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

Fusion Energy Research & Development
Towards DEMO Reactor of Japan

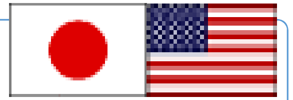
Ministry of Education, Culture, Sports, Science and Technology(MEXT)

IWABUCHI Hideki

FUSION POWER ASSOCIATES
41ST ANNUAL MEETING
Fusion Energy: Achievements and Opportunities 2020

JAPAN/U.S. Fusion Research Collaboration

● Cooperation in the field of fusion research between Japan and the United States started in 1979. 2019 marked the 40th anniversary.



1977

✓ Prime Minister Fukuda and President Carter discussed a new Japan-US cooperation on fusion.

1979

✓ Agreement between the Government of Japan and the Government of the United States of America on Cooperation in Research and Development in Energy and Related Fields

✓ The Japan-US Coordinating Committee on Fusion Energy (CCFE)

1988

✓ Agreement between the Government of Japan and the Government of the United States of America on Cooperation in Research and Development in Science and Technology

2007

✓ Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project

2019

✓ **The 40th Anniversary of the JAPAN/U.S. Fusion Research Collaboration**

In 1979, the research cooperation began on the **Doublet III (later DIII-D) Tokamak machine at General Atomics (GA)** in San Diego

A group of Japanese researchers was dispatched and worked together with the US researchers and engineers, producing many world-leading results.

Organization for joint activity

● **We highly value the collaboration in fusion research carried out between Japan and US in the past, and we would like to ensure the continuation of steady collaboration in the future.**

- Agreement between the Government of Japan and the Government of the United States of America on Cooperation in Research and Development in Science and Technology (JAPAN-U.S. Jun ,1988)
  - Implementing arrangement between The ministry of education , culture , sports , science and technology of japan and the department of energy of the united states of America concerning cooperation in research and development in energy and related fields (MEXT-DOE Apr , 2013)
    - The Japan-US Coordinating Committee on Fusion Energy (CCFE)
      - Fusion Technology Planning Committee (FTP)
      - Fusion Physics Planning Committee (FPP)
      - Joint Institute for Fusion Theory (JIFT)
    - HFIR (QST-DOE)
    - DⅢ-D (QST-DOE)
    - FRONTEER (NIFS-DOE)

Staged approach toward Fusion Energy

Scientific Feasibility

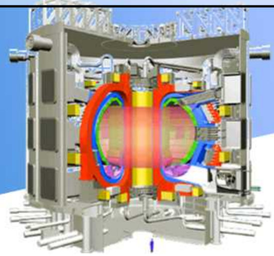
-To achieve break-even plasma condition

JT-60 (QST)

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

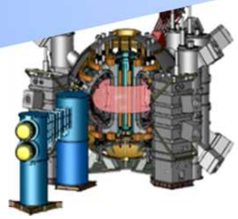
Scientific & Technological Feasibility

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



ITER (ITER Organization)

ITER Project



JT-60SA (QST–F4E)

BA Activities

Current Stage

Technological Demonstration & Economic Feasibility

-To demonstrate electric power generation
-To Improve economic efficiency

DEMO Reactor

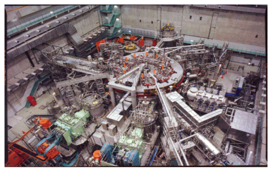
[go-no-go decision in 2030s]

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

Having prospect in the mid-21 Century → Ready to commercialization

Academic Research

FIREX (Osaka Univ.)



LHD(NIFS)

Current Stage

Recent policy reviews

The first policy speech to the Diet by the Prime Minister SUGA Yoshihide
October 28, 2020

<3. Realizing a green society> [Provisional translation]

My administration will devote itself to the greatest possible extent to bring about a green society, while focusing on a virtuous cycle of the economy and the environment as a pillar of our growth strategy.

We hereby declare that by 2050 Japan will aim to reduce greenhouse gas emissions to net-zero, that is, to realize a carbon-neutral, decarbonized society.

Addressing climate change is no longer a constraint on economic growth. We need to adjust our mindset to a paradigm shift that proactive climate change measures bring transformation of industrial structures as well as our economy and society, leading to dynamic economic growth.

The key here is revolutionary innovations, such as next-generation solar cells and carbon recycling. We will accelerate research and development aimed at realizing utilization of such technologies in society.

Attention from politics

Fusion is also drawing attention from the political world in Japan.

The ITER Assembly Ceremony , 28 July 2020

Inspection by MITANI Parliamentary Vice-Minister of MEXT in JT-60SA , 20 Oct 2020

Inspection by TAIRA Former State Minister of Cabinet Office in JT-60SA , 25 Aug 2020

Ceremony for Plasma Simulator “Raijin” of the NIFS , 29 Aug 2020

Inspection by OSHIMA Speaker of the House of Representatives in Rokkasho Fusion Institute , 23 Aug 2020

Ceremony for completion of first TF coil of ITER , 30 Jan 2020

Fusion Science in National Policy

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

◇Chapter 3 Addressing economic and social issues

(1) Sustainable growth and self-sustaining regional development

① ⅰ）Ensuring stable energy and improving energy efficiency

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

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

(2) Promoting excellence in knowledge creation

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

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

5th Strategic Energy Plan
（Cabinet Decision in July 2018）

◇Chapter 2 Basic Policies and Measures towards 2030

Section 3 Promotion of technology development

2. Technical challenges to be addressed

・・・The ITER project, which uses the tokamak and is being implemented through international cooperation, and the Broader Approach Activities aimed at realizing energy from nuclear fusion, there has been progress in on-site construction and the production of the equipment. GOJ will continue to steadily promote these activities from the long-term viewpoint. It will also promote parallel research on the helical and laser types as well as innovative concepts from the perspective of securing technological diversity.

The Long-term Strategy under the Paris Agreement
（Cabinet decision, June 11, 2019）

◇Chapter 3: Cross-sectoral Measures to be Focused

Section 1: Promotion of Innovation

2. Directions of Policy Measures

(4) “Visualization” of Issues in Individual Fields for Commercialization

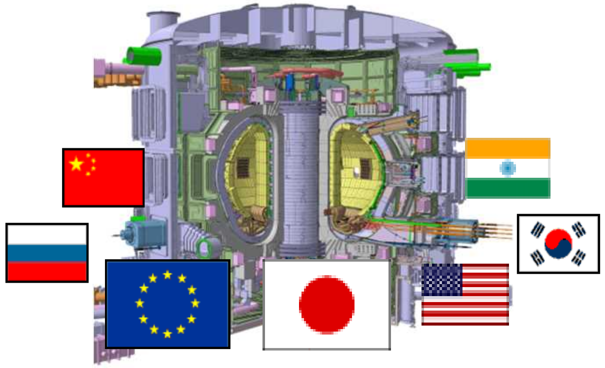
e. Nuclear energy

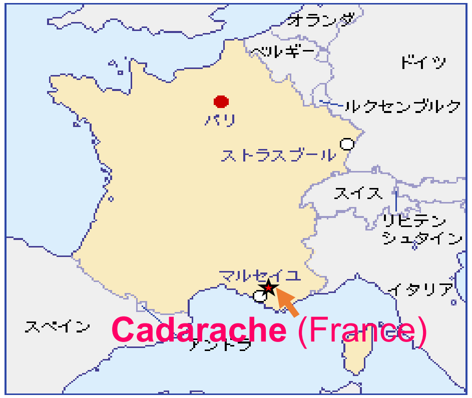
・・・On nuclear fusion energy, in parallel with steady implementation of the ITER project, which uses the tokamak and the Broader Approach Activities, Japan will promote the research on helical and other types based on unique Japanese ideas, aims at establishing scientific and technological feasibility.

ITER Project

Through construction and operation of the ITER, the scientific and technical feasibility of fusion energy is to be demonstrated toward its realization, which is expected to provide a fundamental solution for global energy issues.

[Outline of the Project]





●ITER Agreement; Effectuated on 24, Oct, 2007

●History;

1985	US-USSR summit
1988 – 2001	Conceptual Design Activity & Engineering Design Activity
2001 – 2006	Inter-governmental Negotiation
2007	Effectuation of the ITER Agreement, Establishment of the ITER Organization

●Participating Parties; JA, EU, US, RF, CN, KO, IN

●Construction site; Cadarache (France)

●Cost sharing（Construction Phase）;

EU,	JA,	US,	RF,	CN,	KO,	IN
45.5%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%

※Components are fabricated by the Parties, assembled into ITER by the ITER Organization.

●Schedule; Duration of 35 years;
First Plasma in 2025, Start of DT operation in 2035.

© ITER.org

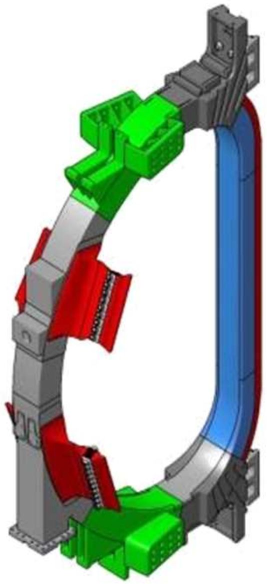
The construction site of ITER (March 2020)

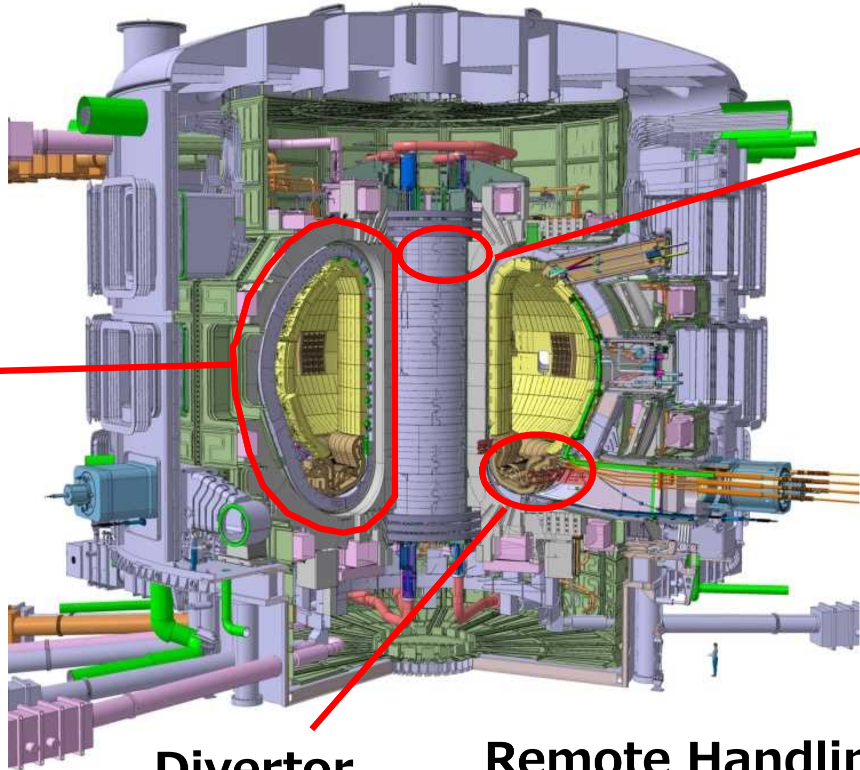
[Status]
Japan is making utmost efforts to manufacture very challenging components in cooperation with industry. QST continued the manufacture of the in-kind components without any delay including TF coil windings and structures.

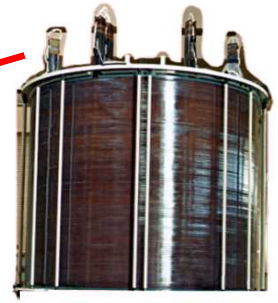
In-Kind Procurement by Japan

● Japan procures components which are indispensable for ITER development and lead to strengthening Japanese international competitiveness of Japanese industry.

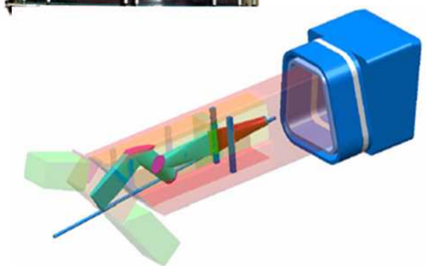
TF Coil







CS coil (conductor)

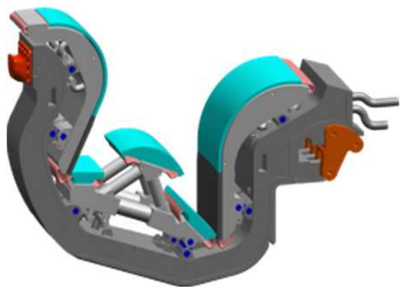


Measuring device

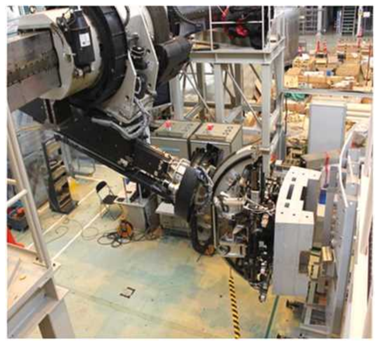
ECH system

NBI system

Divertor (Outer Target)



Remote Handling system



Tritium Plant system

Progress in BA Activities

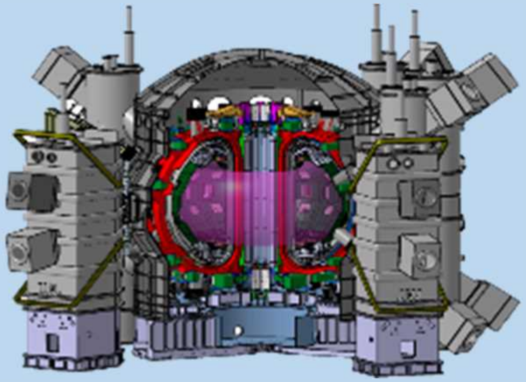
- To support the early realization of fusion energy, JA & EU are jointly implementing 3 projects.
- Phase I(June 2007 - March 2020) ：Completed the development of major research environment necessary for the BA activities.
- Phase II(April 2020-)：Produce research results which contribute and supplement to the ITER project by using the research facilities developed in Phase I as well as by improving the performance of the equipment toward the goal.

Naka Site

Satellite Tokamak programme(JT-60SA)

Support for the ITER project

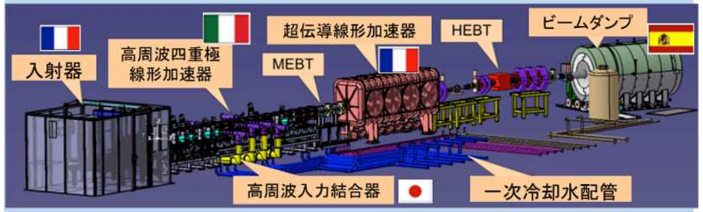
Challenging R&D For DEMO



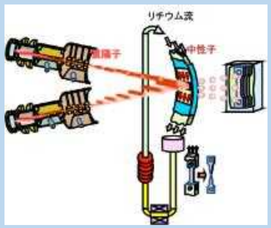
Rokkasho Site

IFMIF/EVEDA Project

Engineering Validation of Elemental Technologies



Engineering Design of IFMIF



IFERC Project

DEMO Design and R&D Coordination Center

ITER Remote Experimentation

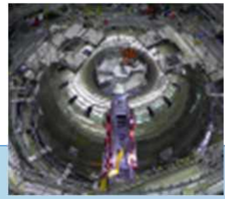
Fusion Computer Simulation Center(CSC)

JT-60SA towards First Plasma

2012.10

2013.3

2014.1

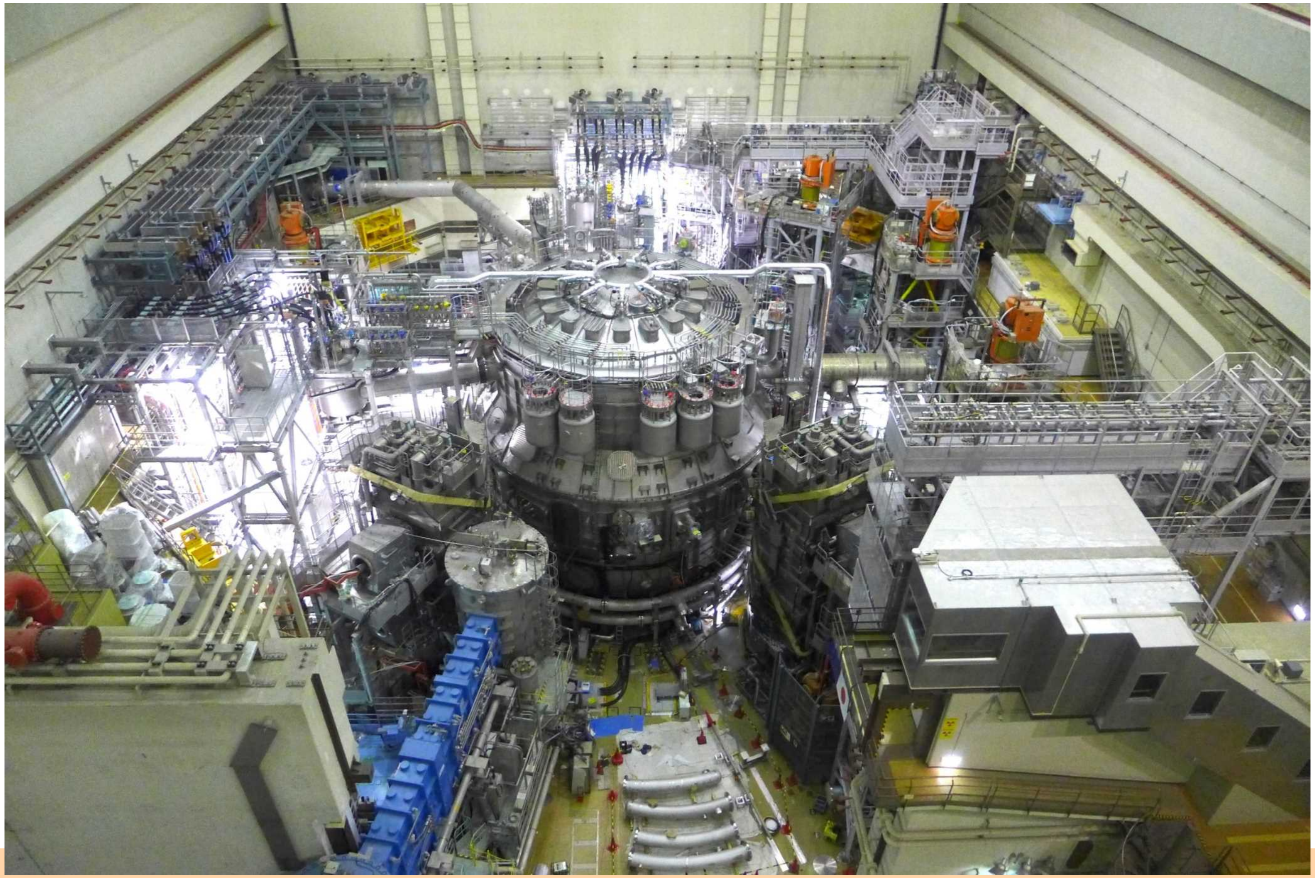


2015.8

2016.11

2018.4

2020.3

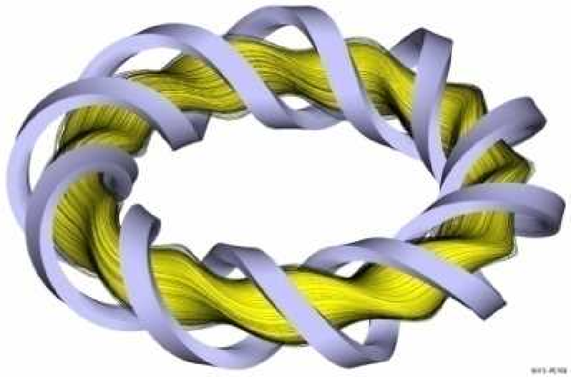


The assembly of JT-60SA was successfully completed on 31st March , 2020.
Currentry , the integrated commissioning is on progress toward the first plasma.
This is due to the efforts of the EU and JA teams under COVID-19 pandemic.

Research on Large Helical Device

Helical type

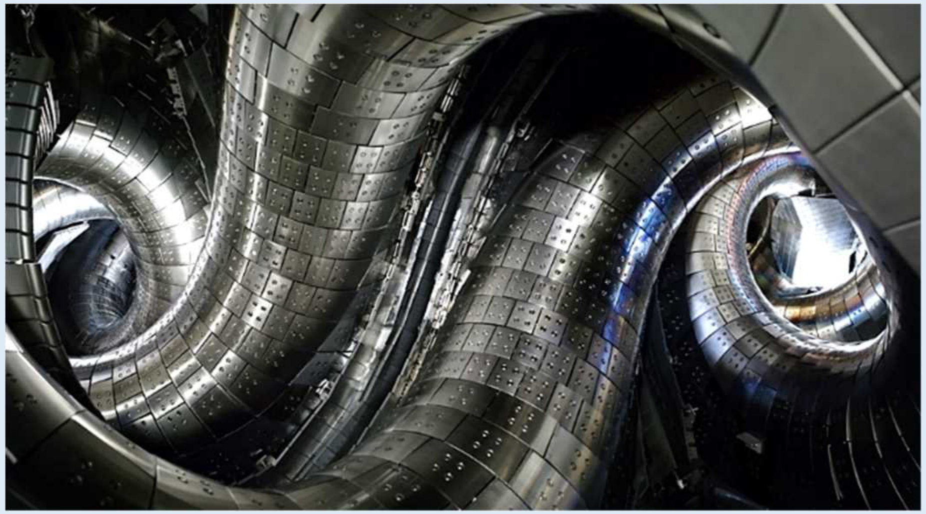
Twisting the external coils：
Helical type (LHD)



◆ Steady State Operation available
for more than one year in principle

◆ Issue
Improvement of plasma performance to realize reactor- relevant plasma
→ **Realization of 120 million ℃** plasma convinces the steady progress

National Institute for Fusion Science Large Helical Device（LHD）



machine diameter: 13.5m
machine height: 9.1m
Net weight: 1,500t
plasma volume: 30m^3

Features of Helical type devices

- “Heliotron" configuration employed for LHD was invented and has been developed in Japan.
- “Steady-state operation” is intrinsically available.
- No plasma current is necessary.

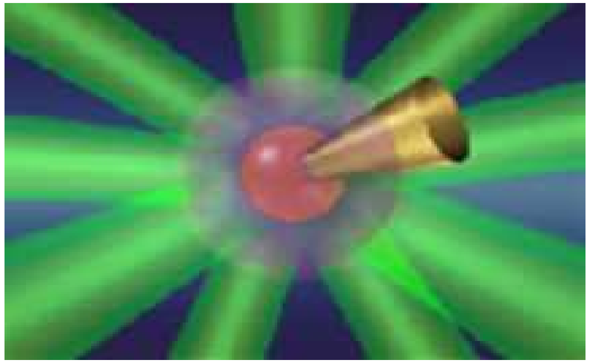
Experimental achievements

- 2006: Highest beta value (plasma pressure) of 5%
- 2008: Highest density of 1.2x10^{21}/m^3 - *world record* -
- 2013: Long-pulse operation of 48 minutes - *world record* -
- 2017: Deuterium experiment started
  Identification of isotope effect
  - *first observation in helical devices* -
- 2018: Ion/electron temperatures of 120/64 million degrees
- 2019: Ion/electron temperatures of 80/150 million degrees

Research with High-power lasers

High-power lasers

Advantage of Fast ignition type: Fast ignition type is the method that realizes fusion ignition by compressing the fuel with high - power laser and heat it with high intensity laser.



It is expected that Fast ignition may make possible an ignition with one-tenth of the energy compared to central ignition, which realizes ignition only by implosion.

Research with High-power lasers

Mainly in Institute of Laser engineering (ILE), Osaka University

LFEX（L）Gekko-XII（R）

Chamber area

Lawrence Livermore National Laboratory

OSAKA UNIVERSITY

Background and current situation

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

The next steps

- As FIREX-I project , the heating physics and scaling will be clear to realize the ignition temperature, in advance of FIREX-II for the demonstrate of ignition.
- Promote the research in the field of High Energy Density Science including laser fusion science under interdisciplinary collaborations, industry-academia collaborations, and international collaborations, with a view of application to a wide range of fields such as academic, medical, and industrial fields. (ex. new Project Arrangement with DoE).

Japan's Policy on DEMO Reactor

The Science and Technology Committee on Fusion Energy of MEXT published the strategies for the development of DEMO reactor.

December 2017

- **Promotion of R&D for DEMO reactor**
- **Action Plan towards DEMO reactor**

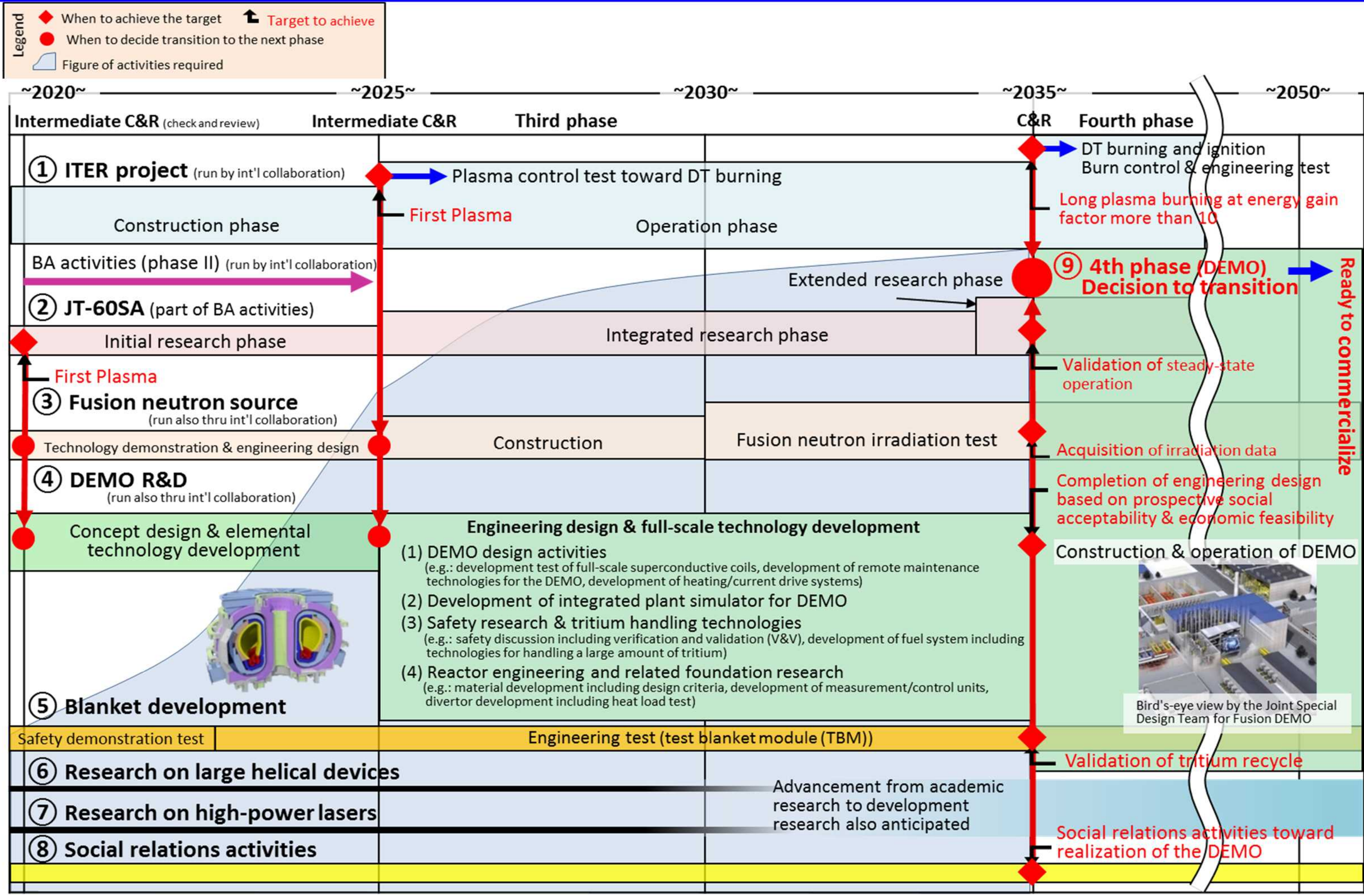
July 2018

- **Roadmap toward DEMO reactor (first report)**

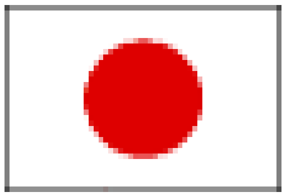
Phased Approach toward DEMO reactor

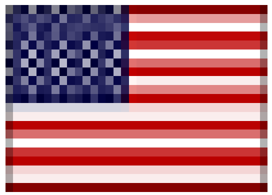
- ✓ Current : Pre-conceptual Design Phase
- ✓ **2021 : 1st Intermediate Check and Review (C&R)**
- ✓ Conceptual Design Phase
- ✓ Within a few years after 2025 : 2nd Intermediate C&R
- ✓ Engineering Design Phase
- ✓ In the 2030s : Final C&R
- ✓ Construction Phase

Roadmap toward DEMO Rector



The 40th Anniversary of the JAPAN/U.S. Fusion Research Collaboration





The JAPAN/U.S. Fusion Research Collaboration

In 1977, President Carter and Prime Minister Fukuda discussed a new US-Japan cooperation on fusion.

A governmental agreement on Japan and US Joint Activity in the field of fusion research and development was established, and the Japan-US Coordinating Committee for Fusion Energy (CCFE) was established in August 1979.

This cooperation has been continuing for **40 years**,

- ✓ Many excellent results being obtained across the wide range of activities.

We highly value the collaboration in fusion research carried out between Japan and US in the past, and we would like to ensure the continuation of steady collaboration in the future.

In 1979, the research cooperation began on the **Doublet III (later DIII-D) Tokamak machine at General Atomics (GA)** in San Diego

A group of Japanese researchers was dispatched and worked together with the US researchers and engineers, producing many world-leading results.

The major research programs

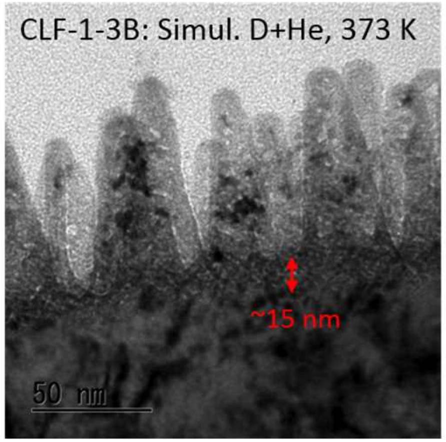
■ Joint Planning Program

FTPC
(Fusion Technology Planning Committee)
Collaboration on the research of fusion technology aiming at realization of fusion energy
Superconducting Magnets, Plasma Heating Related Technologies, In-Vessel/High Heat Flux Materials and Components, etc.

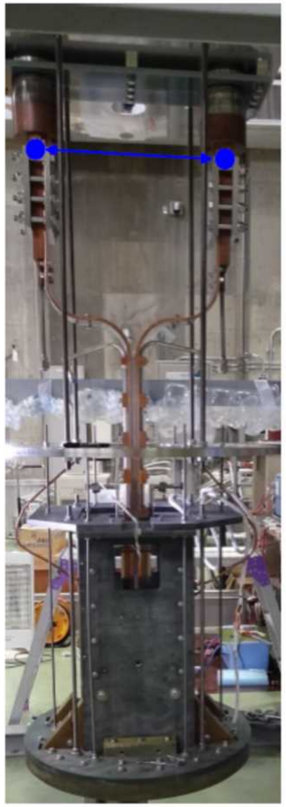
FPPC
(Fusion Physics Planning Committee)
Collaboration on the experimental research of fusion plasma physics
Steady-state Operation, MHD and High Beta, Confinement, Diagnostics, , High Energy Density Science

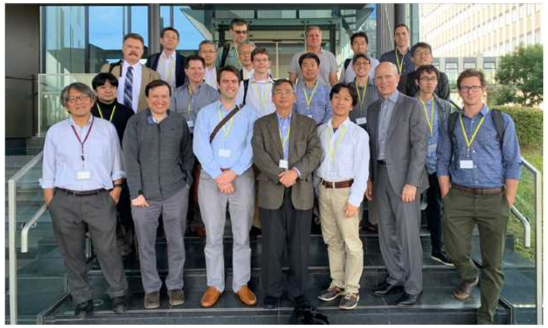
JIFT
(Joint Institute for Fusion Theory)
Collaboration to advance the theoretical understanding of plasmas and to develop fundamental theoretical and computational tools

FTPC Activity Results



TEM analysis (NIFS) of D+He irradiated RAFM in PISCES (UCSD)


High-temperature superconductor sample of MIT tested at NIFS, 2018


JIFT workshop at Kobe (Japan) 2019

Collaborations for Tokamak Experiments

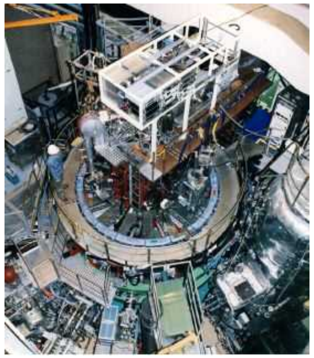
- **US-Japan Collaboration has opened new windows in all the key research areas .**

JT-60U

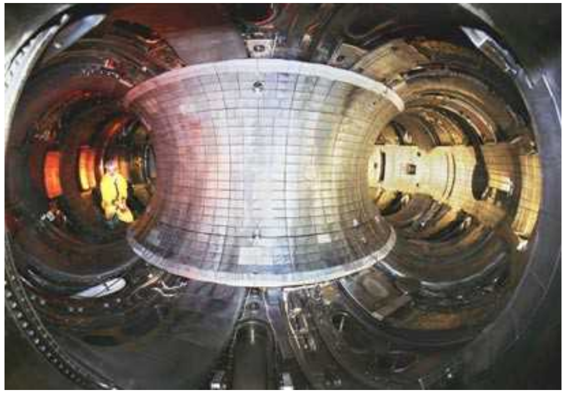
Confinement
MHD Stability
High Energy particle
Current Drive
Divertor

↕

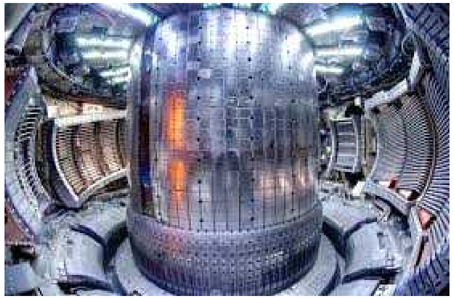
Modeling
Simulation



JFT-2M



TFTR (using IEA)



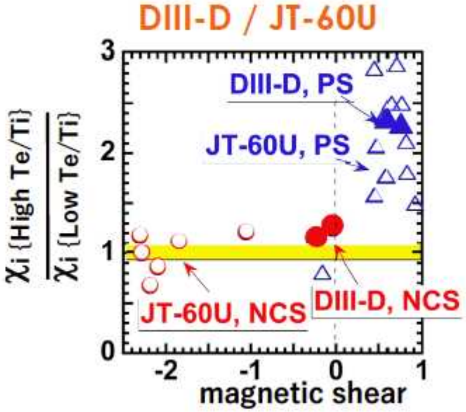
Alcator C-mod

DIII-D

NSTX

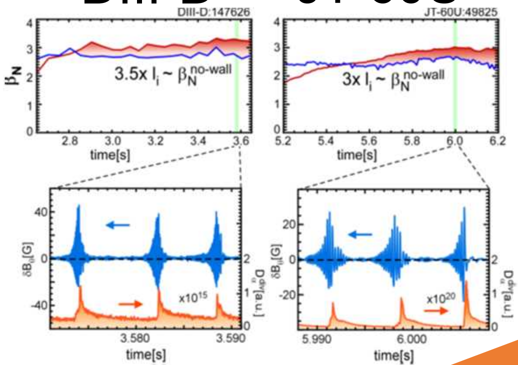
Doublet III / DIII-D Collaboration

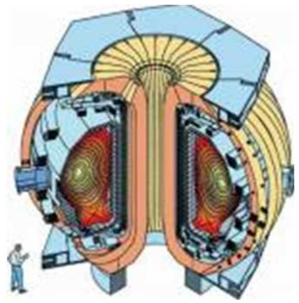
- Many harvest, such as papers and presentations at conferences, has been continuously achieved to date.
  - ✓Oral presentations at IAEA FEC by QST researchers.
    - ➢2016 FEC, M. Yoshida, 2012 FEC G. Matsunaga…



2020 and future

DIII-D JT-60U





DIII-D: 1986

- Since then , many Japanese researchers, mainly from JAERI / JAEA / QST , have joined the Doublet III and the DIII-D experiments.
- Fruitful and world leading scientific findings have been obtained.
- Synergetic results combining DIII-D and JT-60U data.

Doublet III: 1978

- The Doublet III project was initiated as an US-Japan collaboration project at 1979.
- During the first 5years (1979-1984), 50 person-year of JAERI researchers joined on site and utilized 50% of the machine time.
  - ✓US week – Japanese week – US week…
- Strong partnership between US-Japan was established.

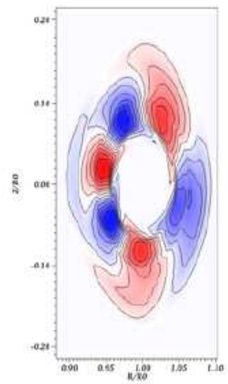
Joint Institute for Fusion Theory (JIFT)

Objectives (1) to advance the theoretical understanding of plasmas, with special emphasis on stability, equilibrium, heating, and transport in magnetic fusion systems; and (2) to develop fundamental theoretical and computational tools and concepts for predicting nonlinear plasma evolution

Activities Each year the JIFT program usually consists of four topical workshops (two in each country) and six exchange scientists (three from each country). So far, during its 40 years of successful operation, JIFT has sponsored 245 long-term visits by exchange scientists and 138 topical workshops.

Through JIFT, close and long-lasting scientific connections have been established between the U.S. and Japanese fusion theory communities.

4th JIFT Exascale Computing Workshop at PPPL (July 2018)



Collaboration research: LHD TAE instability (D.A. Spong and Y. Todo)

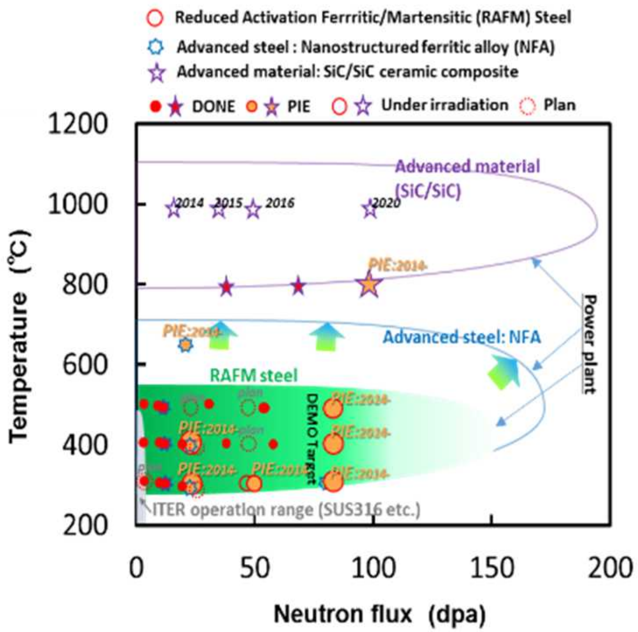
JIFT Steering Committee Meeting (Nov. 2004)

Research on Materials

QST-DOE irradiation projects

Collaboration to design, conduct and evaluate joint irradiation experiments in the High Flux Isotope Reactor (HFIR) of the Oak Ridge National Laboratory

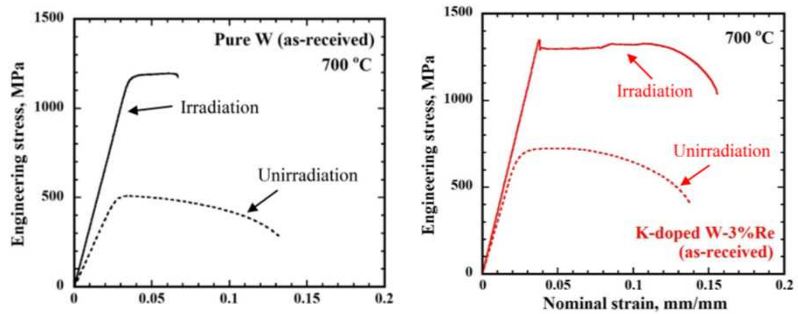
Starting from 1982, investigate the irradiation response of Japanese and U.S. structural materials to high levels of atomic displacement (~80dpa)



MEXT-DOE Material program

The joint research project between DOE of U.S. and MEXT of Japan in Fundamental Studies of Irradiation Effects in Fusion Materials Utilizing Fission Reactors

1981~ RTNS-II, 1987~ FFTF/MOTA, JUPITER, 2001~ JUPITER-II, 2007~ TITAN, 2013~ PHENIX, 2019~ FORNTIER



Tensile properties of neutron-irradiated and non-irradiated W (left) and K-doped W-3%Re alloy (right) developed during PHENIX project