Development of Technology Bases for Japanese Strategy to Fusion Power

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Fundamental question from ordinary people

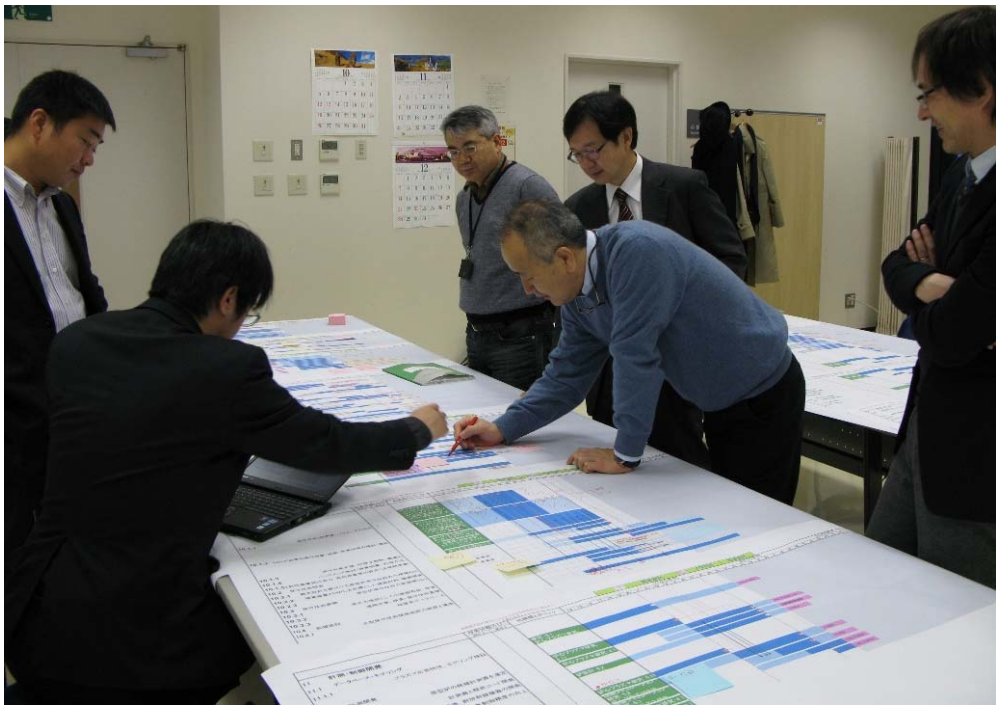
When will fusion energy be available ?

* Joint-Core Team

for establishment of technology bases required for development of DEMO

(July,2013 – March,2015)

Members: H.Yamada (Leader), R.Kasada, A.Ozaki, Y.Sakamoto, R.Sakamoto, H.Takenaga, T.Tanaka, H.Tanigawa,
Experts: K.Okano, K.Tobita
Secretariat: O.Kaneko, K.Ushigusa



J Fusion Energ
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ORIGINAL RESEARCH

Development of Strategic Establishment of Technology Bases for a Fusion DEMO Reactor in Japan

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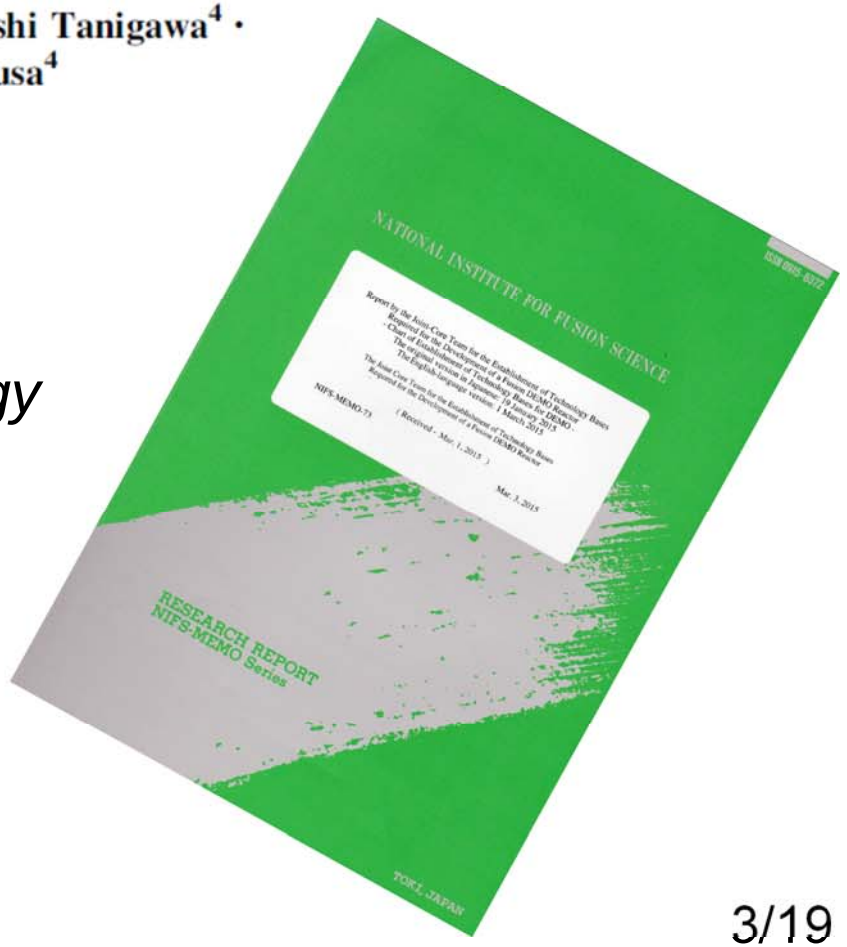
Essence of the **Joint-Core Team Reports** has been published in *Journal of Fusion Energy*

Full documents in English are available on the web.

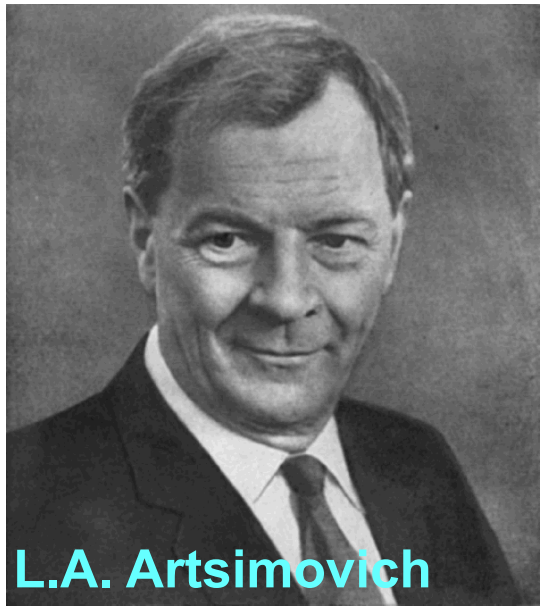
You can get them by googling



Outline

1. **Introduction**
   1) How should we answer the question "*When will fusion energy be available ?*" ?
   2) Overview of what Joint-Core Team discussed
2. **Joint-Core Team reports for the establishment of technology bases required for the development of DEMO**
   1) Basic concept of DEMO
   2) Chart of establishment of technological bases for DEMO
3. **Emerging outcomes and prospects**
4. **Conclusions and remarks**

Lev Artsimovitch famously replied "Fusion will be ready when society needs it"


L.A. Artsimovich

Is this true ?

Society does not need fusion energy now.
We have to prepare to answer the question.

Justification of huge investment and long leading/loading time

- ✓ Show plan to stakeholders any time how close we are approaching targets/milestones and an eventual goal
- ✓ Define commitment of responsible sectors to implement this plan
- ✓ Do this plan, then Check & Action at the time due

We are not ready to answer seriously to the question "When will fusion energy be available" now.
However, we can show how we are approaching the answer

Raised awareness towards development of DEMO in discussion of Japanese fusion policy

In order to proceed to the DEMO phase, Fusion Community should

1) grasp the whole status of all related programs with integrated views
2) identify common issues and targets
3) reinforce directivity from large projects to each research activity along with the contribution to solution/achievement of these issues/targets as the evaluation axis.

Then the council in MEXT requested JAEA and NIFS to form the Joint Joint-Core Team together with industry and universities.

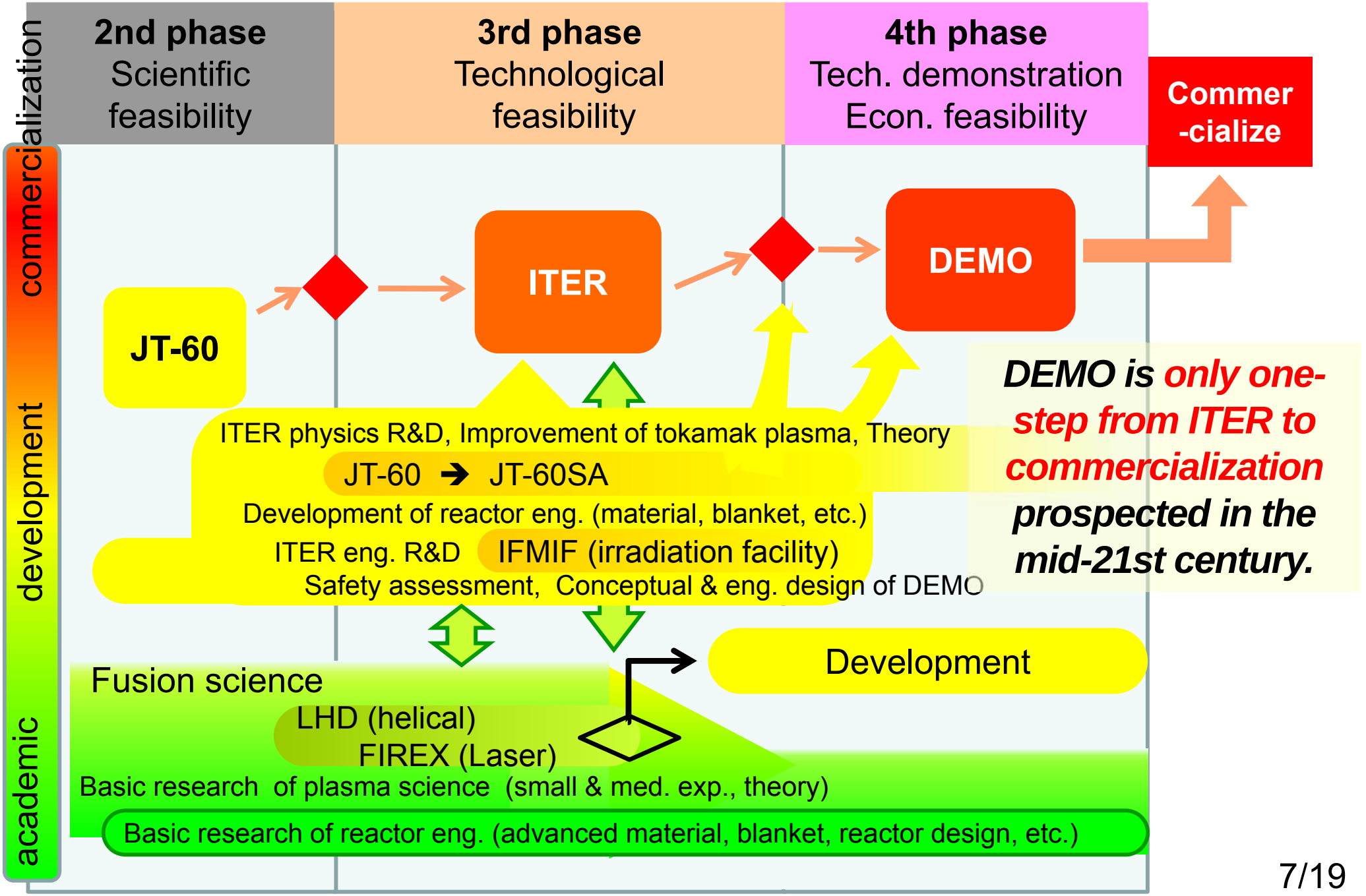
Joint-Core Team made two reports to the council in MEXT

✓ analyzed basic concept of DEMO and structure of technological issues

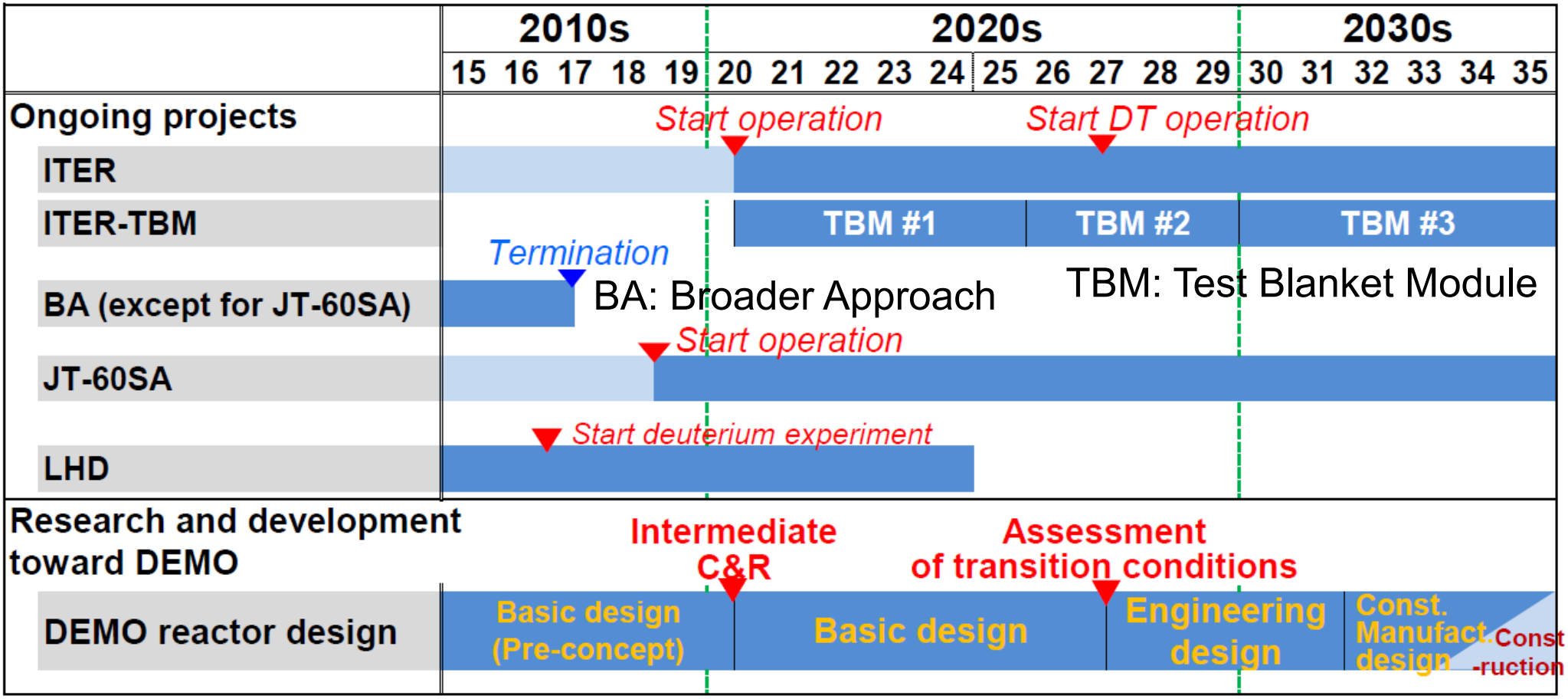
✓ showed the chart which visualizes development of all of the related programs in a timeline and provides an overview picture of all related processes.

Favorable outcomes are appearing. ➔ The Japanese Roadmap

National Policy defined in "Future Fusion R&D Strategy" by Atomic Energy Commission issued in 2005

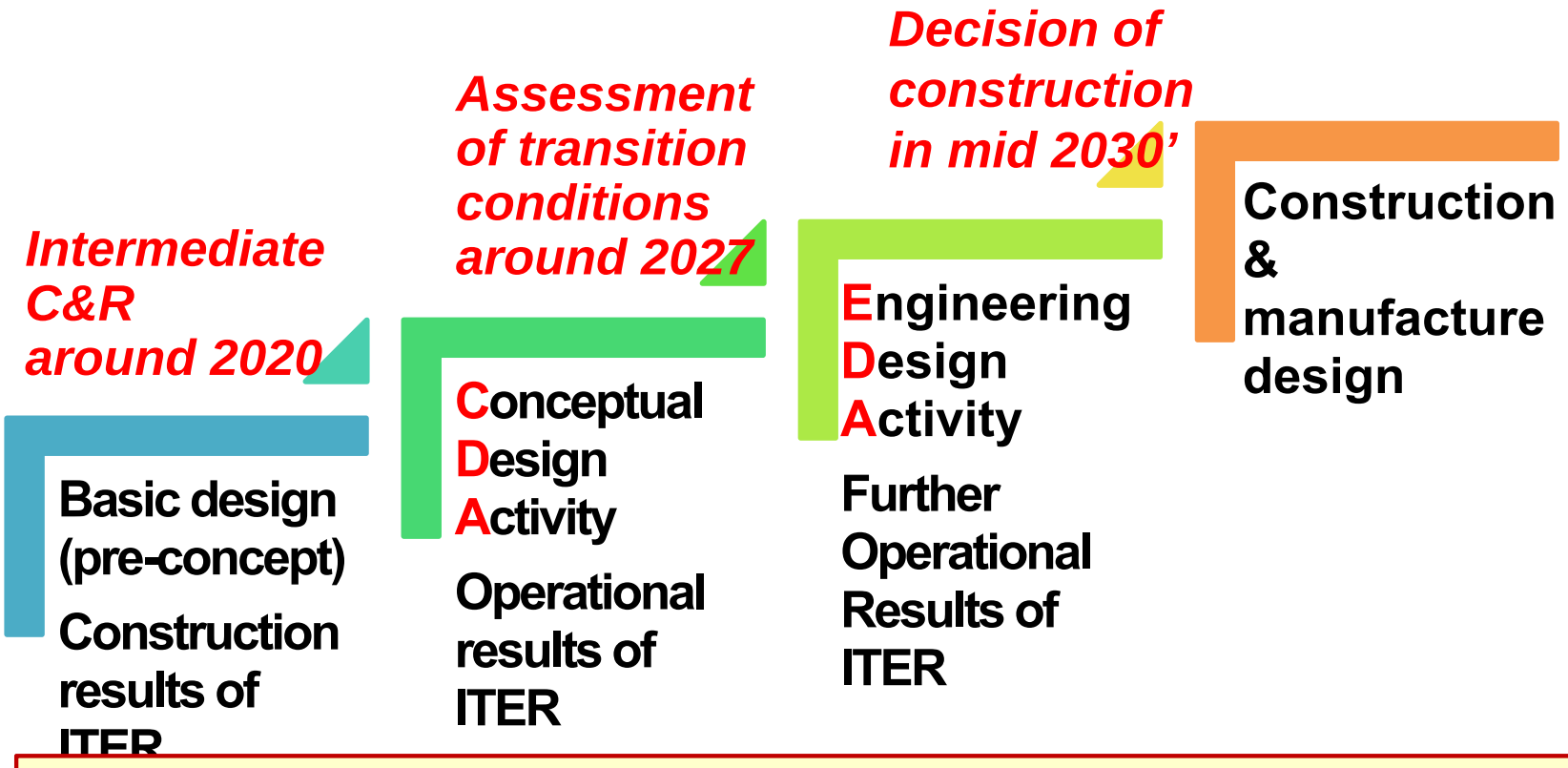


Timeline and Milestones towards DEMO



Projecting the goal of DEMO, it is necessary to define the technological issues to fulfil the *Transition Conditions towards the DEMO phase* **first by a tokamak**, and to approach defined issues by the organized framework for implementation throughout Japan in parallel with the ITER project.

Phased Development with Milestones



- ✓ ITER is the ticking clock of the timeline
- ✓ Major 2 criteria at the assessments and consequent judgement
  1. Maturity of DEMO design
  2. Evidence to support the design (results of R&D)

Basic concept required for DEMO

DEMO goal

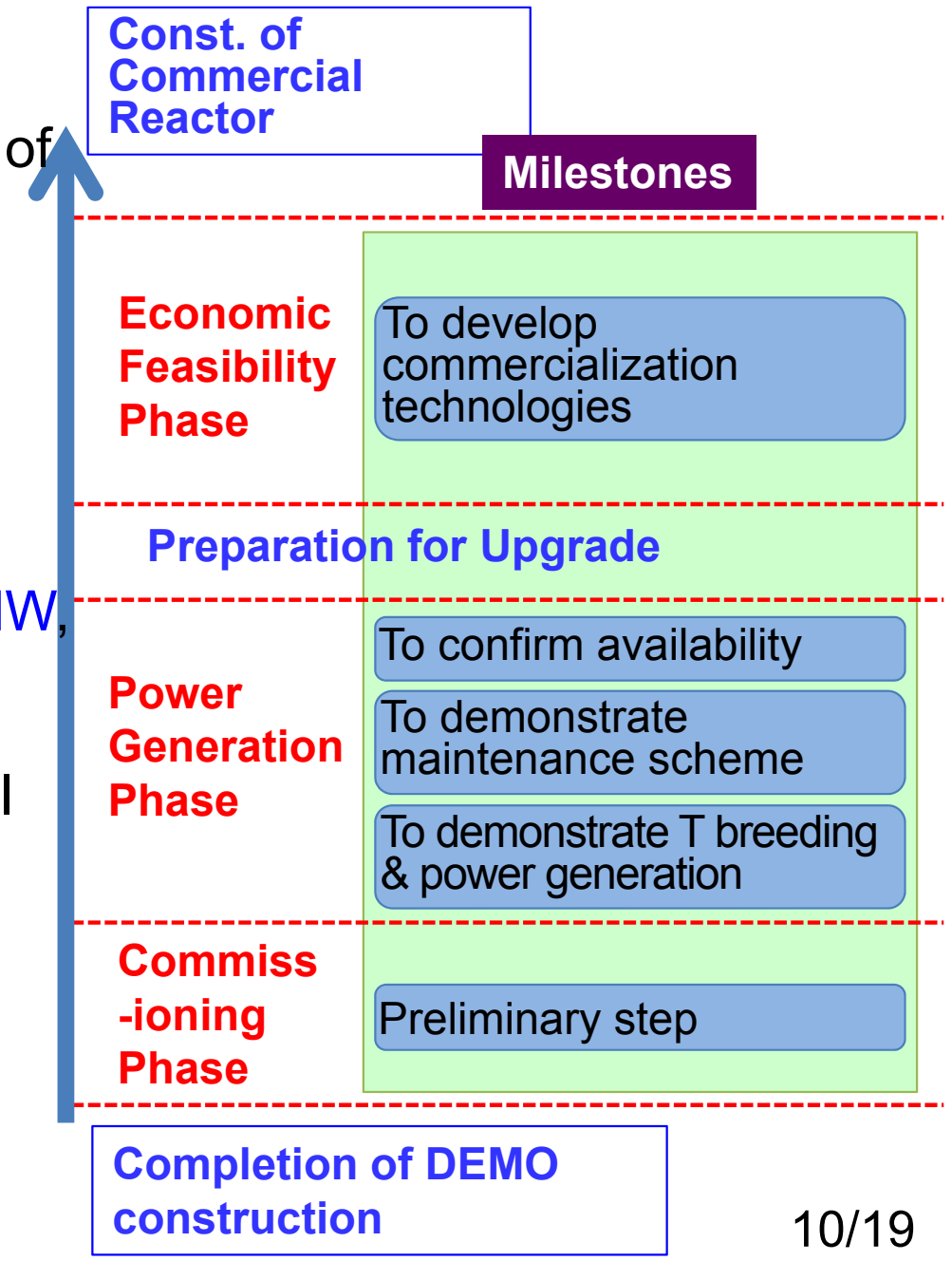
- to indicate the convincing prospect to achieve economic and social rationality of fusion energy competitive with other energy resources

DEMO requirement

- DEMO should be aimed at
  - ✓ steady and stable electrical power generation beyond several hundreds MW,
  - ✓ availability which must be extensible to commercialization,
  - ✓ overall tritium breeding sufficient to fulfil self-sufficiency in fuel cycle

Staged development of DEMO

- To respond the DEMO requirement, operational development stages and their milestones have been identified.

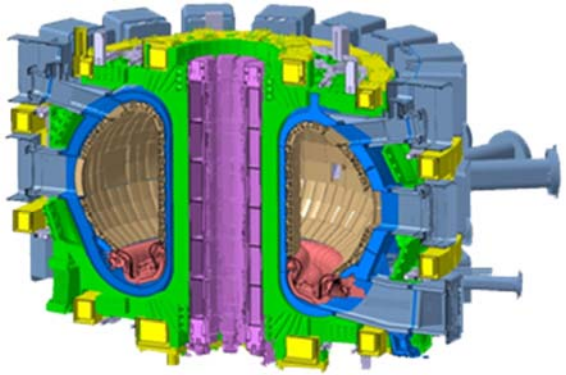


Rough draft option of tokamak DEMO

DEMO

aiming at steady-state operation

ITER



	DEMO	ITER (SSO)
Major Radius/Minor Radius	8.5 m / 2.4 m	6.4 m / 1.9 m
Elongation / Aspect Ratio	1.65 / 3.5	1.8 / 3.4
Fusion Output	1.4 GW	0.35 GW
Plasma Current	12.3 MA	9.0 MA
Toroidal Magnetic Field	5.9 T	5.2 T
Maximum Magnetic Field	12.1 T	11.8 T
Fusion Wall Loading	1.0 MW/m^2	0.35 MW/m^2

Courtesy of K.Tobita

Analysis of technological issues on DEMO

To develop the strategy for DEMO, 11 technological elements of DEMO have been identified and the required procedures have been sorted out.

- ✓ to demonstrate the technological feasibility of DEMO
- ✓ to develop a roadmap with the timeline and implementing entities.

1. Superconducting coils
2. Blanket
3. Divertor
4. Heating and current-drive systems
5. Theory and numerical simulation research
6. Reactor plasma research
7. Fuel systems
8. Material development and establishment of codes and standards
9. Safety of DEMO and safety research
10. Availability and maintainability
11. Diagnostics and control systems
12. (Balance of Plant)
13. (Socio-economics)
14. (Socio-communications)
15. (Helical system)
16. (Laser system)

Structure of Issues, ex.

Commitment
Issue
Hurdle

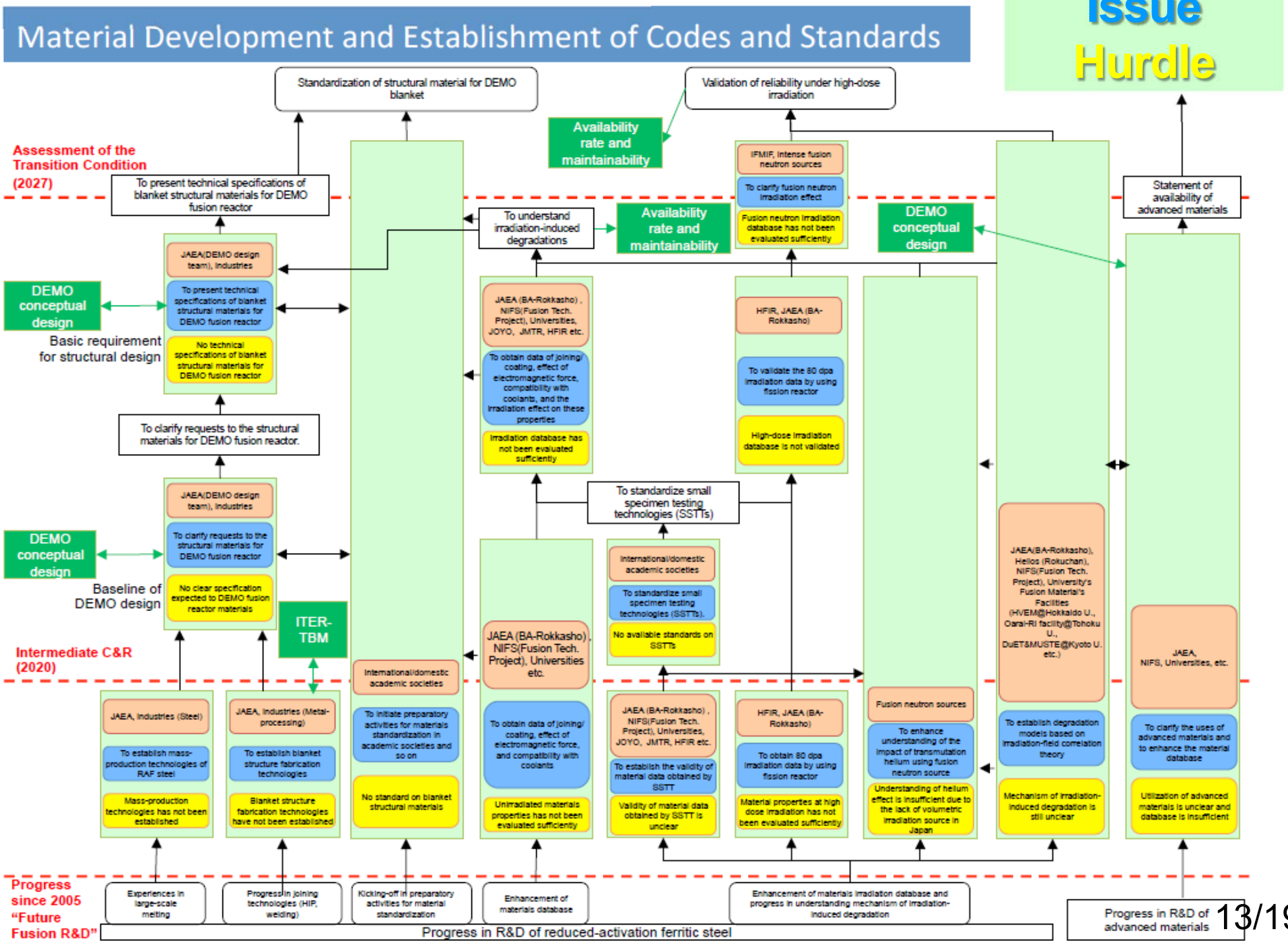
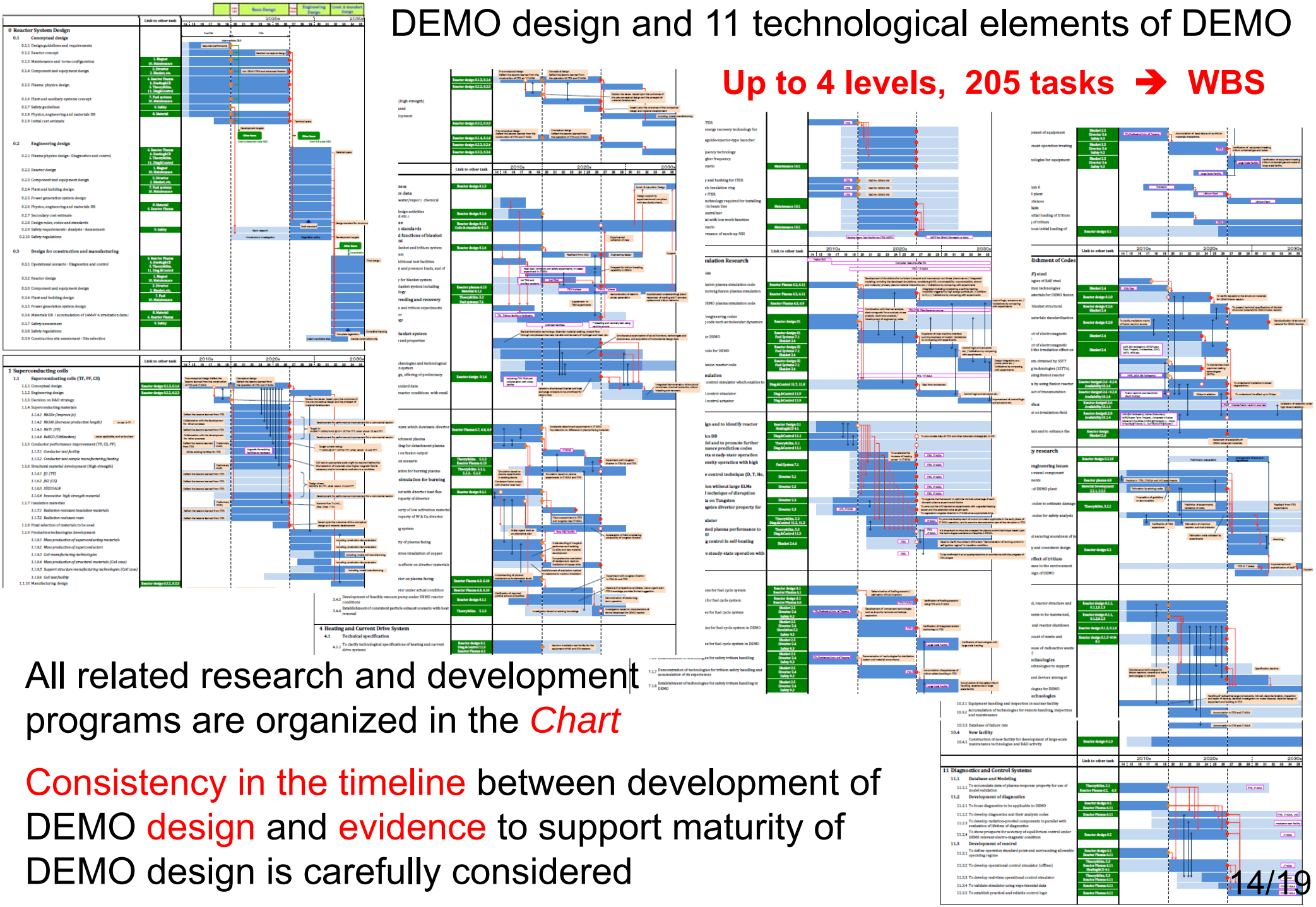


Chart of Establishment of Technological Bases for DEMO

DEMO design and 11 technological elements of DEMO

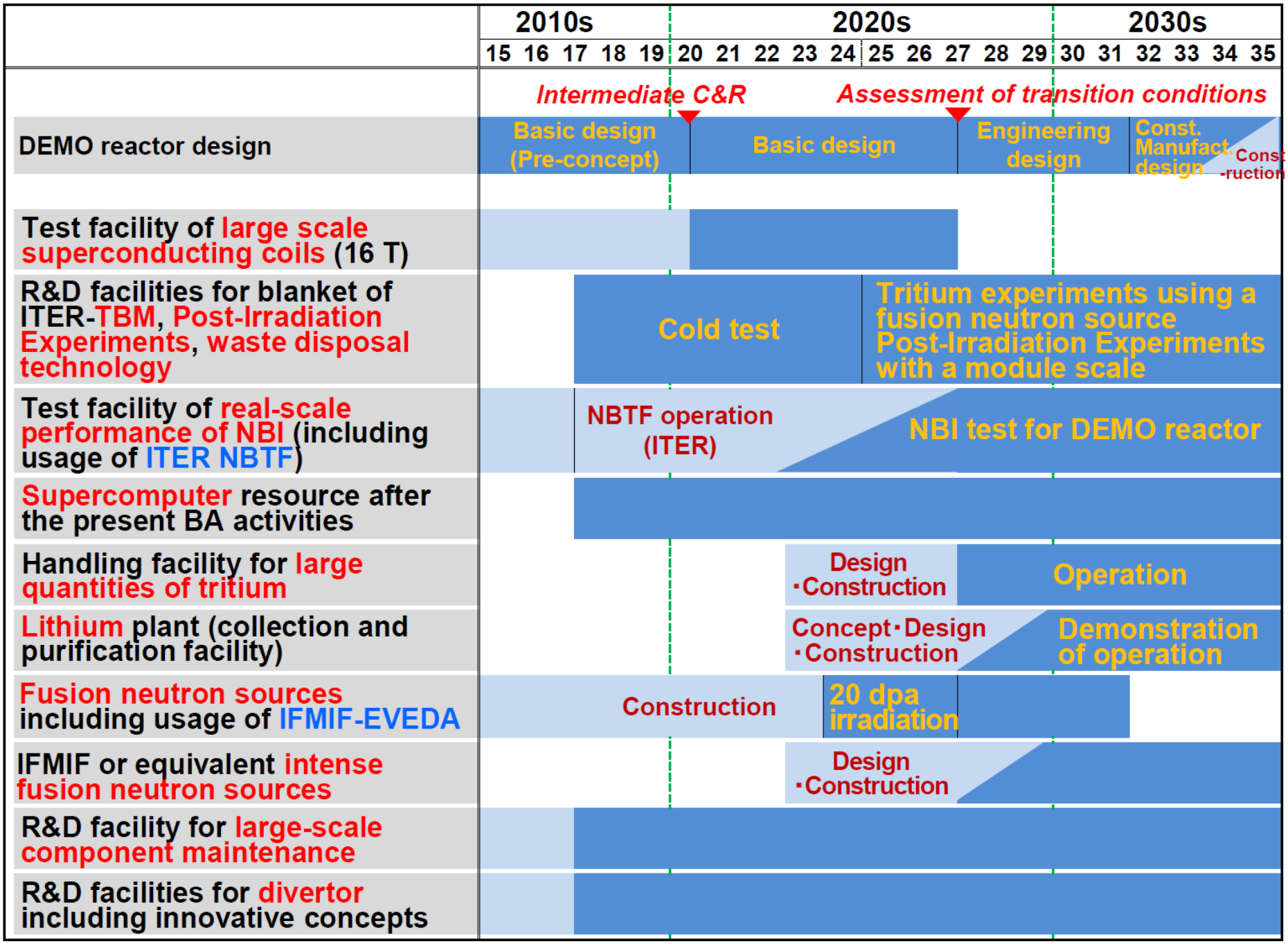
Up to 4 levels, 205 tasks ➔ WBS



All related research and development programs are organized in the *Chart*

Consistency in the timeline between development of DEMO design and evidence to support maturity of DEMO design is carefully considered

Newly Required Facilities and Platforms



Principal matters recognized in Chart

4 principal matters of weight recognized in formulating *Chart of Establishment of Technological Bases for DEMO*

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*, "**fusion neutron source**" and "**Test Blanket Module (TBM)**" 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. Also, since budgetary and human resources, and R&D and production bases in Japan are insufficient to conduct all the R&D for DEMO alone, international cooperation and collaboration is inevitable.

Framework for Implementation throughout Japan towards Establishment of Technology Bases for Development of DEMO

MEXT

Science & Technology Committee on Fusion Energy, Council for Science and Technology, MEXT — Policy Roadmap

Task Force on DEMO Comprehensive Strategy — Action plans, Proactive management

DEMO Japan

Joint Special Design Team for DEMO

General Coordination Gr.

JAEA base in Rokkasho

NIFS

Indus. **Univs.**

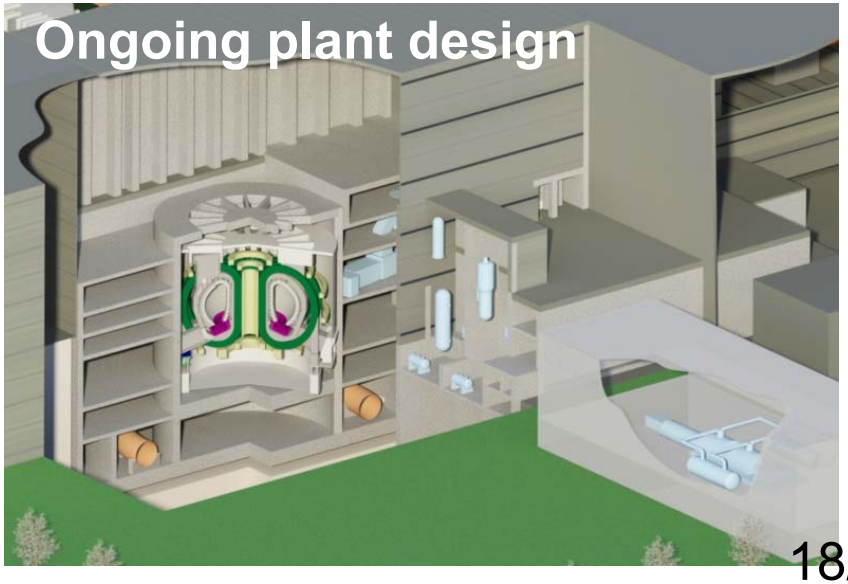
Related Academic Societies

Industry, Research Institutes, Universities, etc.

- Superconducting coil
- Divertor
- Blanket
- Heating & current-drive systems
- Reactor plasma
- Theory and computational simulation
- Fusion fuel systems
- Diagnostics & control
- Fusion materials & establishment of codes and standards
- Safety of DEMO and safety research
- Availability & maintenance

Joint Special Design Team for Fusion DEMO

- Joint JAEA-industry-academia team organized in June 2015
- Implementation charged action plans along with the guidance of TF
- 73 members : 30% from JAEA, 40% from Univ./NIFS/RIs, 30% from Industry
- Responsible for DEMO Design R&D for the coming decades
- On going activities:
  - ✓ *Developing the project management plan*
  - ✓ *Compiling DEMO design basis in light of knowledge obtained in BA and previous reactor design activities*
  - ✓ *Enhancing DEMO plant design with the aid of industry*



Courtesy of K.Tobita

Conclusions and Remarks

Japanese endeavors to show how (strategy/tactics/way) and how close (timeline) we are approaching DEMO are being reinforced well after the Joint-Core Team reports.

The **Task Force on DEMO Comprehensive Strategy** in MEXT and **Joint Special Design Team for Fusion DEMO** in Rokkasho have been established to put recommendation in the Joint-Core Team reports into effect. Related R&D programs will be aligned along with the action plans by the TF and then the Japanese fusion roadmap.

In order to promote acceleration and breakthrough by innovation and to incorporate a comprehensive state of progress of fusion R&D, complementary and alternative concepts, for example, helical and laser systems and should be managed in good balance and in a strategically linked manner.

Back-up and Supplement

Issues addressed at assessment of DEMO design

Maturity of DEMO design will be reviewed at the Intermediate C&R and the Assessment of Transition Conditions

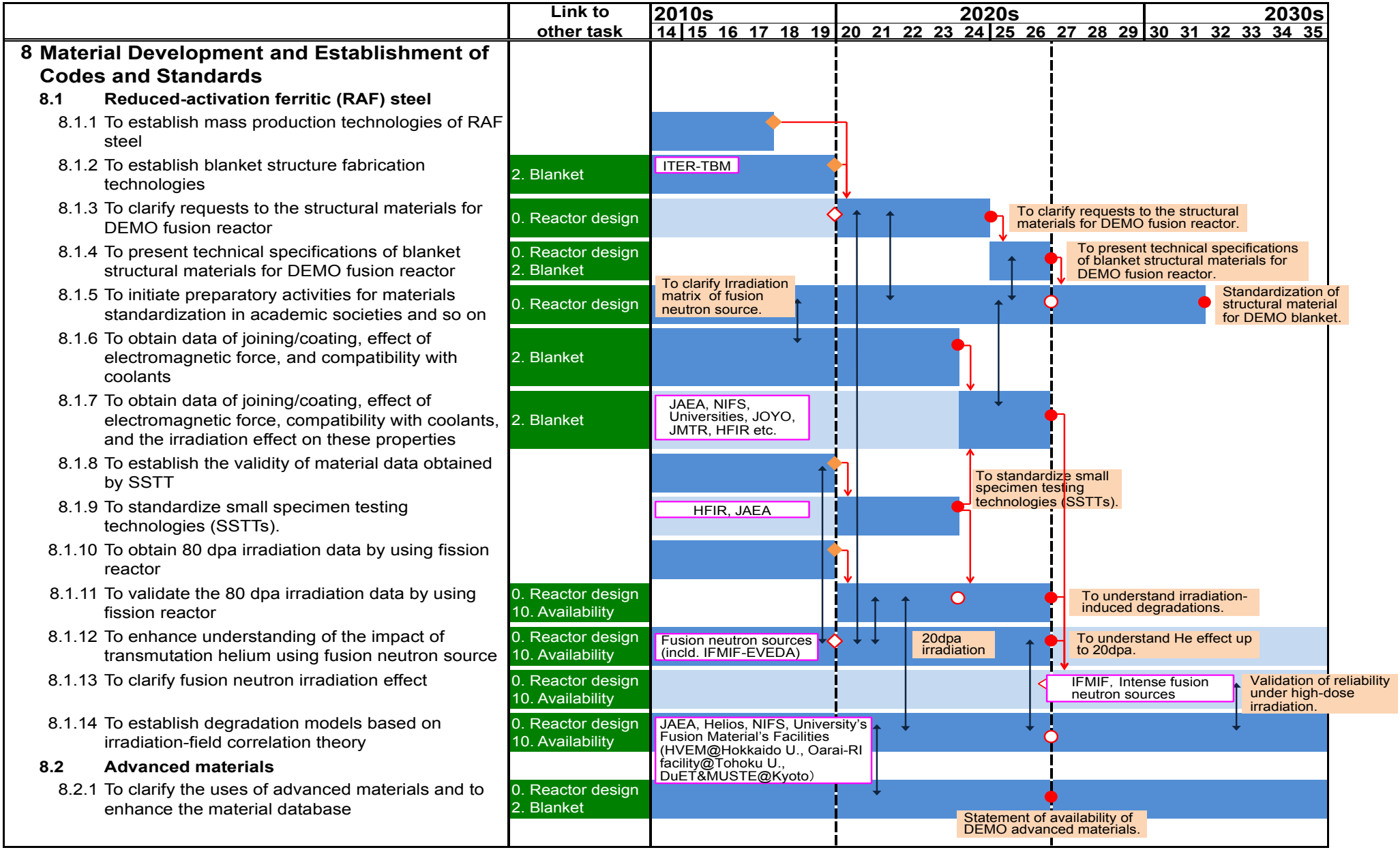
- **Operation plan*** of DEMO
- Basic concept and design parameters
- Components and facilities of DEMO plant and their specifications
- Development of software and databases for DEMO design
- Primary cost assessment (to be rationalized after *Intermediate C&R*)
- Safety design guidelines
- Management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

Analyse what should be established and how long they take.
Then, elaborate upon the **operation plan** and the life time of DEMO.

Technology and data envisaged: operational technique, validation of plasma prediction codes, operability(output stability, controllability, and operational margins), failure rate, plant maintenance, worker dose rate, handling and management of wastes, environmental monitoring, development of advanced technology for commercialization (blanket, divertor and materials).

Plot the structure of issues in timeline

ex. Material Development and Establishment of Codes and Standards



Basic concept required for DEMO (3)

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

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.

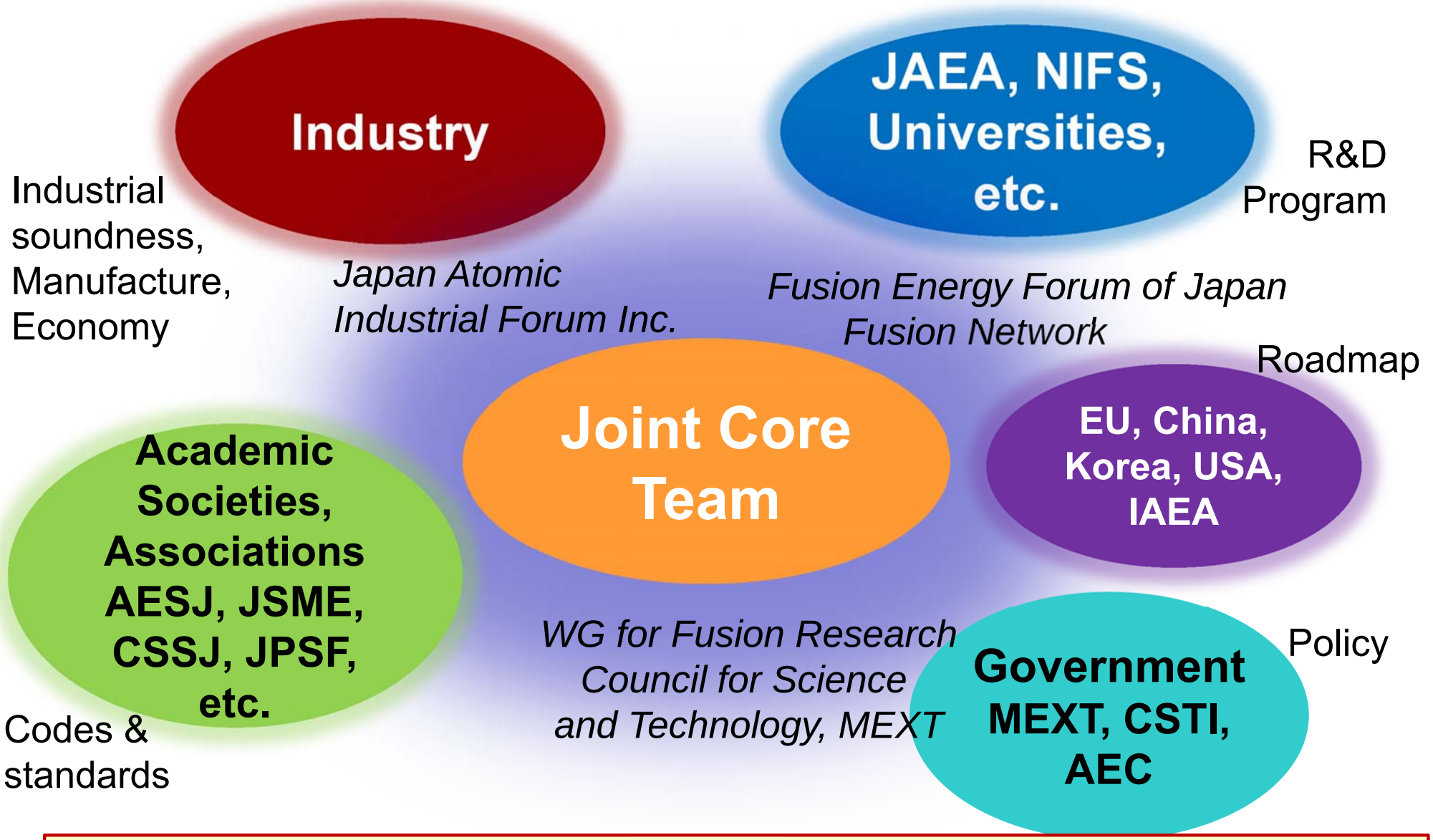
Safety issues:
Security of safety to suppress exposure of the public as well as the workers in a DEMO plant to As Low As Reasonably Achievable (ALARA) is necessary. No public evacuation in any event.

Cost:
The construction cost of DEMO should be at the acceptable level from the view of subsequent commercialization.

International Cooperation and Collaboration

Budgetary and human resources, and R&D and production bases in Japan are insufficient to conduct all the R&D for DEMO alone.

- The most important point is result from the ITER project.
- The effective extension from the ongoing projects should be promoted for facilities of fusion neutron source for material development, and a large-real-scale test facility for development of heating and current-drive system.
- Since the fission neutron irradiation facility is not available in Japan now and its test has to depend on the HFIR in the United States, the bilateral cooperation with the United States should be maintained.
- Since a large-scale tokamak experiment will not be available in Japan until the start of JT-60SA in 2019, cooperation with tokamak experiments abroad and simulation, specifically regarding the detachment scenario and the tungsten issue, which are related to development of the divertor, is indispensable.
- Since a variety of concepts of TBM in ITER depending on contributing countries/party will be tested, good cooperative relation should be established so that achievement by other countries/party will be reflected in the DEMO design appropriately.



Terms of Reference; to develop strategy for the establishment of technology bases required for development of DEMO through investigations of

1. Concept definition of DEMO premised for investigation
2. Activities requiring resource commitment and their goals
3. Scientific and technological review of work for the above mentioned activities

Highlighted topic: (Intensive) fusion neutron source

Major issues in blanket structure material

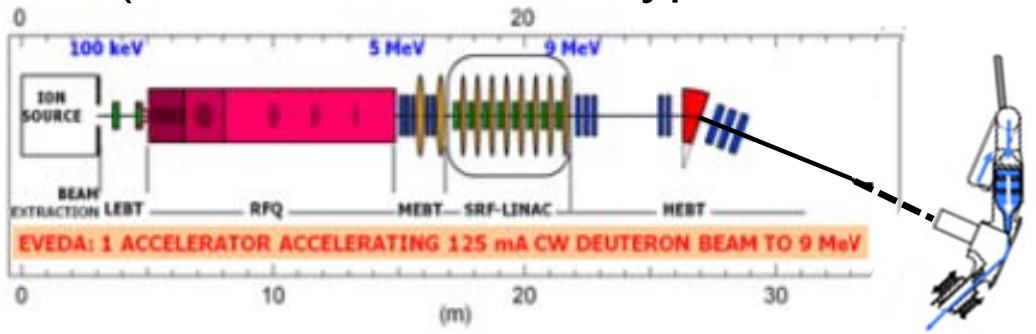
- ✓ Compilation of 80dpa irradiation data by using fission reactor to evaluate material properties at high dose irradiation
- ✓ Establishment of testing standards is required for Small Specimen Testing Technologies (SSTTs) that are the basis for compiling the irradiation data.
- ✓ Establishment of degradation model based on irradiation-field correlation theory
- ✓ Validation and enhancement of understanding of the impact of transmutation helium using fusion neutron source
- ✓ Establishment of mass-production technology of RAF steel
- ✓ Establishment of blanket structure fabrication technologies

Evidence to validate prediction models is necessary before the *Assessment of Transition Conditions* not relying solely upon the IFMIF

➔ **Fusion neutron irradiation up to about 20 dpa** is required at the *Assessment of Transition Conditions* to DEMO phase

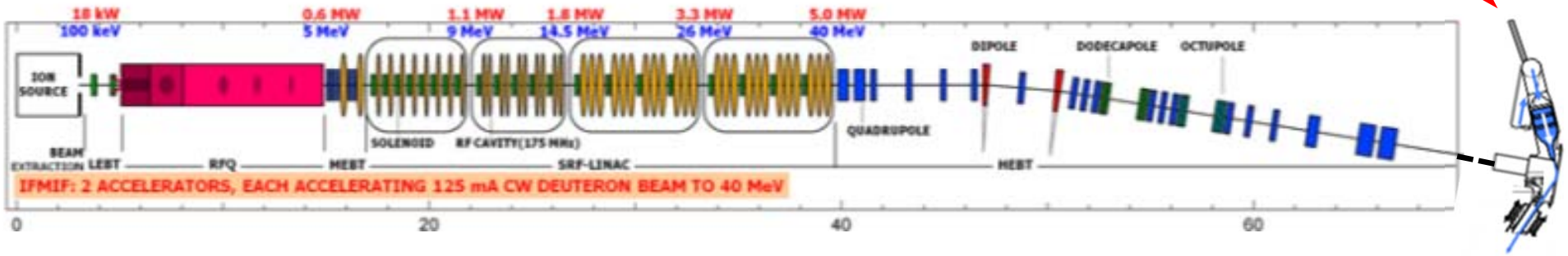
Fusion Neutron Source using IFMIF/EVEDA property

LIPAc (Linear IFMIF Prototype Accelerator) ➔ **A-FNS-9 MeV**, 125 mA



Lithium target

Full size IFMIF single accelerator ➔ **A-FNS-40 MeV**, 125 mA

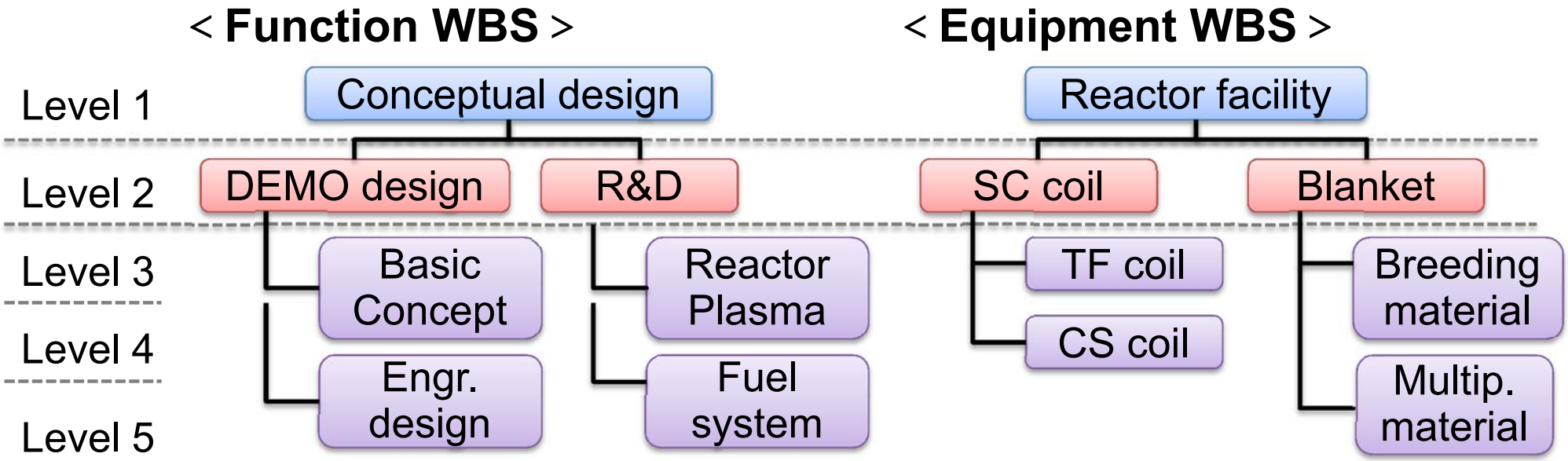


Beam energy (MeV)	Neutron yield(n/d)	Neutron flux(/cm²/s)	dpa (/fpy)	Helium production (appm/fpy)	He pro. dpa (/fpy)
40 (IFMIF)	8.76E-02	1.22E+15	49.7	6.24E+02	12
40 (A-FNS/DONES)	8.76E-02	5.90E+14	24.7	3.12E+02	12
9 (A-FNS)	7.11E-03	4.78E+13	1.51	6.60E+00	4.4

Courtesy of K.Ushigusa, T.Nishitani

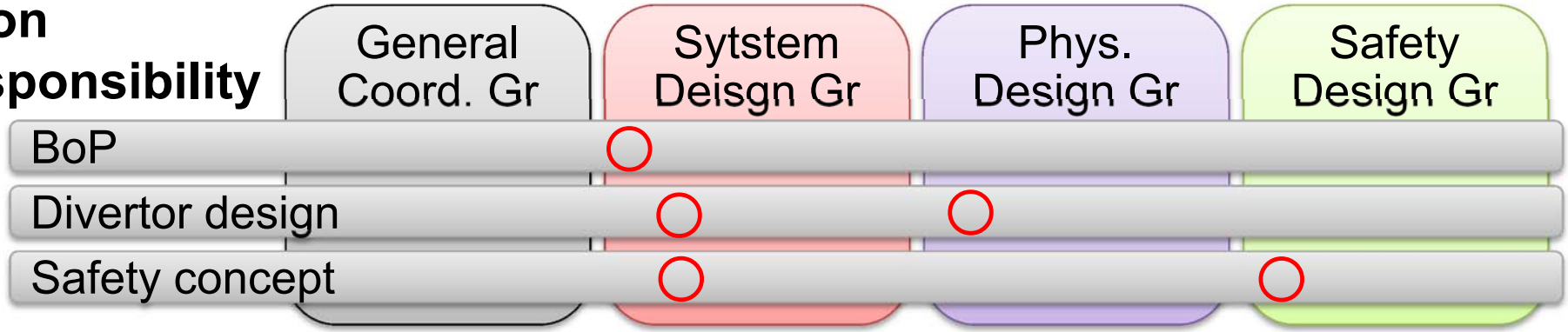
Joint Special Design Team for Fusion DEMO at Rokkasho: Enhancement of project management

Development of WBS based upon Joint-Core-Team Reports



Resultant documentation

Division of Responsibility



Process control **Configuration management**

Courtesy of A.Aoki

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
  - 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 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**.

Fusion in high-level governmental policy

1. Strategic Energy Plan

Revised at least every 3 year
Prospects in the next 20 years
The latest version issued in April, 2014
Just one sentence about "fusion" in 90-page document

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

2. Science and Technology Basic Plan

Revised every 5-year
Defines the priority of investment (250 billion $ for 5 years)
Just one sentence about "fusion" in the latest version for FY2011 – 2015

"R&D of fusion should be promoted with attention to consistency with the energy policy and the atomic energy policy, at the same time, its characteristics and the status of R&D."

Two sentences in the draft for FY2016-2021

"R&D of Innovative technology such as fusion which is important technology for future shall be conducted towards its establishment"
"Big science such as fusion, accelerator, space shall be promoted nationally by making efficient use of facilities home and abroad, and developing framework to activate international collaboration with foreign countries"

Points in Check & Review in Fusion R&D 1.

in "*Future Fusion R&D Strategy*" by AEC issued in 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 • 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 operation method to obtain economical prospects	• Conduct ITER support research and preparatory research for high-beta steady-state plasma and launch research using National Centralized Tokamak	• Attainment of sustaining high-beta (β_n=3.5-5.5) plasma in collision-less regime in National Centralized Tokamak.

Points in Check & Review in Fusion R&D 2.

in "*Future Fusion R&D Strategy*" by AEC issued in 2005

Issues	Performance goal by check and review in the interim phase	Transition conditions to the DEMO phase
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 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	• 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
6. Conceptual design of DEMO	• 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	• Completion of conceptual design of DEMO consistent with the development of fusion plasma research and fusion technology