues. • (Facility) Looking at the situation of the irradiation facilities in Japan, is it necessary to have a new irradiation facility? (Concentration of resources is required or not.) • (Target) What is the target of IFMIF irradiation? Is it possible to compensate modeling/simulation and non-fusion-irradiation experiments for the properties which cannot be evaluated by IFMIF? • (Modeling and simulation) Is it possible to compensate modeling/simulation for the differences between the fusion neutron irradiation environment and IFMIF alternatives.</td>
<td>JAEA: Fusion reactor structural materials group and blanket group NIFS: Fusion engineering project Universities: Material scientists Academia: JSME etc.</td>
<td>BA-Rokkasho, Helios</td>
</tr>
<tr>
<td>4)</td>
<td>To built large scale hot lab facility for neutron-irradiated samples. • If it is necessary to obtain the neutron irradiation effects data necessary for material standard formulation, further test facilities which can handle a large amount of samples is needed (with taking advantage of IFMIF) or not.</td>
<td>JAEA: Fusion reactor structural materials group and blanket group NIFS: Fusion engineering project Universities: Material scientists Academia: JSME etc.</td>
<td>BA-Rokkasho</td>
</tr>
<tr>
<td>4)</td>
<td>To enhance R&amp;D of advanced materials. • Is it possible to make DEMO-TBM as a test bed of advanced materials? This means that the advanced materials will be ready or not at 20 years later from now. (The expected technical maturity should be comparable to the current FB2H at the time.)</td>
<td>JAEA: Fusion reactor structural materials group and blanket group NIFS: Fusion engineering project Universities: Material scientists Academia: JSME etc.</td>
<td>BA-Rokkasho, University’s facilities (HVEM in Hokkaido U., Hot Lab in IMR-Oarai, Tohoku U., DuET&amp;MUSTER in Kyoto U. etc.)</td>
</tr>
<tr>
<td>4)</td>
<td>To enhance the collaboration with industry. • In order to solve the above issues, is it possible to keep and enhance cooperation with industries (materials manufacturers, heavy industry, etc.) for more than 10 years. (for example, ensuring the melting furnace and achievable raw materials for low activation spec)</td>
<td>JAEA: Fusion reactor structural materials group</td>
<td>Industrial facilities(Steel companies)</td>
</tr>
</tbody>
</table>
### Intermediate C&R (around 2020)

**Table I C&R Items in the future fusion R&D (planned at 2005)**

<table>
<thead>
<tr>
<th>Issues</th>
<th>Performance goal by check and review in the interim phase</th>
<th>Transition conditions to the DEMO phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Demonstration of burn control in self-heating regime using experimental reactor</td>
<td>• Lay out plans for achieving the technological goals of experimental reactor based upon the actual ITER</td>
<td>• Demonstration of maintenance of plasma with $Q \geq 20$ (for duration longer than about several 100 s) and burn control in ITER</td>
</tr>
<tr>
<td>2. Realization of non-inductive steady-state operation with $Q \geq 5$ using experimental reactor</td>
<td>• Lay out plans for achieving the goals based upon the actual ITER</td>
<td>• Demonstration of non-inductive current drive plasma with $Q \geq 5$ (for duration longer than about 1,000 s)</td>
</tr>
<tr>
<td>3. Establishment of integration technology using experimental reactor</td>
<td>• Complete ITER facilities • Acquire integration technology related to manufacturing, installation, and adjustment of components</td>
<td>• Establishment of integration technology through the operation and maintenance of ITER. Verification of safety technology</td>
</tr>
<tr>
<td>4. Establishment of high-beta steady-state operation method to obtain economical prospects</td>
<td>• Conduct ITER support research and preparatory research for high-beta steady-state plasma and launch research using National Centralized Tokamak</td>
<td>• Attainment of sustaining high-beta ($\beta_n=3.5-5.5$) plasma in collision-less regime in National Centralized Tokamak.</td>
</tr>
<tr>
<td>5. Development of materials and fusion technologies related to DEMO reactor</td>
<td>• Complete establishing technological basis for power generation blanket. Complete manufacturing test components to be used in the functional test of ITER • Acquire reactor irradiation data of reduced activation ferritic steels up to 80dpa and determine test materials to be used in the irradiation test under neutron irradiation environment similar to that of fusion reactor</td>
<td>• Demonstration of tritium breeding and recovery functions, removal of heat and power generating blanket in a low-fluence DT experiment on ITER • Completion of verification of heavy irradiation data of reduced activation ferritic steels up to a level of 80 dpa</td>
</tr>
<tr>
<td>6. Conceptual design of DEMO</td>
<td>• Determine the overall goal of DEMO • Conduct preliminary work on the conceptual design of DEMO • Make requests for the required development of fusion plasma research and fusion technology</td>
<td>• Completion of conceptual design of DEMO consistent with the development of fusion plasma research and fusion technology</td>
</tr>
</tbody>
</table>
合同コアチーム活動の起点となる問題意識

プラズマ・核融合学会誌 （平成26年12月号）
salon記事 「今後の核融合原型炉開発に向けて」
坂本修一前研究開発戦略官、山田弘司

問題提起

原型炉段階へ進むためには、
核融合コミュニティが
① 全体を統合的視座で把握、
② 共通目標を設定し、
③ その実現への寄与を評価軸と捉えて、プロジェクトや組織、
制度の運営から、個々の研究活動まで 指向性を強化
することが必要ではないか

⇒ 目標へどれだけ近づいたかを見せることができる計画
（コミットメント）とその実行
合同コアチーム報告書の要点（1）

1. 核融合原型炉に求められる基本概念
目的：
他のエネルギーと競合可能な経済・社会的合理性の達成見通し
目標：実用化に備え、以下を実現
数十万kWを超える定常かつ安定な電気出力
実用に供しうる稼働率
燃料の自己充足性を満足する総合的なトリチウム増殖

2. 進め方
(1) まず、最も開発段階の進んだトカマク方式によって第四段階への移行条件を満足させ得るための技術課題を共通目標として定め、ITER計画ともに全日本体制で課題解決に当たる必要

(2) 加速と課題解決を促し、また移行判断等において、総合的進捗状況を踏まえられることができるよう、相補的・代替的方式、革新的概念など、研究開発において一定の多様性を持った取組をバランスのとれた形で、より戦略的につなげて進める必要
3. 原型炉技術基盤構築の時系列展開を可視化、総覧チャートを作成
   2020年ごろ: 中間チェック・アンド・レビュー（ITERのファーストプラズマ）
   2027年ごろ: 原型炉段階への移行判断（ITERにおけるDT燃焼実証）
を想定し、炉設計と研究開発の課題解決への取組を示した

4. 技術基盤構築において今後、特に留意すべき点
   (1) ITER計画は明確なクリティカルパス、その着実な遂行は必須
   (2) ITER計画以外で、最も喫緊に取り組むべきこと
       「炉設計活動の強化」と「ダイバータ研究開発の戦略的加速」
   (3) 全体を律速するクリティカルパスになると考えられるもの
       「テストブランケットモジュール(TBM)」と「核融合中性子源」
   (4) 産学官の共創の場の構築、実効的なものとするための措置

申し送り: まとめるとまでに至らなかった重要な点
   「核融合エネルギーの社会科学的検討」
   「ヘリカル方式及びレーザーア方式についての調査・検討」
ITER計画について

✓ ITER計画の進捗状況は時系列展開全体に大きな影響
✓ 判断の要件について、その判断の時期と基準の具体化を進める必要
✓ 特に、エネルギー増倍率、ブランケット機能、長時間維持の実証等についての成果がいつ、どこまで見込めるのか、の共通認識に立って、具体的な判断の要件が今後の原型炉開発ロードマップに位置づけられる必要

炉設計活動の強化について

✓ 炉設計は初期段階から11の技術課題項目とリンク
✓ 技術課題項目の開発目標・要求性能・技術仕様を確定し、研究開発を推進するため、炉設計活動の体制を拡充し、早急に強化する必要
✓ 特に、ダイバータ、ブランケット、保守、安全性の課題は重点的検討必要

ダイバータ研究開発の戦略的加速について

✓ ダイバータは原型炉で想定される運転条件と現在の科学的理併及び技術成熟度とのかかい離が極めて大
✓ 炉設計活動における特段の強化と合わせて、中間C＆R及び移行判断の要件の目標達成を指向した研究開発の戦略的な加速が不可欠
テストプランケットモジュール(TBM)

- ITER-TBM最終設計レビュー 2018年に設定
- 性能実証試験、照射後試験
- 先進プランケット開発に関連した他極との協力体制

核融合中性子源

- 移行判断前に、それまでに備わった材料に関わる知見からなる予測モデルを実験検証し、適用範囲を確認する必要 ➔ 20dpa程度の照射

全日本体制を実効的なものとするための措置

- 原型炉に向けた技術基盤構築にはリソースを最大限に活かし、さらなる展開を図るため全日本体制で取り組むことが必要不可欠
- 研究機関、大学、企業が問題意識と戦略を共有し、一体となって課題解決に向けた研究開発を推進するための体制、すなわち「産学官の共創の場の構築」

二つの観点を指摘

- 原子力機構六ヶ所サイトを原型炉開発に向けた中心拠点として発展
- 人材の流動性と多様性を高める:クロスアポイント制度の積極的導入
原型炉開発の技術基盤構築を進めるための体制（案）

商用炉＝発電

＜核融合科学技術委員会＞
核融合研究推進政策の議論・決定、ロードマップの策定

評価

方針提示

＜原型炉開発総合戦略TF＞
- 要素技術の俯瞰的把握・調整、
- 全体戦略の最適化（アクションプラン案の策定等）

情報共有・要請等

各要素技術の状況把握等

関連学協会

原型炉概念設計
＜原型炉合同特別チーム @JAEA六ヶ所研究所＞
- 課題解決に向けた企画立案・実施
- 関連WSの開催等

総合調整
（チーム内の総合調整、TF及び学協会等との調整等）

理論解析

B大学

超伝導

B大学

A大学

重電
メーカー

ダイバータ・プランケット

NIFS

C大学

トリチウム化学

D大学

JAEA

大学

NIFS

大学・研究機関、民間企業の人材を総合

メーカー

重電
メーカー

A大学

NIMS

プラント工学

加熱

C大学

メーカー

重電
メーカー
イタズラ書き

Comprehensive DEMO Strategy Task Force

Fusion Science and Technology Committee