# Report by the Joint-Core Team for the Establishment of Technology Bases Required for the Development of a Fusion DEMO Reactor

## - Chart of Establishment of Technology Bases for DEMO -

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**The original version in Japanese: 19 January 2015**
**The English-language version: 1 March 2015**

Joint-Core Team
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## Abstract
In accordance with the request of the Working Group on Fusion Research, the Nuclear Science and Technology Committee, the Subdivision on R&D Planning and Evaluation, the Council for Science and Technology, the Ministry of Education, Culture, Sports, Science and Technology, the joint-core team has worked on strategy for establishment of technology bases required for development of a fusion DEMO reactor by taking into account the progress of the ITER project, the BA activities, and academic researches such as the Large Helical Device. Based upon the previous report on Basic Concept of DEMO and Structure of Technological Issues (original version in Japanese issued on the 18th, July, 2014), the timeline of research and development to resolve technological issues has been shown from the integrated view. This overview is referred to as "Chart of Establishment of Technology Bases for DEMO". The highlighted and emergent requirements which have been identified in this Chart are remarked.

This report is documented by the joint-core team of members and experts from the National Institute for Fusion Science, the Japan Atomic Energy Agency, Kyoto University, the Japan Atomic Industrial Forum, Inc., and Keio University.

The electric file is available at http://www.naka.jaea.go.jp/english/index.html

## Keywords:
fusion DEMO reactor, reactor design, technology bases, technological issues, roadmap, timeline, critical path

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## Agenda

# 1. Introduction

The Working Group on Fusion Research, the Nuclear Science and Technology Committee, the Subdivision on R&D Planning and Evaluation, the Council for Science and Technology, the Ministry of Education, Culture, Sports, Science and Technology (hereafter referred to as “MEXT”) in the 7th term (March 2013 – February 2015) has discussed establishment of the function to compose strategy for the development of a “DEMOnstration fusion reactor” (hereafter referred to as “DEMO”) with integrated viewpoints towards the next *Fourth Phase Program* with a core project of DEMO [1], which has the goals of technological demonstration and economic feasibility of fusion energy. This function will be the core engine for the establishment of technology bases for the development of DEMO.

Based upon thorough discussions, the Working Group on Fusion Research requested, at the 37th meeting on 3 July 2013, the Fusion Research and Development Directorate, the Japan Atomic Energy Agency (hereafter referred to as “JAEA”), and the National Institute for Fusion Science (hereafter referred to as “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 [2].

The terms of reference of this joint-core team for the establishment of technology bases required for development of DEMO defined by the Working Group on Fusion Research are as follows [2]:

1. 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 Broader Approach (BA) activities and academic research such as the Large Helical Device (LHD), and standing on the consensus in the Japanese fusion community.

2. 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

3. Notes

1) To conduct wide cooperation and exchange with researchers and technological experts in industry, government, and academia so as to stand on consensus in the Japanese fusion community. In particular, expansion of cooperation and exchange between scientific societies is encouraged.
2) In order to refer a political deliberation to the Working Group on Fusion Research, a representative of the joint-core team is requested to report on the status of activities routinely.

In accordance with the request by the Working Group on Fusion Research, the joint-core team, whose members are listed at the end of this report, was launched and has engaged with assigned issues. The joint-core team has reviewed the analyses in “Future Fusion Research and Development Strategy” (hereafter referred to as “Future Fusion R&D”) determined by the Atomic Energy Commission’s Advisory Committee on Nuclear Fusion in October 2005 [1] and other reports to date and has taken into account the most recent scientific and technological achievements and their latest prospects. Summary of issues in the investigated strategy for the establishment of technology bases required for DEMO was reported as an interim report at the 38th meeting of the Working Group on Fusion Research (24 February 2014) [3] (hereafter referred to as the “Interim Report”). Based upon the “Interim Report”, further analysis has been made by the joint-core team by taking account of comments at the Working Group on Fusion Research, and complied documentation was reported at the 41st meeting of the Working Group on Fusion Research (24 June 2014) [4]. The report finalized by further amendments due to comments on this 41st meeting and required revision dated 18 July 2014 (hereafter referred to as the “Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)”) was submitted to the 42nd meeting of the Working Group on Fusion Research (1 August 2014) [5].

Based upon the basic concept of DEMO and structure of technological issues documented in the “Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)” [5], the joint-core team has sorted out tasks regarding the development of the design of DEMO, and the research & development programs to resolve the issues and to provide the required evidence to support the design into the consistent timeline, as a whole with attention paid to the Working Break-down Structure (WBS). Then the overview picture to make the linkage of all related programs visible has been proposed.

The Roadmap of DEMO Development will be defined by the Japanese government in future. Since the proposed overview picture will make an essential contribution to formulation of the comprehensive strategy, which will be the main body of the Roadmap of DEMO Development, this overview picture is referred to as *Chart of Establishment of Technological Bases for DEMO*. This report describes this chart and highlighted remarks recognized in the process to formulate this chart.

The joint-core team has promoted communication with the community in order to fulfil the remarks defined in 3.Notes, 1) of the term of reference and has proceeded with the examination with the formulation of *Chart of Establishment of Technological Bases for DEMO* based upon diversified opinion from the community. The joint-core team has had more than 30 open meetings in these 18 months. Opinions collected after the publication of the “Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)” are attached to the present report of the Japanese-language version as reference materials (not available in this English-language report). Also, in order to stimulate the future vision in common in the community, the article to describe the prospected direction towards DEMO from the perspective of the administrative authority and the joint-core team has been published in *Journal of Plasma and Fusion Research* [6].

# 2. Timeline of Research and Development to Resolve Technological Issues

## 2-1. Most Important Milestones

Fundamental concept for the changeover to the DEMO phase (*Fourth Phase Program*) is documented in “Future Fusion R&D”, where “Performance goal by check and review in the interim phase” (hereafter referred to as “*Intermediate C&R*”) and “Transition conditions to the DEMO phase” (hereafter referred to as “*Assessment of Transition Conditions*”) are defined as shown in Check and Review Items in Future Fusion R&D (draft) (see Table I). These two points are the most important milestones in the timeline.

Table I  Check and Review Items in Future Fusion R&D (draft)

from “Future Fusion R&D”, The Atomic Energy Commission’s Advisory Committee on Nuclear Fusion, October 2005

| Issues | Performance goal by check and review in the interim phase | Transition conditions to the DEMO phase |
| --- | --- | --- |
| 1. Demonstration of burn control in self-heating regime using experimental reactor | • Lay out plans for achieving the technological goals of experimental reactor based upon the actual ITER | • Demonstration of maintenance of plasma with Q≥20 (for duration longer than about several 100 s) and burn control in ITER |
| 2. Realization of non-inductive steady-state operation with Q≥5 using experimental reactor | • Lay out plans for achieving the goals based upon the actual ITER | • Demonstration of non-inductive current drive plasma with Q≥5 (for duration longer than about 1,000 s) |
| 3. Establishment of integration technology using experimental reactor | • Complete ITER facilities<br>• Acquire integration technology related to manufacturing, installation, and adjustment of components | • Establishment of integration technology through the operation and maintenance of ITER. Verification of safety technology |
| 4. Establishment of high-beta steady-state | • Conduct ITER support research and preparatory research for | • Attainment of sustaining high-beta ($\beta_n$=3.5-5.5) plasma in |

| | | |
|---|---|---|
| operation method in order to obtain economical prospects | high-beta steady-state plasma and launch research using National Centralized Tokamak | collision-less regime in National Centralized Tokamak. |
| 5. Development of materials and fusion technologies related to DEMO reactor | • Complete establishing technological basis for power generation blanket. Complete manufacturing test components to be used for the functional test in ITER<br>• 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 | • Demonstration of tritium breeding and recovery functions, removal of heat and power generating blanket in a low-fluence DT experiment on ITER<br>• Completion of verification of heavy irradiation data of reduced activation ferritic steels up to a level of 80 dpa |
| 6. Conceptual design of DEMO | • Determine the overall goal of DEMO<br>• Conduct preliminary work on the conceptual design of DEMO<br>• Make requests for the required development of fusion plasma research and fusion technology | • Completion of conceptual design of DEMO consistent with the development of fusion plasma research and fusion technology |

As described in the “Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)”, it is relevant to elaborate the timeline of technological development with the presumption of the *Intermediate C&R* around 2020 when the first plasma of ITER is expected and the *Assessment of Transition Conditions* around 2027 when the fusion burning with deuterium and tritium (DT burning) fuels will be demonstrated in ITER.

This means that the ITER project is the ticking clock of the timeline and it is beyond question that its steady progress is indispensable. Since the progress of the ITER project has a great impact on the development of the timeline, it is necessary to deepen discussions about an appropriate time and criteria of *Intermediate C&R* and the *Assessment of Transition Conditions* by revisiting the grounds of the items described in Table I based upon the common understanding of how much and when the achievement is prospected by the ITER project.

## 2-2. Level of Completion of DEMO Design

In case commercialization of fusion energy is sought in the middle of the 21st century, the term between the *Intermediate C&R* and the *Assessment of Transition Conditions* should be defined as the preparation term towards the DEMO phase (*Fourth Phase Program*) and the start of engineering R&D at the proper level in response to *Intermediate C&R* should be promoted for early realization of DEMO. *Intermediate C&R* requests the start of the operation of ITER as well as maturity of conceptual design of DEMO. In "Future Fusion R&D", the goal at *Intermediate C&R* is defined as (1) to determine the overall goal of DEMO, (2) to conduct preliminary work on the conceptual design of DEMO, and (3) to make requests for the required development of fusion plasma research and fusion technology, as shown in Table I.

During the coming several years until the *Intermediate C&R*, ITER and JT-60SA are under construction, and development on fusion technologies remains on a limited scale. These situations imply that limited amount of technical information will be provided to the DEMO design activity, albeit input expected on know-how accumulated throughout the construction of these machines. However, anticipating that most of all of the R&Ds are embarked upon or expanded after the *Intermediate C&R* along technical requirements and basic specifications defined by the DEMO design activity in the coming several years, it is an urgent matter to establish and reinforce the design activity to address the following issues till *Intermediate C&R*:

- Operation plan of DEMO*
- Basic concept and design parameters
- Components and facilities of DEMO plant and their specifications
- Development of software and databases for DEMO design
- Primary cost assessment (to be rationalized after *Intermediate C&R*)
- Safety design guidelines
- Management and disposal scenario of radioactive-waste
- Definition of R&D issues to be implemented for decision on DEMO concept
- Resources procurement strategy including initially loading tritium

*) To elaborate upon the operation plan and the life of DEMO based on the technology and data which need to be developed or accumulated during the in-service period.
Technology and data envisaged: operational technique, validation of plasma prediction codes, operational characteristics (output stability, controllability, and operational margins), failure data of plant components and auxiliary facilities, plant operation and maintenance, worker dose data, handling and management of wastes, environmental monitoring data in normal operation, development of advanced technology for commercialization (blanket, divertor and materials).

It will be necessary at the *Intermediate C&R* that establishment of technological bases to support the overall goal of DEMO and the conceptual design of DEMO by evidence is predictable. And then, consistency between the design of DEMO and achievement/evidence by the research and development programs will be needed at the *Assessment of Transition Conditions*.

## 2-3. Chart of Establishment of Technology Bases for DEMO

Based upon examination described in the "Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)", in particular, the structure of technological issues in the following 11 elements of DEMO,

(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,

all related research and development programs are organized in the *Chart of Establishment of Technological Bases for DEMO* around the development of the design of DEMO as the primary axis with attention paid to required evidence to support the maturity of the design of DEMO and consistency in the timeline.

The stages of the design have been defined based upon the fundamental concept in "Roadmap and Technological Strategy towards Commercialization of Fusion Energy" [7] by the Fusion Energy Forum as follows:

| | |
|---|---|
| • till the *Intermediate C&R* | : Basic design (Pre-concept) |
| • till the *Assessment of Transition Conditions* | : Basic design and R&D activity supporting conceptual design |
| • till the decision of construction of DEMO | : Engineering design and R&D activity supporting engineering design |
| • after the decision of construction of DEMO | : Construction and manufacture design |

The outline of the development of the design of DEMO, and newly required facilities and platforms which have been pointed out in the "Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)" are extracted from the entire chart and shown in Fig. 1. Figure 1 is the summary of *Chart of Establishment of Technological Bases for DEMO* consisting mainly of major projects, development of the design of DEMO and newly required R&D facilities and platforms in the followings:

- Test facility of large-scale superconducting coils which fulfils the specification of DEMO (Test facility of superconducting conductor and coils with around 16 T)
- R&D facilities for blanket (development of ITER-TBM (Test Blanket Module), post-irradiation experiments, development of waste disposal technology)
- Test facility of real-scale performance of NBI (including expansion of ITER NBTF (Neutral Beam Test Facility[1]))
- 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 (International Fusion Material Irradiation Facility / Engineering Verification and Engineering Design Activity))
- R&D facility for large-scale component maintenance.

In addition,

- R&D facility for divertor including innovative concept

is added since it is necessary to elevate the technological maturity of divertor most from the present level in order to assess technological feasibility of DEMO, as mentioned below.

Notation of *Chart of Establishment of Technological Bases for DEMO*

By arranging the program packages shown as the structure of the issues in “Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)” as tasks which will be developed to WBS, the overview picture of development of all related programs is made visible. Notation is as follows:

(1) Preparation phase of the task is shown in a light colour bar and its full-scale development is shown in a deep colour bar.

(2) In case there is strong linkage and/or overlap with other elements or tasks in other elements, linked counter items are documented in the column of “Link to other tasks”.

(3) Milestones are marked by the following symbols.

① open diamond ◇: completion of preparation for necessary condition of the *Intermediate C&R*. Note that further improvement is continued.

② closed diamond ◆: completion of task and meeting the *Intermediate C&R*.

③ open circle ○: completion of preparation for necessary condition of the *Assessment of Transition Conditions*. Note that further improvement is continued.

[1] NBTF is now under construction in Padova, Italy, in order to demonstrate the real full performance of the neutral beam injector for ITER.

④ closed circle ●: completion of task and meeting of the *Assessment of Transition Conditions*.

(4) Remarks for the task are inserted by the text box without a frame border.

(5) Remarks for the platform such as facility are inserted by the text box with a frame border.

(6) Linkage and interference between tasks in the same element are shown by bidirectional arrows.

Complete picture of *Chart of Establishment of Technological Bases for DEMO* is shown in Fig. 2.

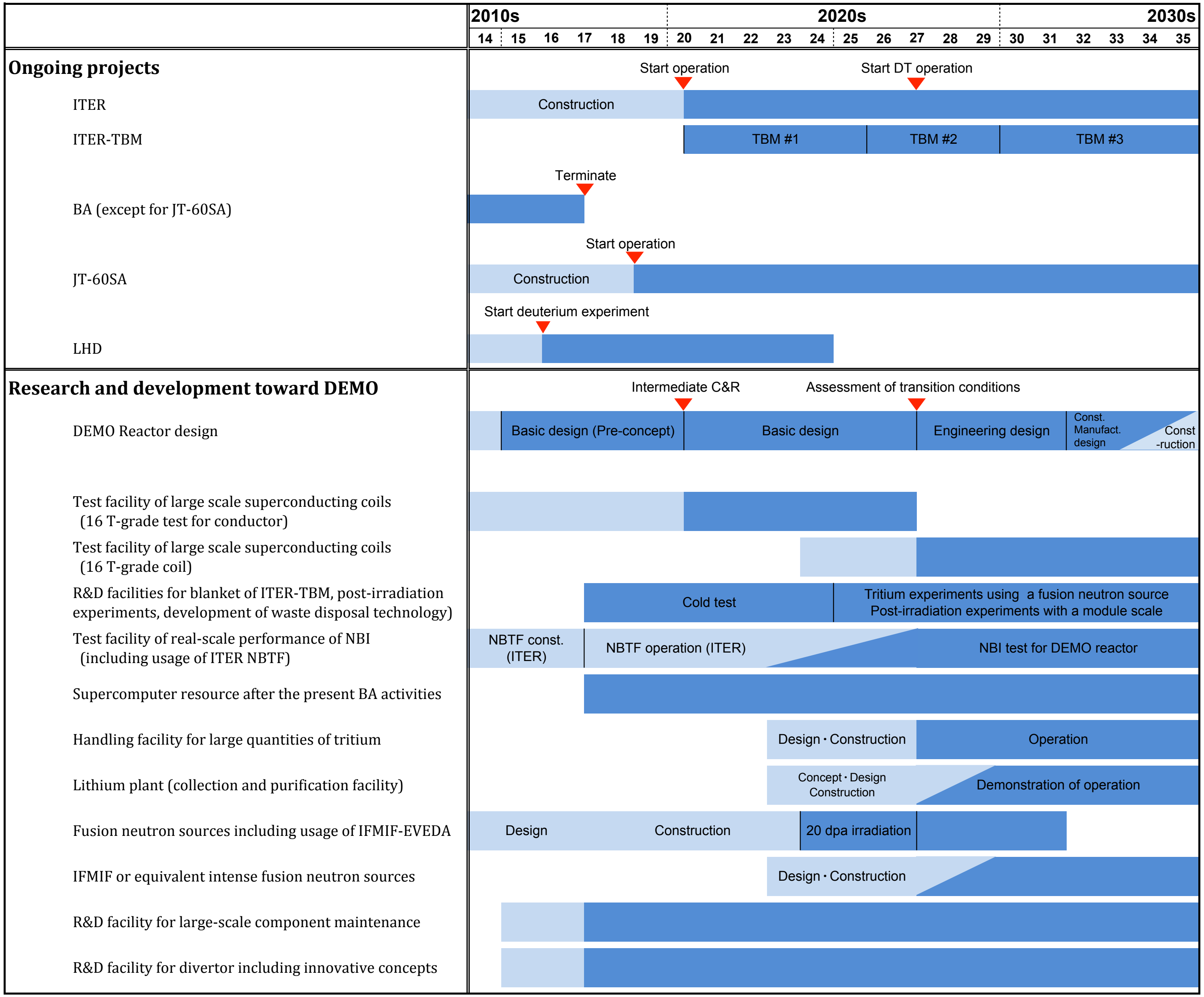


Fig. 1 Summary of *Chart of Establishment of Technological Bases for DEMO* consisting of major projects, development of the design of DEMO and newly required R&D facilities and platforms.

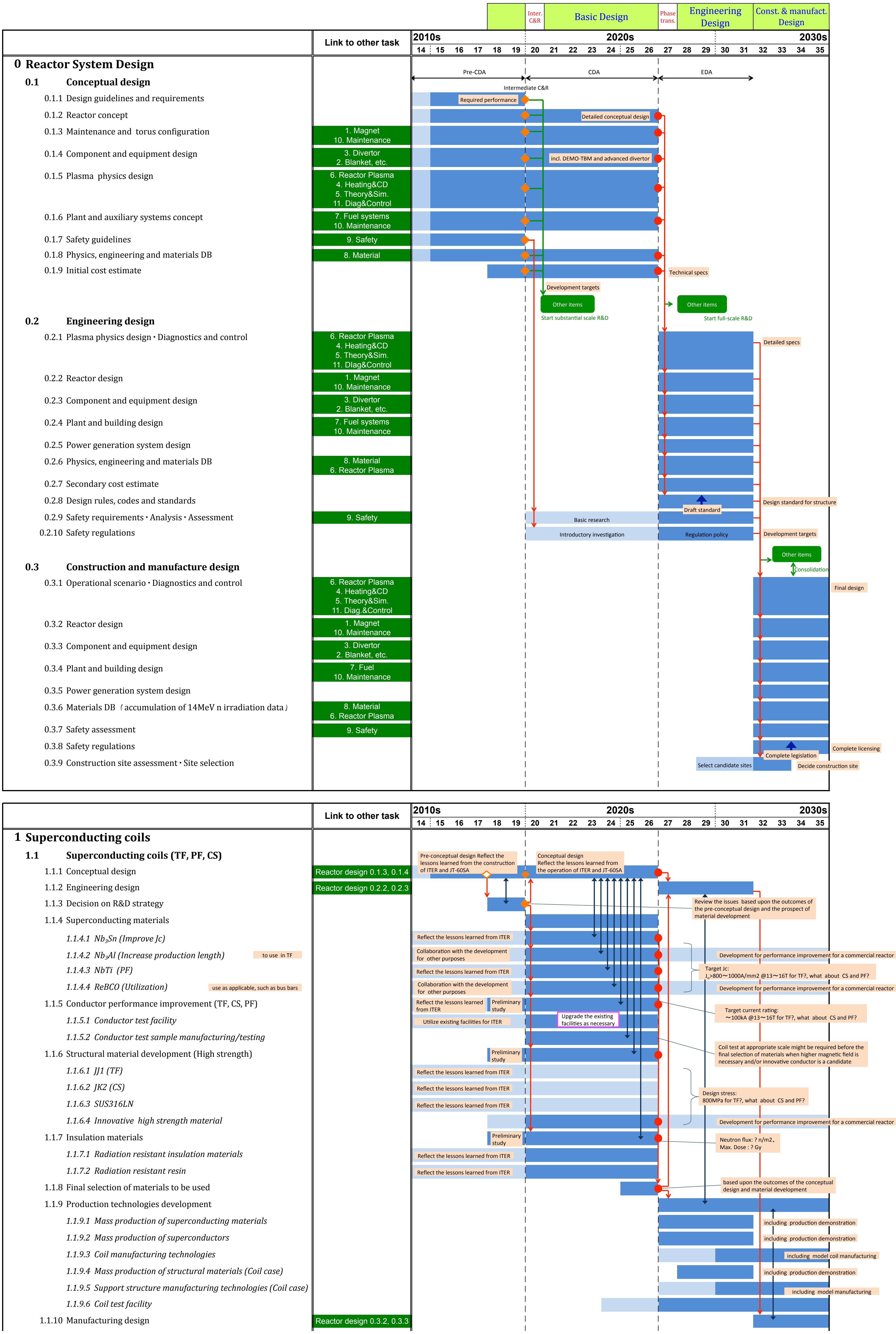


Fig.2 Chart of Establishment of Technological Bases for DEMO (1)

| Task | Link to other task |
|---|---|
| **1.2 Coil support structures** | |
| 1.2.1 Conceptual design | Reactor design 0.1.3, 0.1.4 |
| 1.2.2 Engineering design | Reactor design 0.2.2, 0.2.3 |
| 1.2.3 Decision on R&D strategy | |
| 1.2.4 Structural material development (High strength) | |
| 1.2.5 Final selection of materials to be used | |
| 1.2.6 Manufacturing technologies development | |
| 1.2.7 Manufacturing design | Reactor design 0.3.2, 0.3.3 |
| **1.3 Cryogenic System** | |
| 1.3.1 Conceptual design | Reactor design 0.1.4, 0.1.6 |
| 1.3.2 Engineering design | Reactor design 0.2.3, 0.2.4 |
| 1.3.3 Manufacturing design | Reactor design 0.3.3, 0.3.4 |
| | **Link to other task** |
| **2 Blanket** | |
| **2.1 Design of DEMO blanket system** | Reactor design 0.1.3 |
| **2.2 Expansion of basic/reference data** | |
| 2.2.1 Compatibility, vapor pressure, （water/vapor） chemical reaction rate etc. | Safety 9.2.3 |
| 2.2.2 Compile data base for use in the design activities （properties of packed pebble bed etc.） | Reactor design 0.1.4 Safety 9.2.3 |
| **2.3 Validated reference data base Data base supporting design standards** | Reactor design 0.1.8 Code & standards 8.1.5 |
| **2.4 Demonstration of integrated functions of blanket system in fusion environment** | |
| 2.4.1 Pre-conceptual design of DEMO blanket and tritium system | Reactor design 0.1.4 |
| 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 soundness 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 | Reactor plasma 6.13 Material 8.1.2 |
| **2.5 Demonstration of tritium breeding and recovery** | Theory&Sim. 5.2 Fuel systems 7.1 |
| 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 Integrated circulation loop tests simulating reactor conditions | |
| 2.6.3 Development of heat exchange technologies and technological investigation on power generation system | |
| 2.6.4 Investigation on DEMO-TBM design, offering of preliminary design and their comparison | Reactor design 0.1.4 |
| 2.6.5 Expansion of fundamental and standard data | |
| 2.6.6 Integrated demonstration under reactor conditions with small mock-up | |
| **3 Divertor** | |
| **3.1 Plasma operation scenario** | |
| 3.1.1 Understanding of physical mechanism which dominate divertor operation | Reactor Plasma 6.7, 6.8, 6.9 |
| 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 | Theory&Sim. 5.1.2 Reactor Plasma 6.13 |
| 3.1.6 Development of theoretical simulation for burning plasma | Theory&Sim. 5.1.1, 5.1.2, 5.1.3 |
| **3.2 Development of theoretical simulation for burning plasma** | |
| 3.2.1 Decision of consistent fusion output with divertor heat flux | Reactor design 0.1.1 |
| 3.2.2 Understanding of heat removal property of divertor components (steady & transient) | |
| 3.2.3 Clarification of heat removal property of low activation material | |
| 3.2.4 Demonstration of heat removal property of W & Cu 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 hydrogen behavior on plasma facing components | Reactor Plasma 6.9, 6.10 |
| 3.4.2 Understanding of hydrogen behavior under actual condition | Reactor Plasma 6.9, 6.10 |
| 3.4.3 Development of feasible vacuum pump under DEMO reactor conditions | Reactor design 0.1.1 |
| 3.4.4 Establishment of consistent particle exhaust scenario with heat removal | Theory&Sim. 5.1.3 |
| **4 Heating and Current Drive Systems** | |
| **4.1 Technical specification** | |
| 4.1.1 To clarify technological specifications of heating and current drive systems | Reactor design 0.1 Diag.&Control 11.3 Reactor Plasma 6.1 |

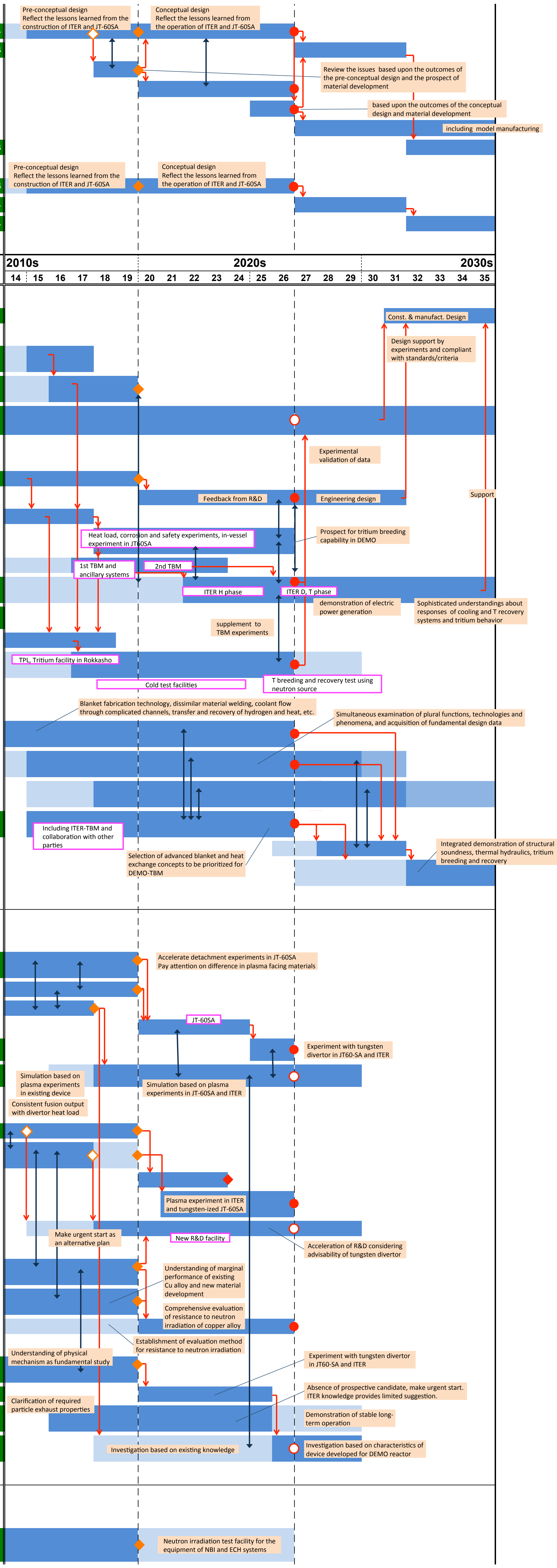


Fig.2 Chart of Establishment of Technological Bases for DEMO (2)

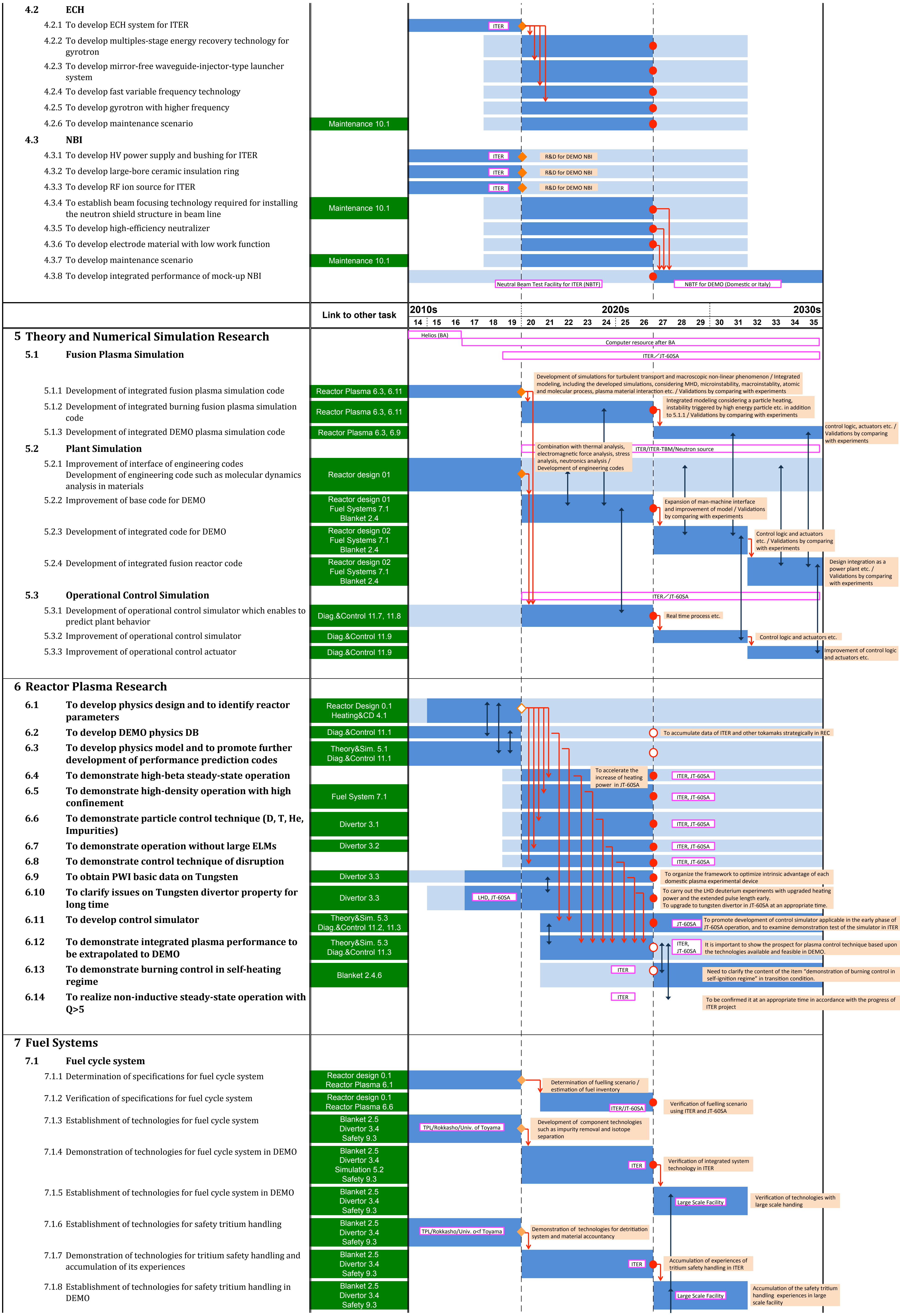


Fig.2 Chart of Establishment of Technological Bases for DEMO (3)

| Task | Link to other task |
|---|---|
| 7.1.9 Accumulation of data base for development of equipment treating tritium | Blanket 2.5<br>Divertor 3.4<br>Safety 9.3 |
| 7.1.10 Accumulation of experiences of equipment operation treating tritium | Blanket 2.5<br>Divertor 3.4<br>Safety 9.3 |
| 7.1.11 Establishment of manufacturing technologies for equipment treating tritium in DEMO | Blanket 2.5<br>Divertor 3.4<br>Safety 9.3 |
| 7.1.12 Construction of large scale facility | |
| **7.2 Securing Lithium** | |
| 7.2.1 Examination of process to secure lithium 6 | |
| 7.2.2 Establishment of concept for lithium 6 plant | |
| 7.2.3 Accumulation of plant operation experiences | |
| **7.3 Securing Initial Loading of Tritium** | |
| 7.3.1 Examination of process for securing initial loading of tritium | |
| 7.3.2 Preparation of securing initial loading of tritium | |
| 7.3.3 Investigation of start-up scenario without initial loading of tritium | Reactor design 0.1 |

| | Link to other task |
|---|---|
| **8 Material Development and Establishment of Codes and Standards** | |
| **8.1 Reduced-activation ferritic (RAF) steel** | |
| 8.1.1 To establish mass production technologies of RAF steel | |
| 8.1.2 To establish blanket structure fabrication technologies | Blanket 2.4 |
| 8.1.3 To clarify requests to the structural materials for DEMO fusion reactor | Reactor design 0.1.8 |
| 8.1.4 To present technical specifications of blanket structural materials for DEMO fusion reactor | Reactor design 0.2.6<br>Blanket 2.4 |
| 8.1.5 To initiate preparatory activities for materials standardization in academic societies and so on | Reactor design 0.2.8 |
| 8.1.6 To obtain data of joining/coating, effect of electromagnetic force, and compatibility with coolants | Blanket 2.4 |
| 8.1.7 To obtain data of joining/coating, effect of electromagnetic force, compatibility with coolants, and the irradiation effect on these properties | Blanket 2.4 |
| 8.1.8 To establish the validity of material data obtained by SSTT | |
| 8.1.9 To standardize small specimen testing technologies (SSTTs). | |
| 8.1.10 To obtain 80 dpa irradiation data by using fission reactor | |
| 8.1.11 To validate the 80 dpa irradiation data by using fission reactor | Reactor design 0.2.6, 0.2.8<br>Availability 10.1.4 |
| 8.1.12 To enhance understanding of the impact of transmutation helium using fusion neutron source | Reactor design 0.2.6, 0.2.8<br>Availability 10.1.4 |
| 8.1.13 To clarify fusion neutron irradiation effect | Reactor design 0.3.6<br>Availability 10.1.4 |
| 8.1.14 To establish degradation models based on irradiation-field correlation theory | Reactor design 0.2.8<br>Availability 10.1.4 |
| **8.2 Advanced materials** | |
| 8.2.1 To clarify the uses of advanced materials and to enhance the material database | Reactor design<br>Blanket 2.6 |
| **9 Safety of DEMO reactor and Safety research** | |
| **9.1 Safety regulation and order** | Reactor design 0.2.10 |
| **9.2 Arrangement of safety related engineering issues** | |
| 9.2.1 Establishment of failure scenario of in-vessel component | |
| 9.2.2 Assessing damage of in-vessel components | Reactor plasma 6.8 |
| 9.2.3 Arrangement of safety characteristics of DEMO plant | Blanket 2.2.1, 2.2.2<br>Material 8 |
| **9.3 Safety analysis and assessment** | |
| 9.3.1 Development of computer simulation codes to estimate damage of in-vessel component by plasma | Theory&Sim. 5.2.2 |
| 9.3.2 Development of computer simulation codes for safety analysis | |
| 9.3.3 V&V experiments | |
| 9.3.4 Safety assessment of DEMO plant | |
| 9.3.5 Guidelines for both plasma control and securing soundness of in-vessel components | |
| 9.3.6 Guideline to ensure DEMO plant safety and consistent design conditions | Reactor design 0.2 |
| **9.4 Assessment of environmental effect of tritium** | |
| 9.4.1 Assessment and control of tritium release to the environment | |
| 9.4.2 Develop the guideline of the safety design of DEMO | |
| **10 Availability and maintainability** | |
| **10.1 DEMO reactor design** | |
| 10.1.1 Determination of maintenance method, reactor structure and parameters | Reactor design 0.1.1, 0.1.2, 0.1.3 |
| 10.1.2 Investigation and selection of components to be maintained, method and working process | Reactor design 0.1.1, 0.1.2, 0.1.3 |
| 10.1.3 Optimization of maintenance process and reactor shutdown period | Reactor design 0.1.3, 0.1.6 |
| 10.1.4 Investigation of back end process (amount of waste and disposal process) | Reactor design 0.1.3<br>Material 8.1 |
| 10.1.5 Standard definition for disposal and reuse of radioactive waste (preparation for laws and regulations) | |
| **10.2 Development of maintenance technologies** | |
| 10.2.1 Medium-scale R&D on maintenance technologies to support conceptual design of DEMO | |
| 10.2.2 Development of functional materials and devices aiming at integrated dose of 200 MGy | |
| 10.2.3 Full-scale R&D in maintenance technologies for DEMO | |
| **10.3 Accumulation of maintenance technologies** | |
| 10.3.1 Equipment handling and inspection in nuclear facility | |
| 10.3.2 Accumulation of technologies for remote handling, inspection and maintenance | |

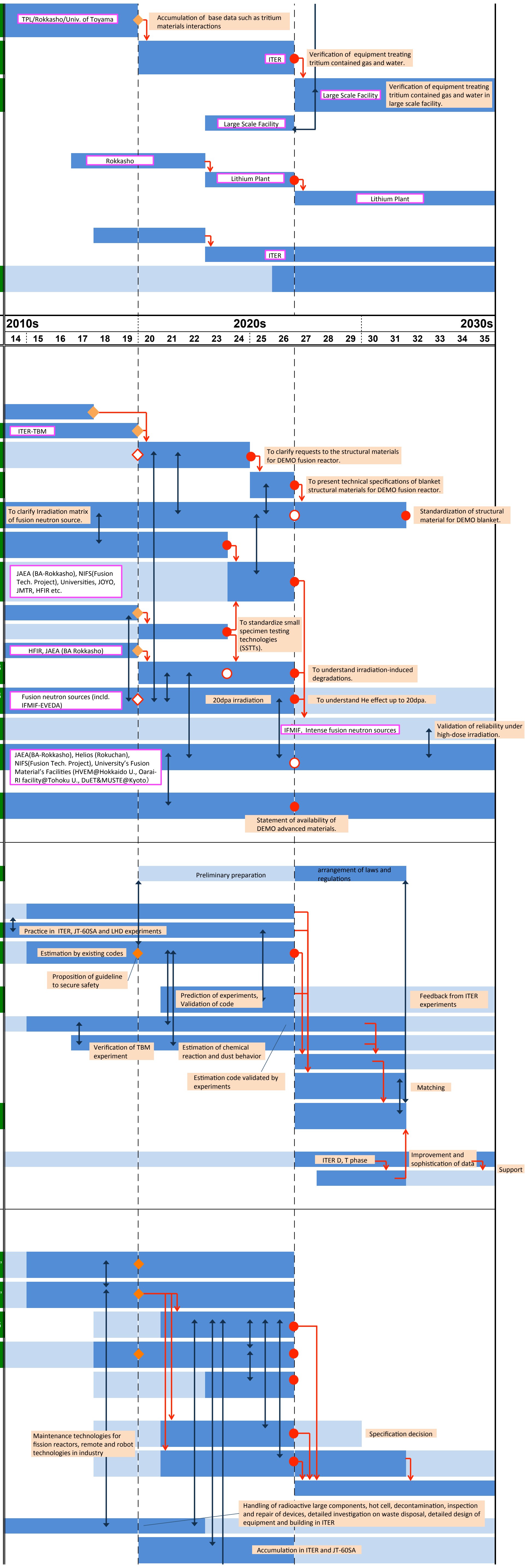


Fig.2 Chart of Establishment of Technological Bases for DEMO (4)


Fig.2 Chart of Establishment of Technological Bases for DEMO (5)

## 3. Highlighted Remarks in Establishment of Technology Bases for DEMO

At the *Assessment of Transition Conditions* towards the next *Fourth Phase Program* with a core project of DEMO, validity of plan, overall maturity of technological bases, clarity of implementing bodies, and appropriateness of a system for cooperation and coordination among participating sectors are needed to be sufficient as a whole from the integrated view. *Chart of Establishment of Technological Bases for DEMO* visualizes all of the related programs and provides a complete picture of related processes. It is expected that the strategic PDCA cycle will be developed by making full use of this 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.

**Reinforcement of DEMO design activity**

DEMO design activity exchanges close links with technological issues in 11 elements from an early stage of the baseline design of a DEMO concept. For this reason, the development organization for the DEMO design needs to be expanded devoting a notable scale of resources and to be urgently enhanced to timely define the development targets, required performance and technical specifications of each technological issue, and to boost necessary research and development without delay. In particular, intensive design work is necessary for divertor, breeding blanket, remote maintenance, and safety issues considering the integrity of the overall system design in that the details of research and development in these technologies are dependent upon the DEMO design.

**Strategic acceleration of research and development of divertor**

There is quite a large gap between the envisioned operational condition of DEMO and the present scientific understanding and technological maturity. Therefore, in addition to significant reinforcement of the DEMO design activity in this field, the strategic acceleration of research and development targeting the milestones of the *Intermediate C&R* and the *Assessment of Transition Conditions* is urgently indispensable.

- Prototype tests and model validation by using the LHD and JT-60SA
- Promotion of basic and focused studies by using laboratory devices
- Improvement of numerical model and validation by experiments
- Proof-of-principle and performance extension tests of innovative concepts
- Effective utilization of empirical knowledge, which can be acquired by manufacturing and procurement of the ITER divertor.

With respect to the above, it is necessary to formulate a strategic plan focused on resolution of technological issues in an integrated manner including international collaborations, and to implement the plan. For example, the European analysis has pointed out that the JT-60SA gains higher-priority by changing wall materials to DEMO relevant tungsten than carbon in the report "R&D Needs and Required Facilities for the Development of Fusion as an Energy Source" [8]. As mentioned in the "Joint-Core Team Report (Basic Concept of DEMO and Structure of Technological Issues)", it is to be required to change the divertor materials to tungsten at an appropriate time, in order to establish a detachment control technology, which is consistent with the DEMO design. Furthermore, divertor research and development facility beyond the presently available facility will be necessary in Japan to address the divertor issues including innovative concepts.

**Test Blanket Module**

With regard to development of ITER-TBM, a TBM Arrangement was signed in November 2014, and a Final Design Review is planned in 2018 as an important milestone. While the development activities for ITER-TBM is enhanced mainly by JAEA recently, development of integrated functional test facilities (heat load, irradiation, and tritium behaviour) and demonstration test plan of performance by using the facilities as well as cooperation with other parties related to advanced concepts still remain insufficient. The related activities should be reinforced with the cooperation among universities, research institutes and industries to resolve the issues and to ensure the completion of transition conditions before the *Assessment of Transition Conditions*. With regard to irradiation test facilities, development of the post-irradiation experiment (PIE) of ITER-TBM, remote handling technology and disassembling and treating technology of large-scale activated components should be noted in addition to the irradiation tests and PIE with a module-scale related to the tritium experiments using a fusion neutron source. Also, with regard to arrangement of development of an advanced blanket concept for DEMO-TBM, not only the third ITER-TBM developed by Japan but also cooperation with other parties which plan a different concept for ITER-TBMs should be considered.

**Fusion neutron source**

Before the *Assessment of Transition Conditions,* it is necessary to experimentally validate the prediction model based upon the knowledge related to the material which will be available by that time in order to confirm the range of application of the prediction model. It is required for this validation to determine a detailed irradiation plan of fusion neutron source to be built in response to the outcome of the IFMIF-EVEDA in time so as to be operated in a manner consistent with the maturity of related technologies which should be reached before the *Assessment of Transition Conditions* and with the data acquisition plan required to the subsequent engineering design activities of DEMO. In other words, it is necessary to determine early on the design of the test cell in order to allow data acquisition related to the material reliability and the functional demonstration of the subcomponent essential to the manufacturing design of DEMO. This determination should be done from the integrated view based upon the results from IFMIF-KEP (Key Element Technology Phase) and IFMIF-EVEDA together with related missions such as ITER-TBM and computer simulation, as well as the role of a fusion neutron source. Therefore, it is important to make full use of facilities prepared by the BA activities and upgrade their capability. Also, the development of the IFMIF or an equivalent intensive fusion neutron source should be advanced with an expanded view of cooperation with other parties in order to explore the development of long-life and advanced blankets to make sure of economic feasibility in DEMO.

**On actions to implement the framework for execution throughout Japan**

A framework for implementation throughout Japan is indispensable to make the most of the effectiveness of human resources and to enable further development for the establishment of technological bases for DEMO. This requires a system for research institutes, universities and industries to share the recognition of perspectives on issues and strategy in common, and to promote research and development together towards resolution of issues, namely, “establishment of co-creation platform of industry, academic and government”. In particular, the following two points of view are highlighted.

(1) The Rokkasho Fusion Institute, JAEA is the base of BA activities with the IFMIF-EVEDA prototype accelerator, radio-isotope treatment facility including tritium, beryllium, etc., super computer and experimental facility of remote handling. This site should be developed as the central core base for development of DEMO. In addition to expansion of facilities and equipment for research and development, enhancement and development of logistics to promote convening human resources throughout industry, education and research, and government in Japan is necessary under the present circumstances that public transportation and accommodations are not sufficient. The Institute should pay special considerations to accept researchers and engineers. For example, logistical assistance of transportation and accommodation for visitors and development of provisions of benefits with respect to commuting injuries are essential for visitors to accomplish duties safely and with security. From the perspective of wide communication with other energy research fields, the Institute, as an institute constituting the Rokkasho next generation energy park[2], is expected to define common tasks in cooperation with other fields and stimulate collaboration in order to establish complementary relation of fusion energy with renewable energy.

2 Next generation energy parks are programs, which are certified by the Ministry of Economy, Trade and Industry, to promote understanding about future environmentally friendly energy through increasing opportunities for citizens to see or touch next generation energy such as renewable energy.

(2) Not only the Rokkasho Fusion Institute, JAEA but also other organizations taking part in development of DEMO should actively introduce a cross-appointment system to promote participation of researchers and engineers belonging to other organizations and to enhance mobility and diversity of human resources. Retainment of concurrent position enables continuous long-term engagement and reinforcement of bases for research and development in both organizations, which leads to security and development of world-class research by the Japanese fusion community. Furthermore, there is the merit for dispatching organizations, such as universities, as the researcher’s salary will be paid by other organizations and the university may then use the salary saved for educational purposes. This program thus enables training of young researchers who can contribute to expanding further the fusion community and to achieving fusion energy in the future.

## 4. 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 backcasting[3], 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.

[3] Backcasting is the methodology to identify the goal backward from the desirable future and then to define the action which should be taken now.

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