International Workshop on μCF and Future Applications
Jul 2 – 3, 2026 @ Liverpool University, UK

Fusion Research Overview in Japan

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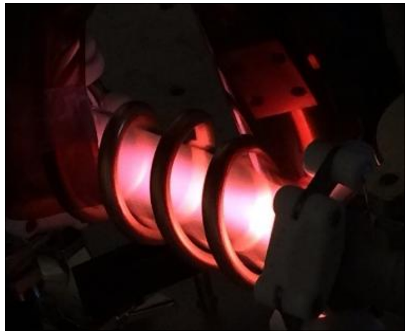
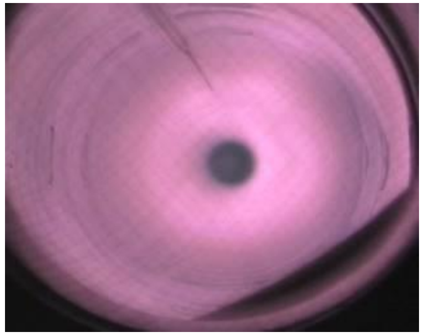
Plasma experiment

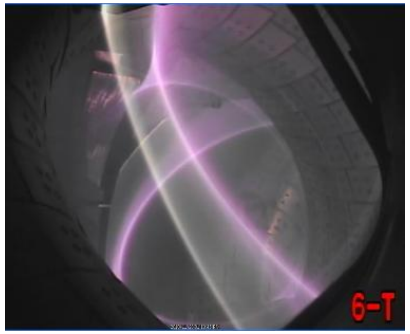
Plasma turbulence, turbulent transport,
Alfven wave, Wave-particle interactions,
Phase space dynamics, Optical vortex,
Negative ion beam, ElectroConvection,,,



T< 1eV, L~ several cm
PF plasma（hand-made）



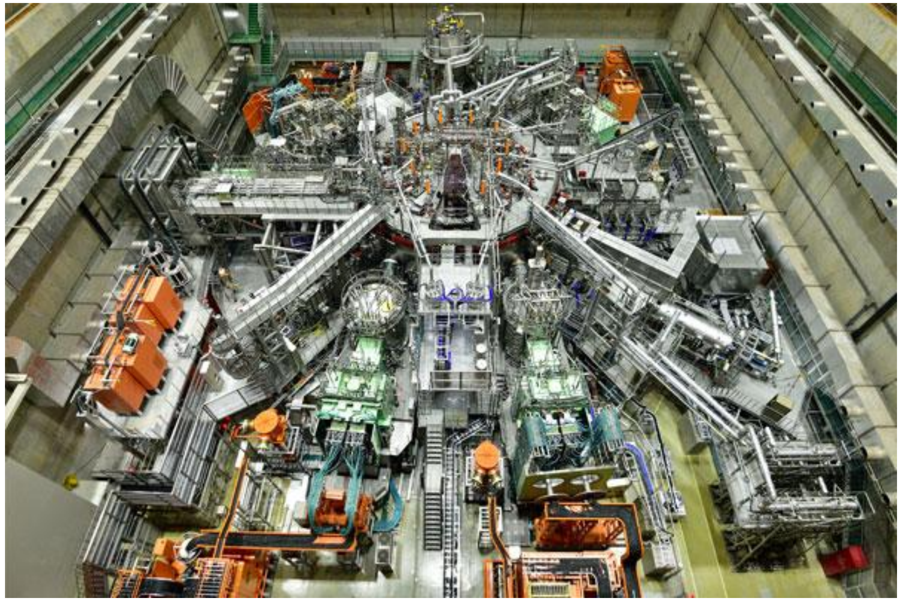
T~several eV、L~10-100cm
Hyper-I (linear device)



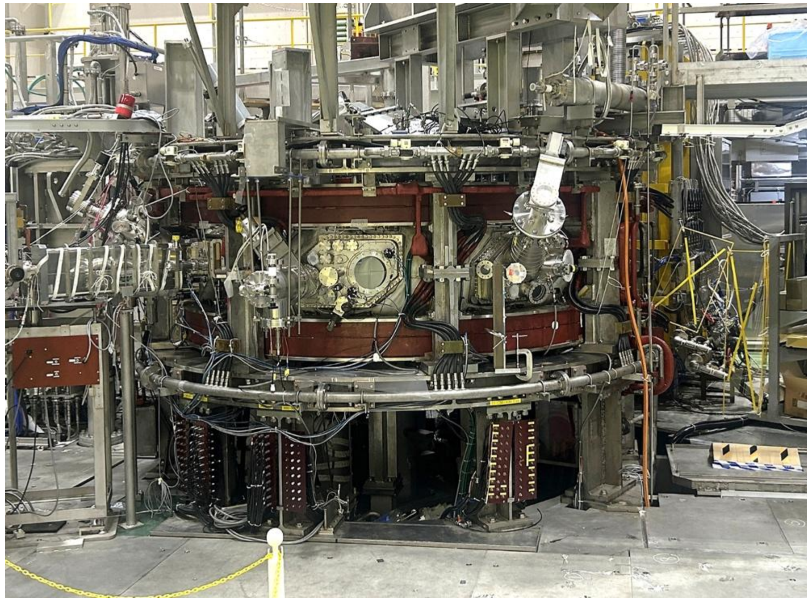
T~ 10 keV、L~1-10m
LHD (Helical device)

National Institute for Fusion Science (NIFS)

Large Helical Device (LHD)



Compact Helical Device (CHD)



NIFS is the second-largest institute for fusion research in Japan, and "Inter-University Research Institute". 110 scientists and 70 students.

Very important period in the dramatic transformation of fusion research

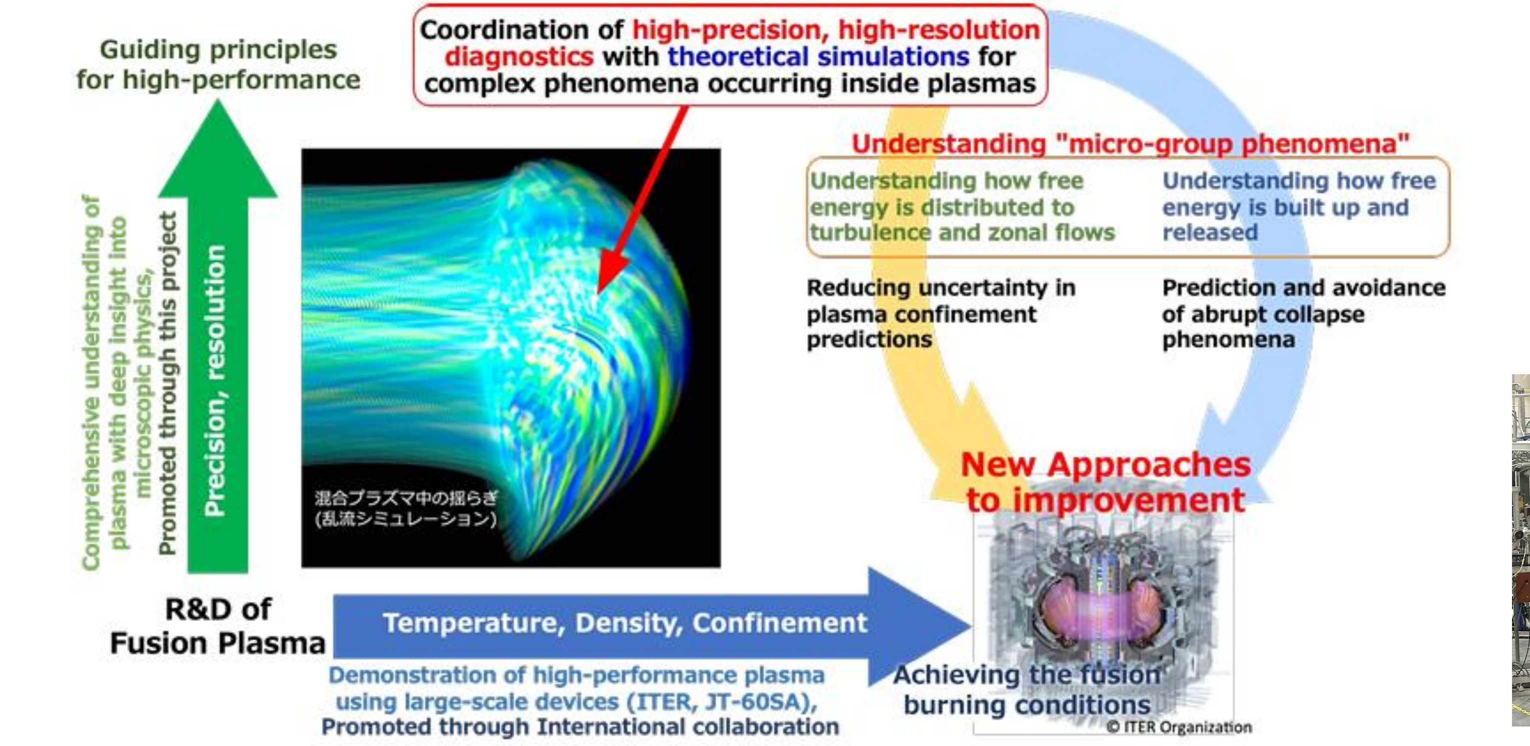
LHD project **(28-year plasma experiment)** **completed in March 2026**

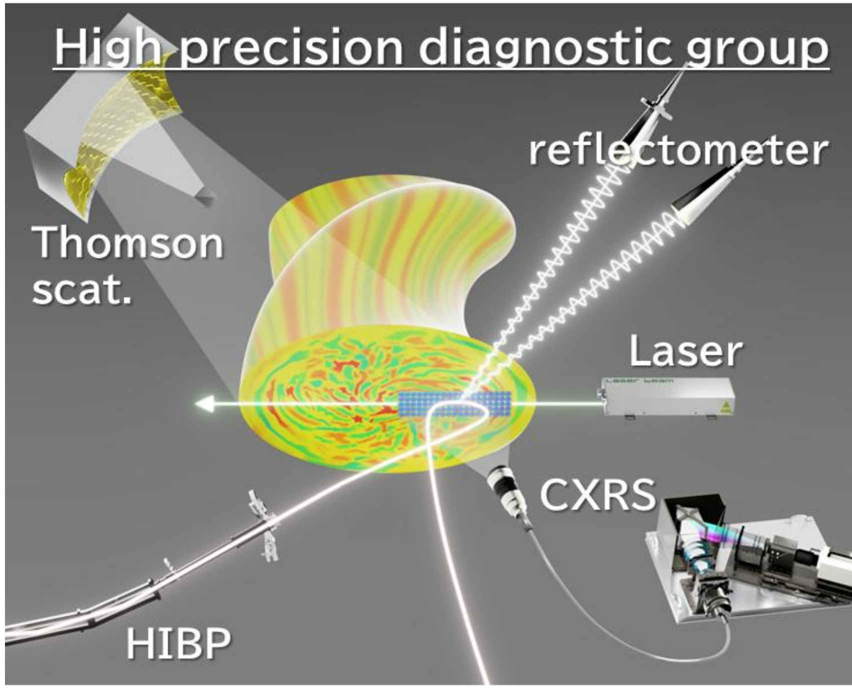
New project "MCPoP" launched in April 2026, and CHD operation will start soon.

MCPoP project (2026-2035JFY)

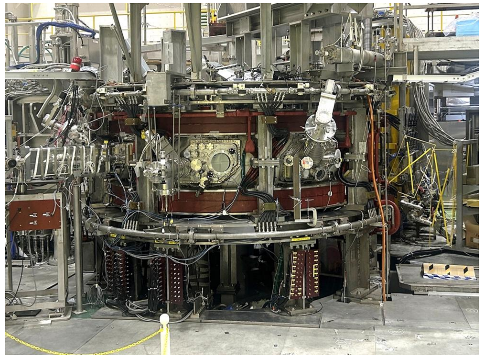
"Micro-Collective Phenomena" of Ultra-high Temperature Plasmas, and Fusion Science

The greatest challenge in realizing fusion energy is to make the fusion system more compact and efficient. As the core plasma decreases in size, the temperature gradient increases, resulting in complex fluctuations that can cause a degradation in confinement and lead to abrupt instabilities. To better understand the causes and effects of these unique plasma fluctuations—an issue relevant not only to fusion reactors but also to space and celestial bodies—we will develop an experimental system capable of precisely controlling and manipulating the microscopic state of ultra-high-temperature plasma. This system will allow us to measure plasma with the highest resolution in the world. By integrating plasma diagnostics with theoretical simulations, we aim to establish guiding principles that will promote innovation in fusion energy.

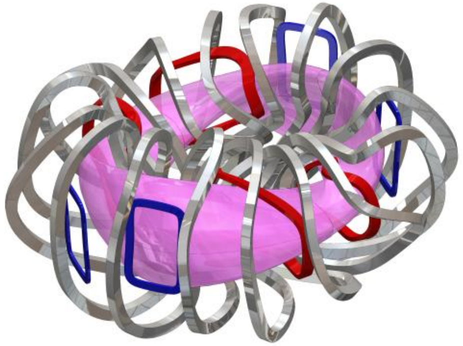




CHD



CHD-U



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2. Research activities worldwide and in Japan
3. New stakeholders
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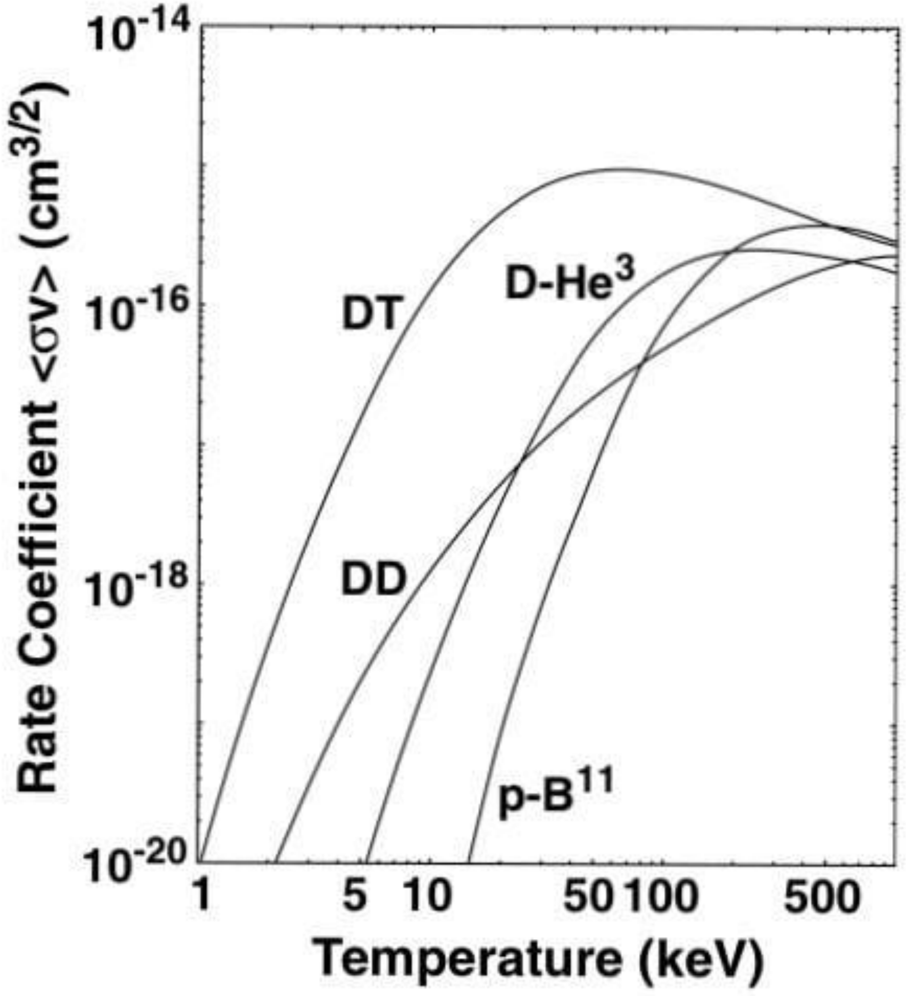
Fusion energy

A star is a system for
generating Fusion Energy

Gravity / Inertia
Magnetic field

High temperature plasma is necessary



Nuclear Reactions

$$D + T \rightarrow He^3 + 3.27 \text{ MeV}$$

$$D + D \rightarrow T^3 + H + 4.03 \text{ MeV}$$

$$D + He^3 \rightarrow He^4 + H + 18.3 \text{ MeV}$$

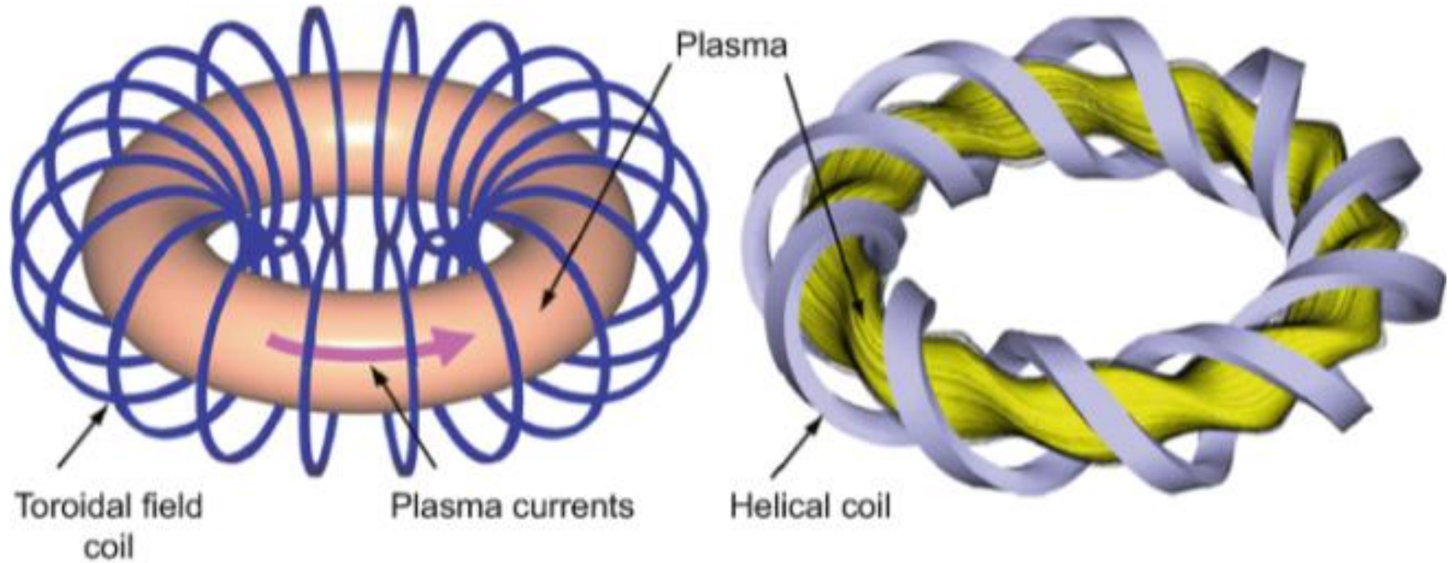
$$H + B^{11} \rightarrow 3He^4 + 8.7 \text{ MeV}$$

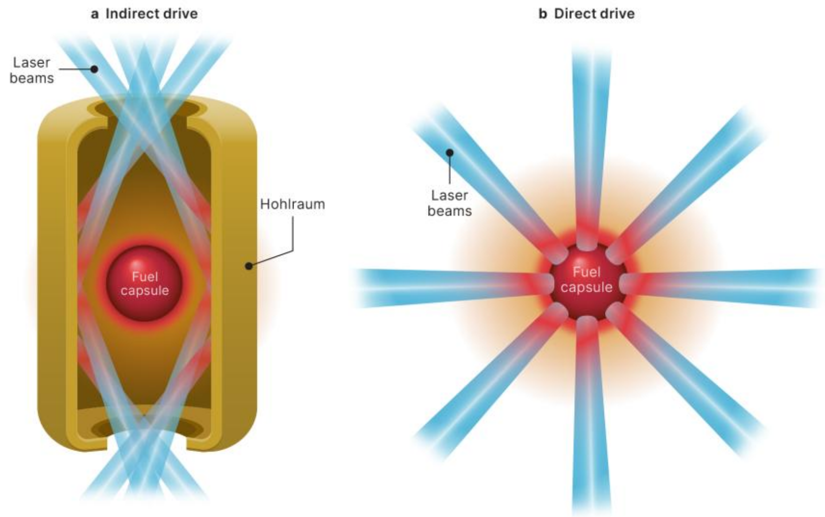
The easiest way is the DT reaction, however, temperatures exceeding 10 keV are required !

High temperature plasma confinement

Yamada JFE2025

www.lle.rochester.edu





	Tokamak	Helical/Stellarator	Inertial/laser
high Temp.	very good	marginal	marginal
high density	good	very good	super
long pulse	marginal	good	-
stability	marginal	good	marginal

Way to Fusion Burning plasma

Fusion energy gain factor:

$$Q = \frac{P_{\text{fusion}}}{P_{\text{input}}}$$

$Q = 1$ The first milestone: Lawson criteria

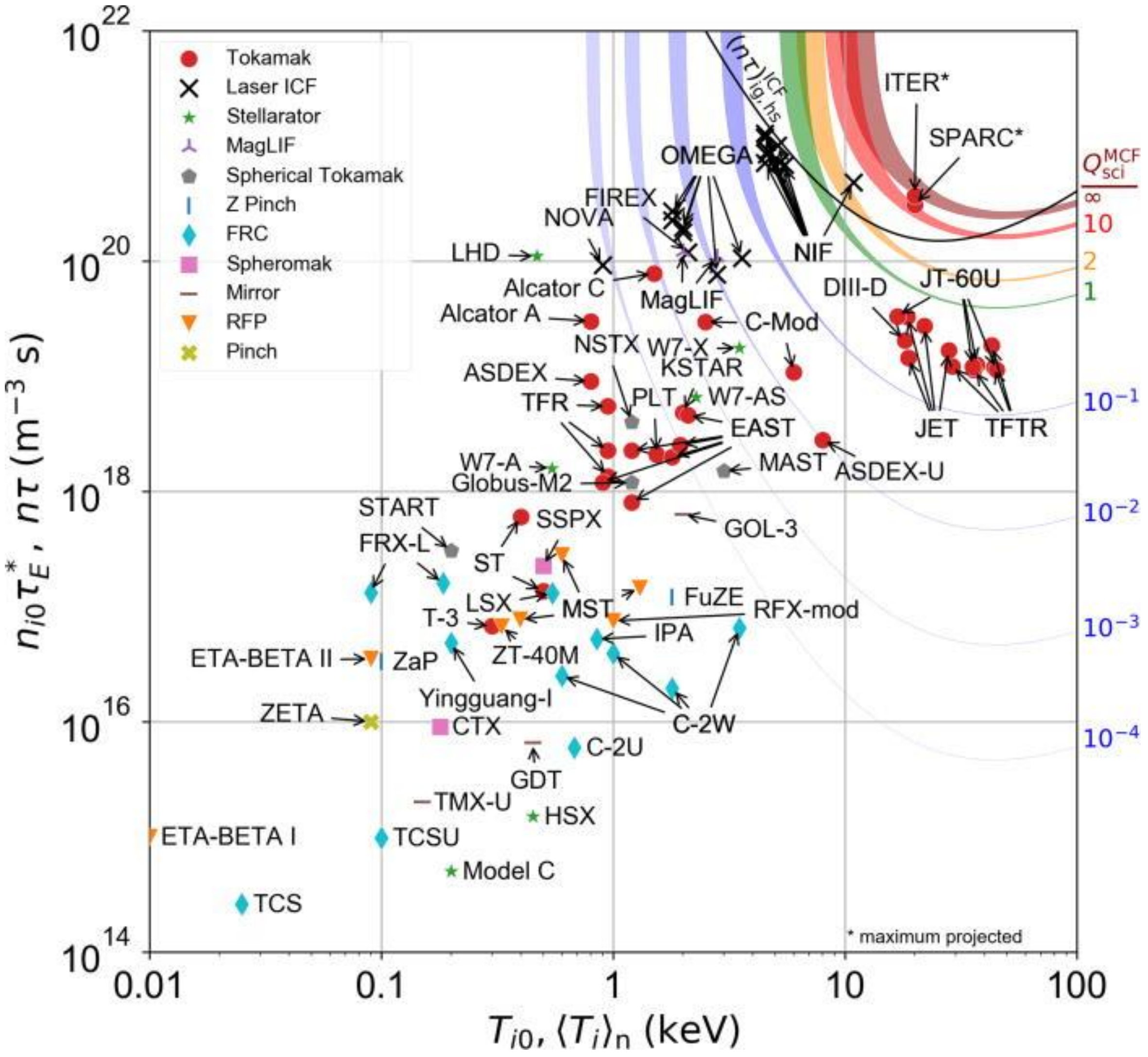
$Q = \infty$ The final target

Lawson criteria:

$$n\tau > 6 \times 10^{19}\ [\mathrm{m^{-3}s}]$$

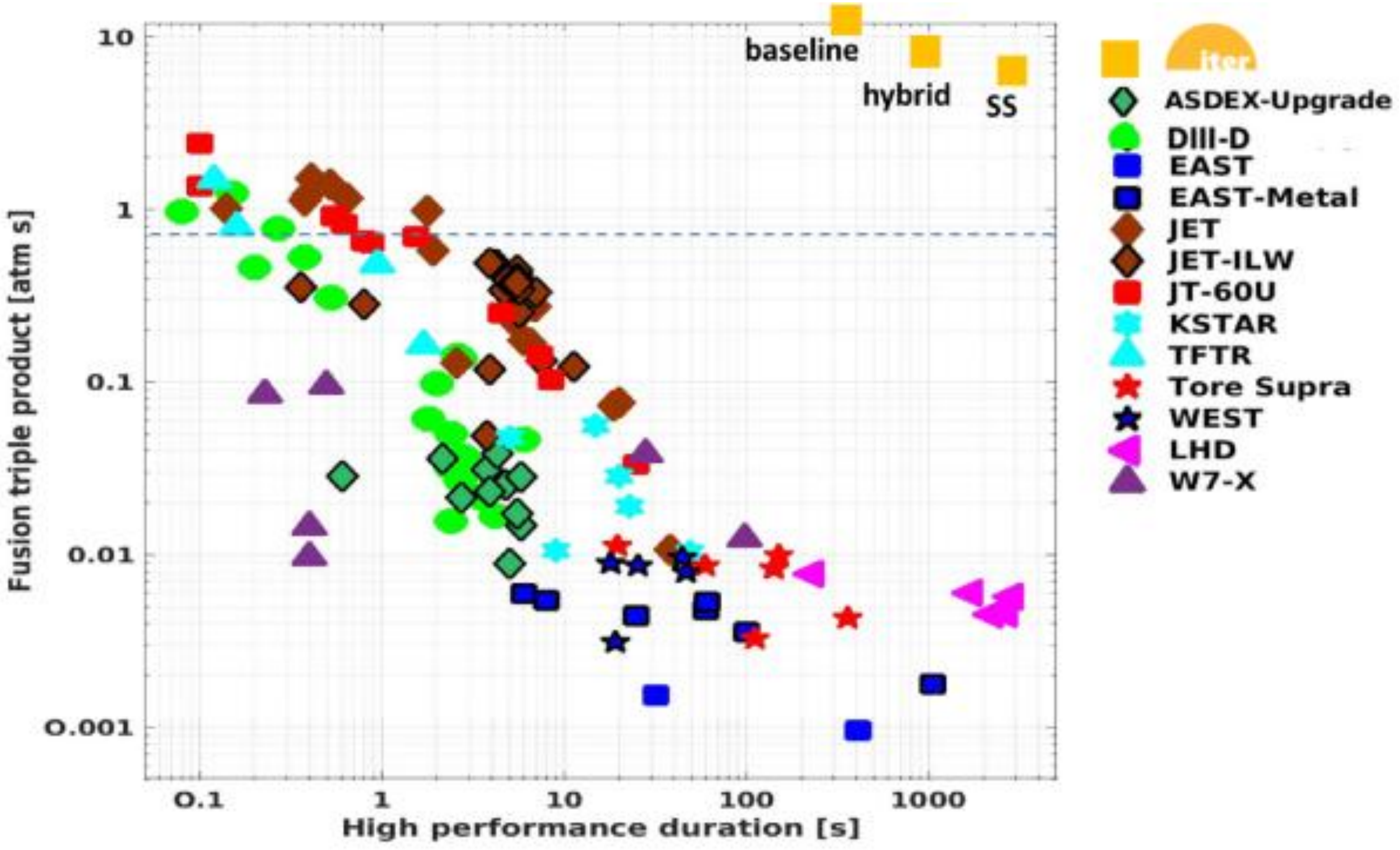
where the confinement time:

$$\tau[s] = \frac{\text{total kinetic energy } [J]}{P_{\text{input}}\ [W]}$$



S.E. Wurzel+ Physics of Plasmas 29, 062103 (2022)

Remaining issues for fusion energy



X. Litaudon *et al* 2024 *Nucl. Fusion* **64** 015001

- Economic efficiency
  ->turbulent transport
  (MCPoP will contribute to)
- Materials engineering
  ->high heat flux and neutron flux
- Fuel cycle
  ->Tritium breeding
- Engineering system
  -> HTS, Remote handling

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Fusion researches in the world

IAEA (2021)

Total	Tokamaks	Stellarators/Heliotrons	Laser Fusion	Altern. Concepts
119	68	12	8	31

Operating	Under construction	Planned
94	8	17

Public	Private
97	22

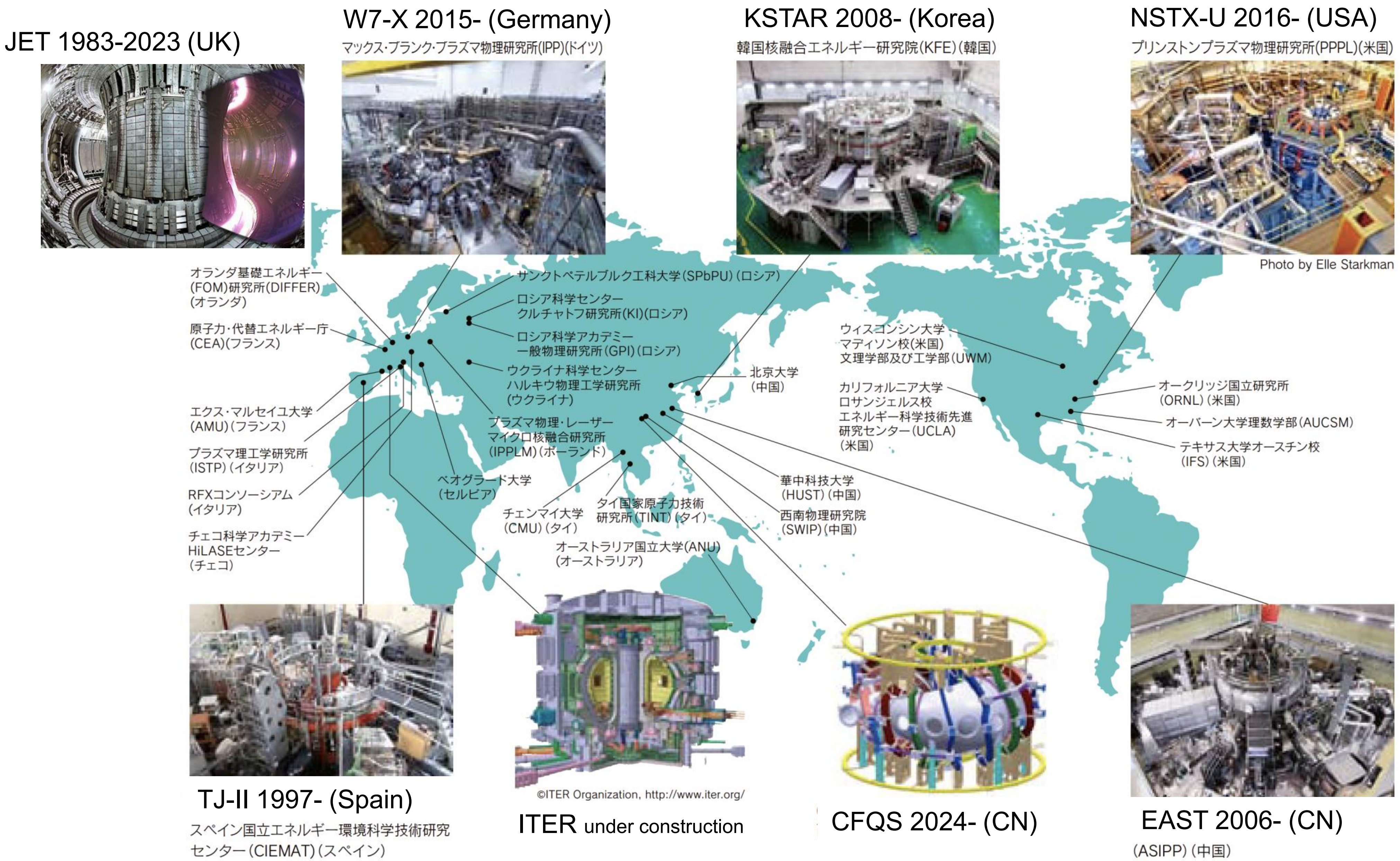
Tokamaks
Stellarators/Heliotr..
Laser Fusion
Altern. Concepts

Search Device Name
No items highlighted

Country	
United States	28
Japan	23
China	9
Russia	8
France	5
Pakistan	4
United Kingdo..	4
Brazil	3
Czech Republic	3
Germany	3
India	3
Iran	3
Italy	3
Canada	2
Costa Rica	2
Republic of K..	2
Spain	2
Switzerland	2
Ukraine	2
Australia	1
Denmark	1
Egypt	1
Kazakhstan	1
Libya	1
Portugal	1
Sweden	1
Thailand	1

too large

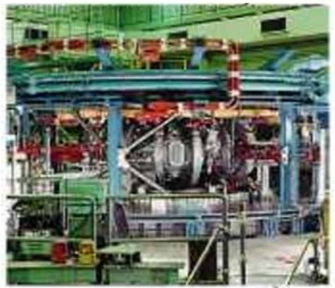
Large Facilities of Magnetic Fusion



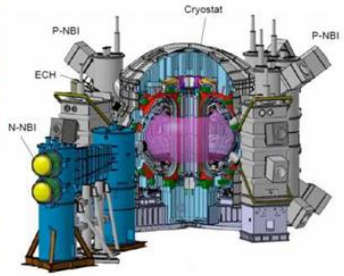
Fusion Research Institutes/Center in Japan

Japan

Heliotron J (Kyoto Univ.)

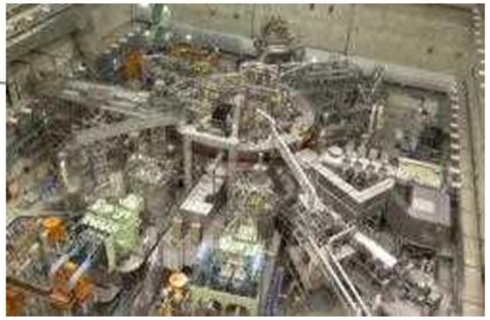


JT60-SA (QST)

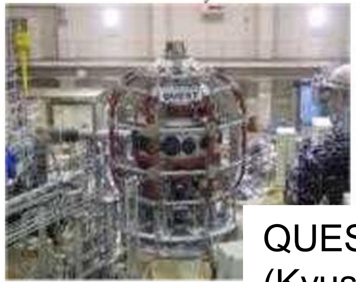


Plasma Simulator (QST, NIFS)

GAMMA10/PDX (Tsukuba Univ.)



LHD / CHD (NIFS)



QUEST (Kyushu Univ.)

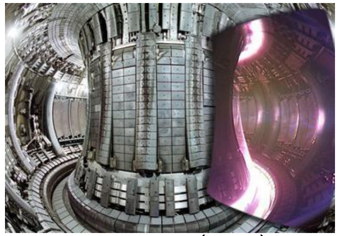
GEKKO XII (ILE Osaka Univ.)

Historical trend of large device construction

1980	1990	2000	2010	2020	2030

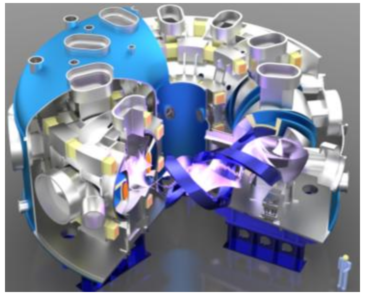
Large Tokamaks
Confinement Demo.

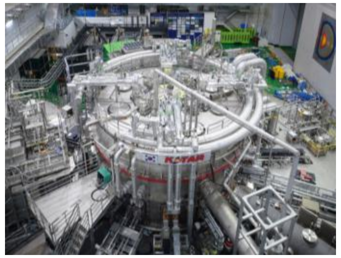

TFTR（US）

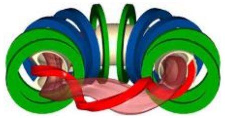

JET（UK）

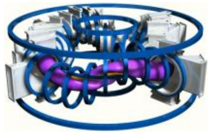

JT-60/60U (Japan)

Superconductor
Steady state


LHD (Japan)


KSTAR (Korea)

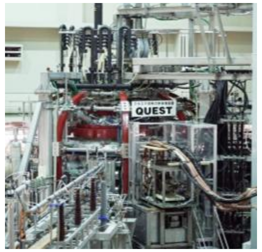

Heliotron J (Japan)

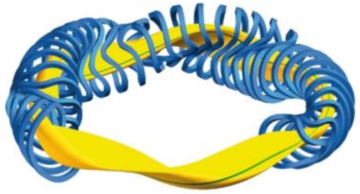

TJ-II (Spain)

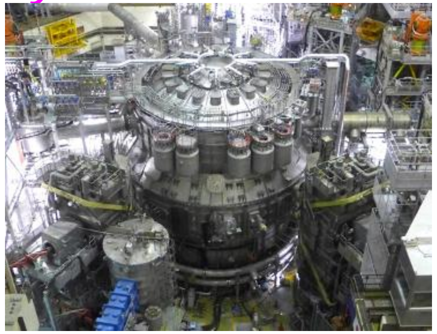

EAST (China)

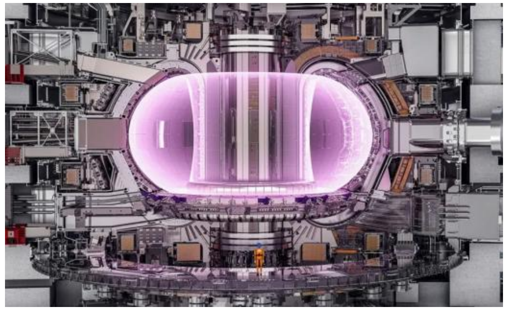
Helical / Stellarator
Diversity

Spherical tokamak
High-Efficiency


QUEST (Japan)


W-7X (Germany)


JT-60SA (Japan/EU)


ITER

System Integration
Burning plasma

ITER

- The world's largest international scientific collaboration aimed at demonstrating the scientific and technological feasibility of fusion energy.
- Construction began in 2007 at Saint-Paul-lez-Durance, France, with deuterium–tritium (DT) operation planned for 2035.
- Members: Japan, the European Union (EU), Russia, the United States, South Korea, China, and India.

Reaction Power：500MW

Major radius ：6.2m

Minor radius ：2.0m

Plasma volume ：$837m^3$

Heating power：73MW

ITER

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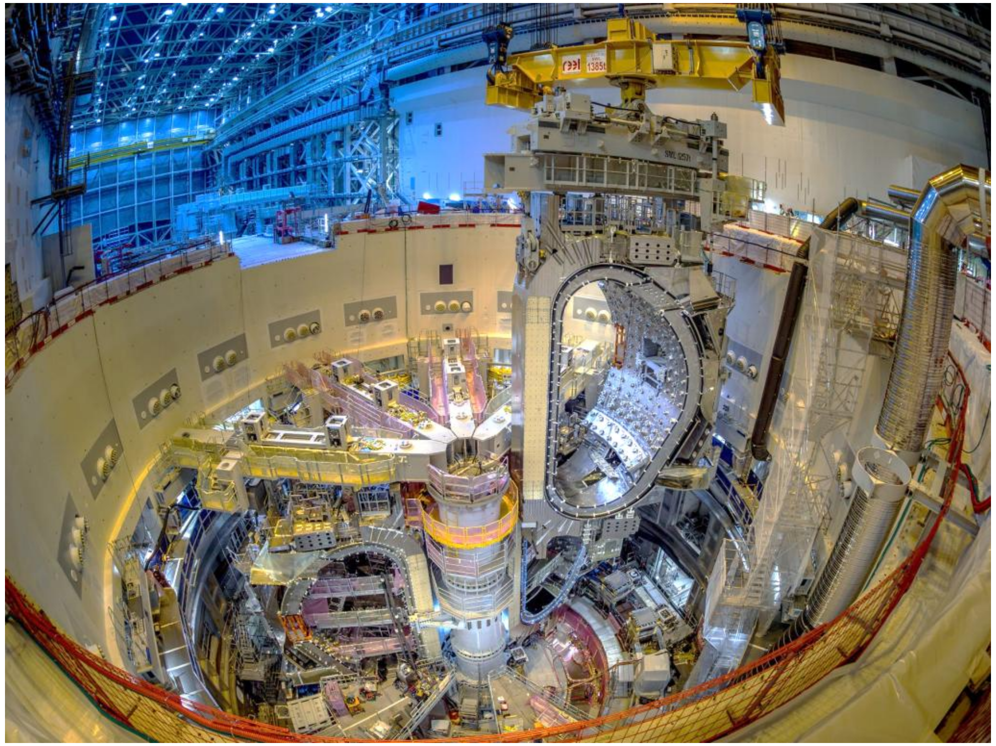
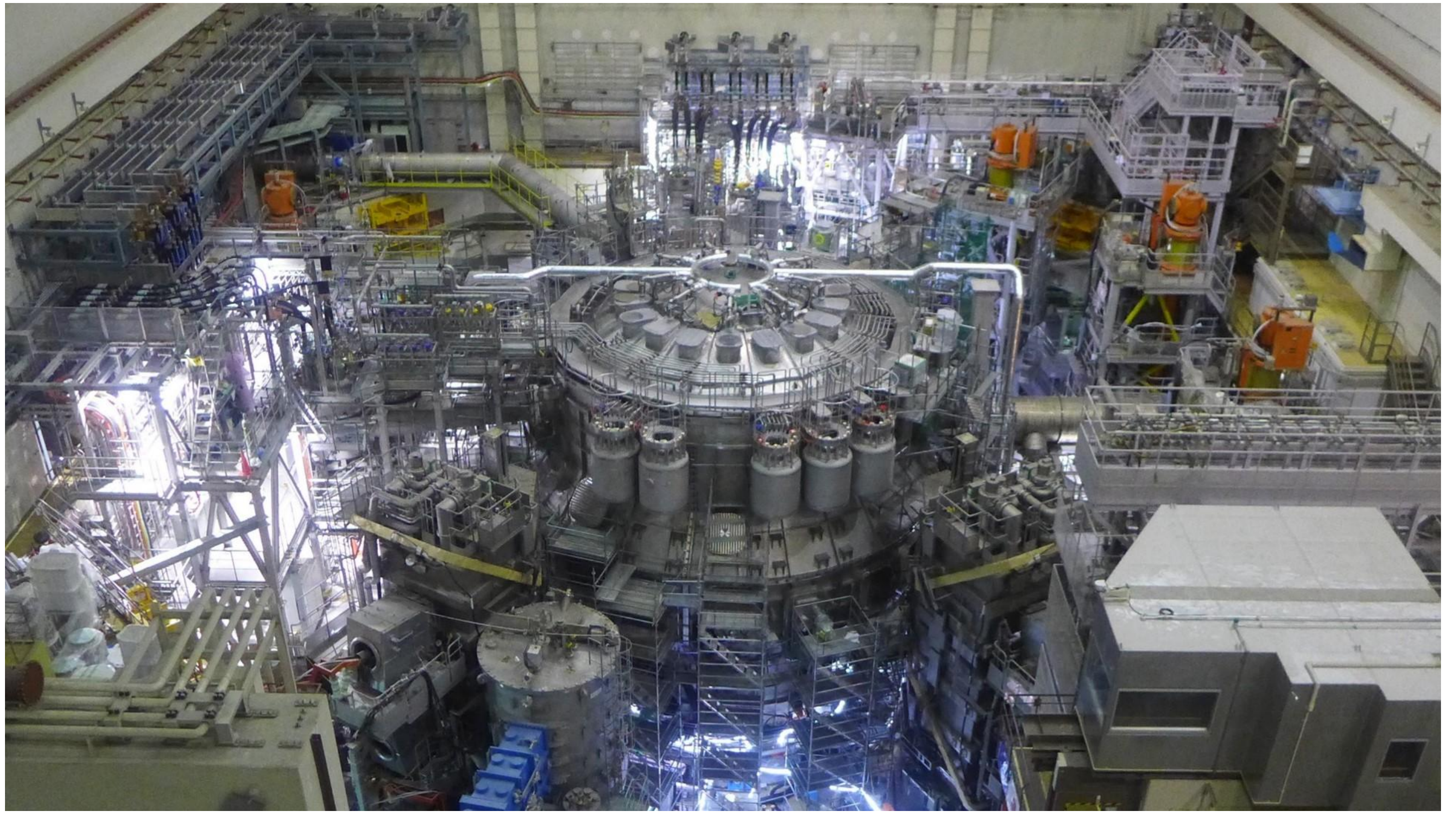
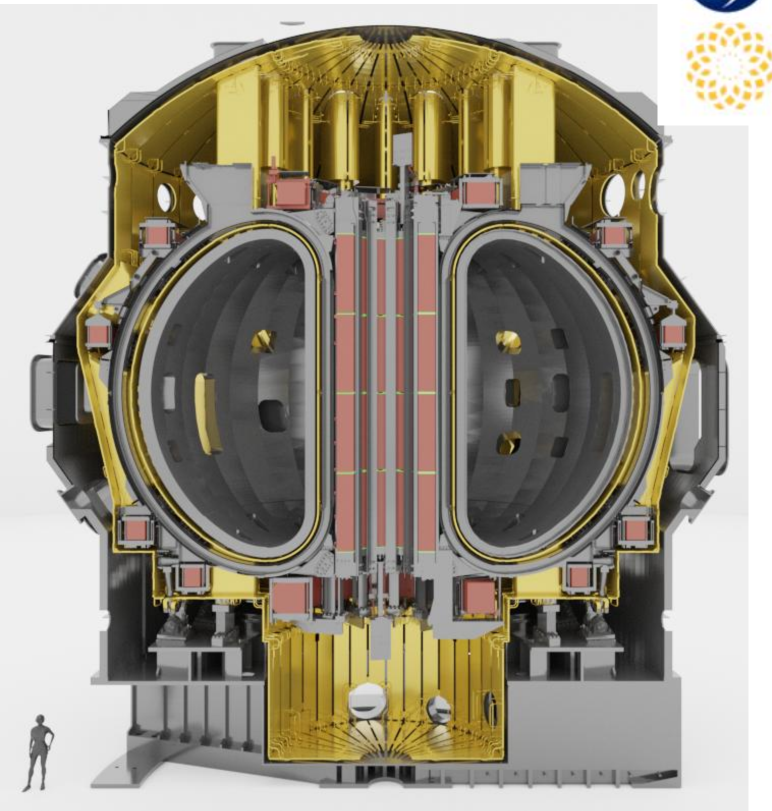


JT60-SA：Tokamak@QST-Naka Institute

Japan

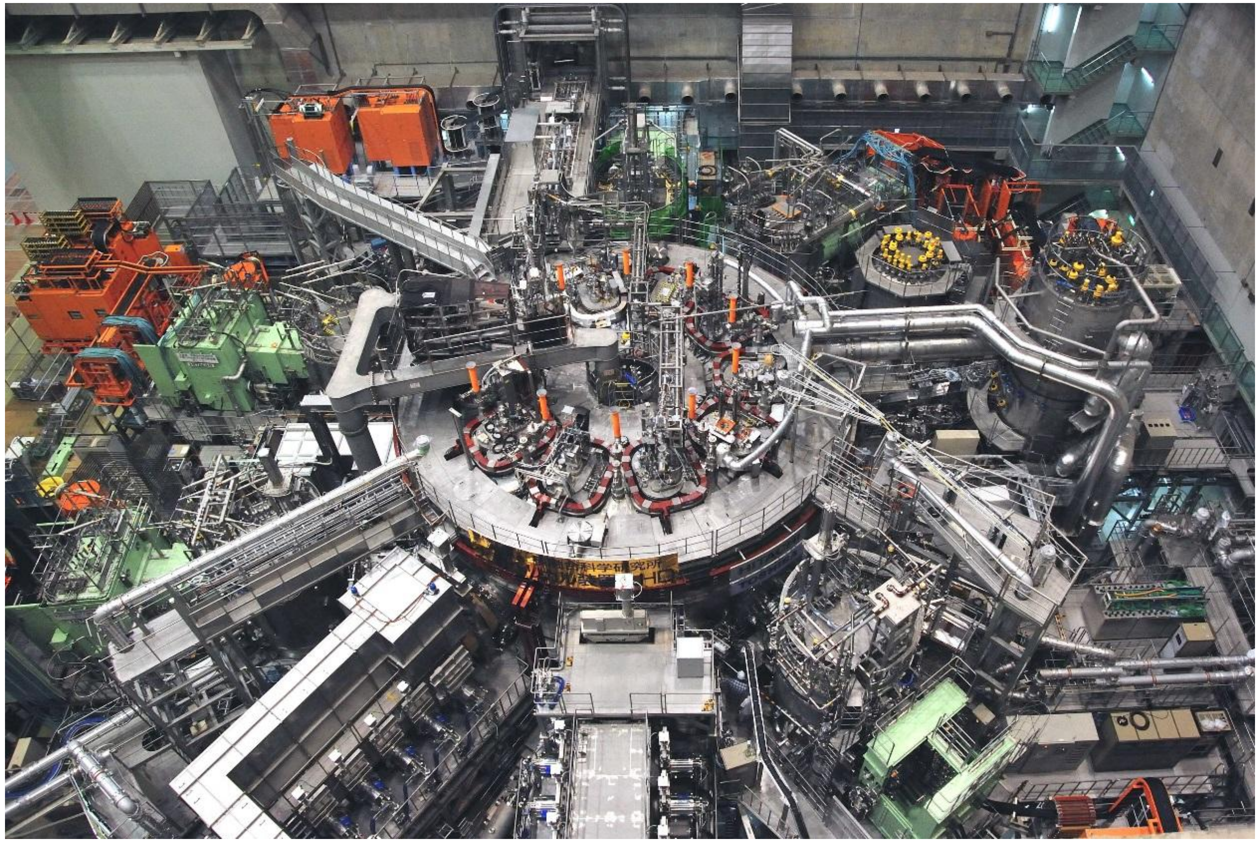


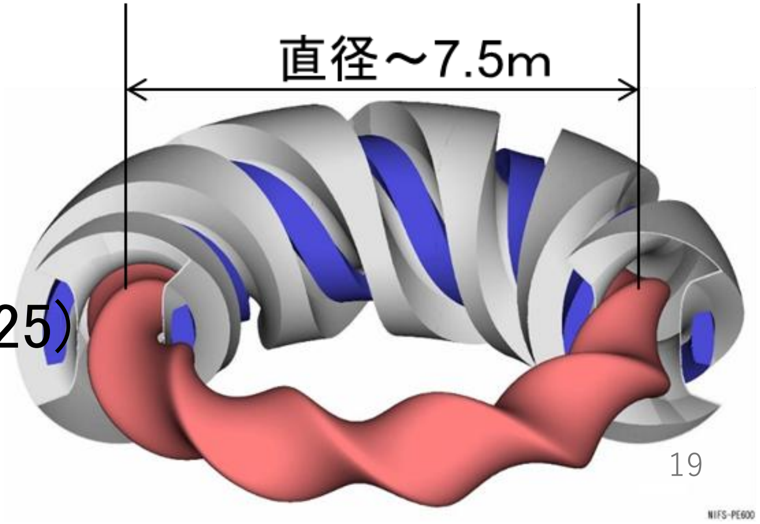


- JT-60SA (SA stands for “super advanced”)
  - The largest tokamak device currently in operation in the world (2023 -)
  - A collaboration project between Japan and the EU

Large Helical Device (LHD)@NIFS

Japan

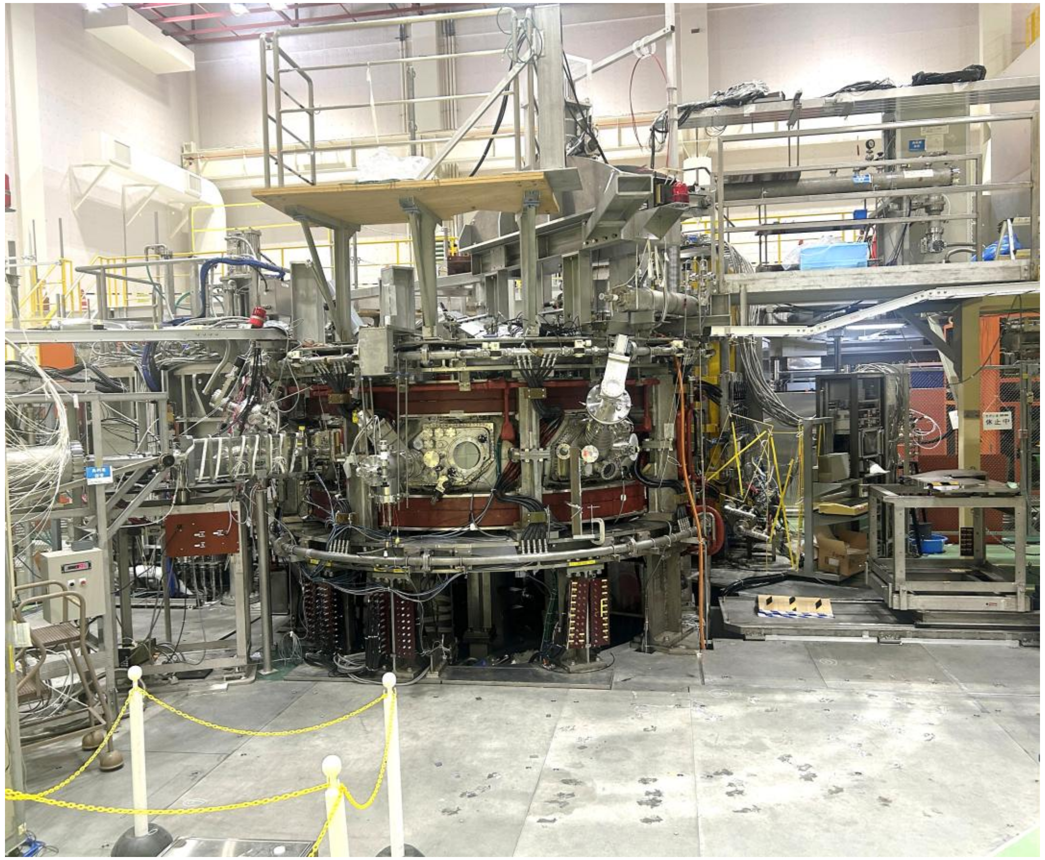


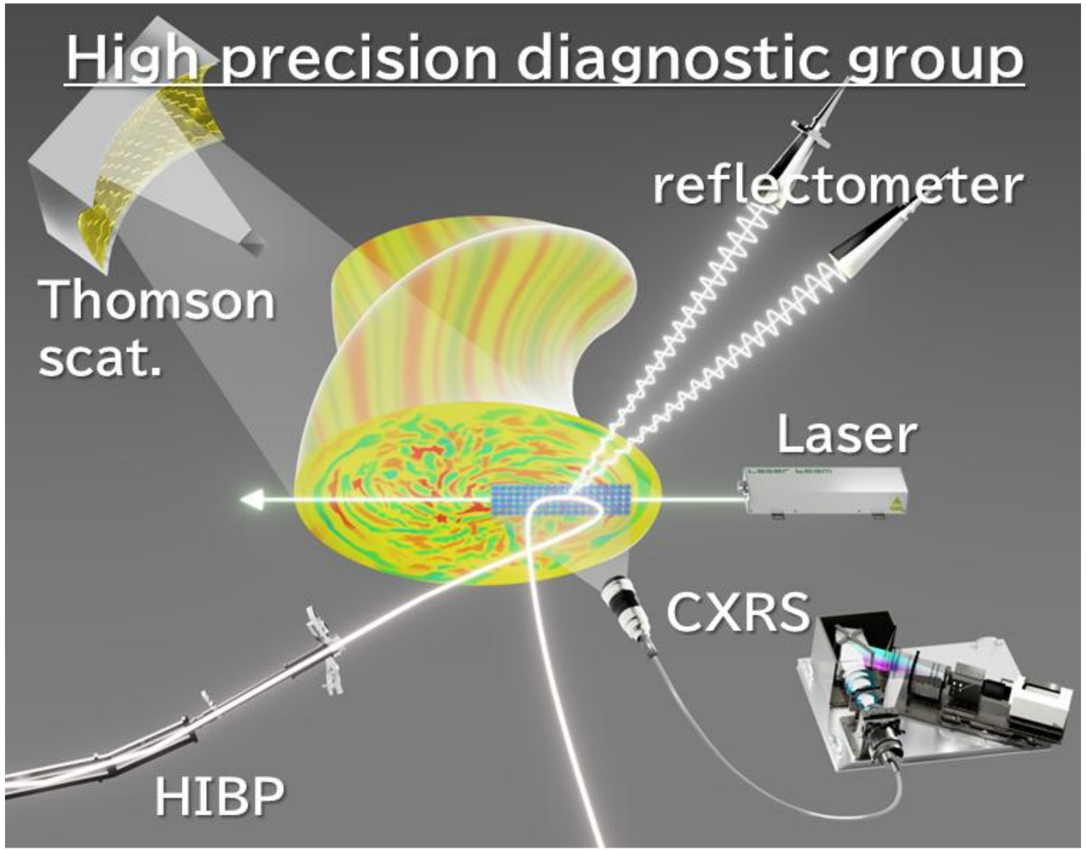


- The largest superconducting device in the world in 1998
- The 28-year plasma operation was completed (1998-2025)
- Demonstration of steady-state operation

Compact Helical Device (CHD) by MCPoP project

Japan





Plasma size becomes smaller, but
plasma diagnostics and control capabilities have advanced significantly, resolving velocity distribution functions with high temporal and spatial resolutions

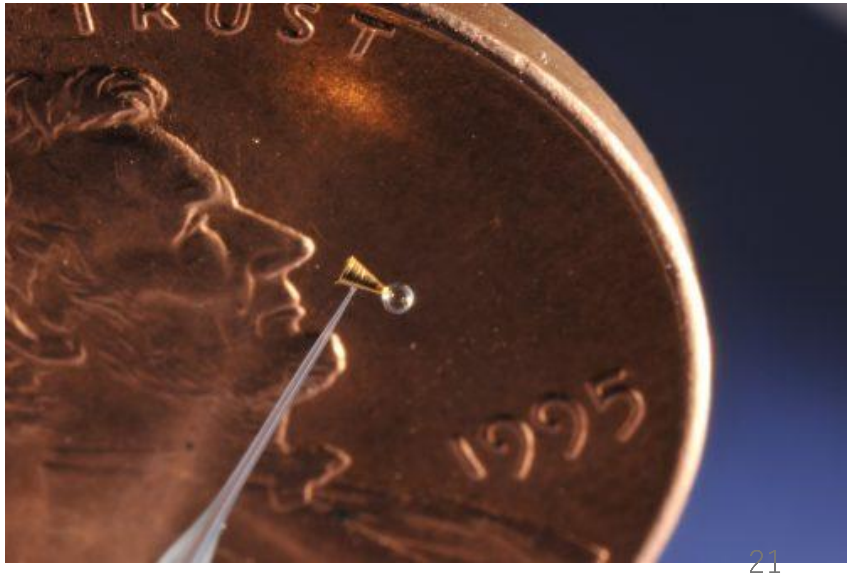
Addressing a critical challenge in fusion energy economics

GEKKO XII：High power laser@ILE Osaka Univ.

Japan

High-density compression exceeding 600x solid density via laser implosion

No. of beams:	12 beams
Shots/day:	3 – 4 shots//day (12 beams simultaneous)
Wavelength: /Illumination config.:	1053 nm or 527 nm(target chamberI) 1053 nm or 527 nm or 351 nm(target chamberII)
Pulse width:	0.1 ns – 4 ns
Energy	1000 J/beam (1053 nm/ > 1.2 ns) 500 J/beam(527 nm/ >1.2 ns) 250 J/beam (351 nm/>2.0 ns)



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5. Moonshot 10 program

Company	Country	Method	Power generation demonstration target	Technical assets	Cumulative funding raised	Major investors	Power Purchase Agreements & Customers
Commonwealth Fusion Systems (CFS)	US	HTS-Tokamak	SPARC：~2027 ARC：2030s	REBCO HTS, High Field Magnet, Superconductor manufacturing technology	~3000M USD	Google、Eni、Bill Gates、Temasek、Khosla Ventures、Mitsubishi Corporation, Mitsui & Co.,,	Google 200 MW、Eni 400 MW PPA
Helion Energy	US	FRC	Orion：2028	Pulse power tech., High-speed switching, High-current energy recovery	~1900M USD	Sam Altman、SoftBank Vision Fund 2、Lightspeed、Nucor,,,	Microsoft 50 MW、Nucor 500 MW
TAE Technologies	US	FRC・p-B11	Early 2030s	Beam control, Plasma control AI, High-power power supply technology	~1500M USD	Google、Chevron、NEA,,,	–
Pacific Fusion	US	Pulsed Inertia Fusion	Early 2030s	Ultra-high-voltage pulsed power, Electromagnetic compression tech.	~900M USD	General Catalyst、Breakthrough,,,	–
General Fusion	Canada	MTF	2030s after LM26	Liquid metal engineering, Large-scale pulsed machinery systems	~500M USD	Jeff Bezos、Temasek,,,	–
Marvel Fusion	Germany	Laser Fusion	2030s	Ultrashort-pulse lasers, Laser processing technology	~400M USD	EQT Ventures、Siemens Energy Ventures、EIC Fund,,,	Siemens Energy
Zap Energy	US	Sheared-Flow Z-Pinch	2030s	High-current discharge technology, Pulsed power supplies	~300M USD	Breakthrough Energy Ventures、DCVC,,,	–
Tokamak Energy	US	Spherical tokamak	2030s	HTS magnets, High-magnetic-field applications	~200M USD	Lingotto、Legal & General、Furukawa Electric,,,	–
Proxima Fusion	Germany	Stellarator	Prototype: 2031 plant: late 2030s	AI-driven 3D magnetic field design, Numerical simulation	~200M USD	Cherry Ventures、Balderton Capital、Lightspeed、EIC Fund,,,	–
Focused Energy	Germany USA	Laser Fusion	2030s	High-power lasers, Target fabrication technology	~200M USD	Prime Movers Lab,,,	–

AIによる調査

Status of domestic venture companies

Japan

Company	Country	Method	Power generation demonstration target	Technical assets	Cumulative funding raised
Kyoto Fusioneering	Japan	Supply chain development	-	gyrotron, blanket, fuel system,,,	~160M USD
Helical Fusion	Japan	Helical	2030s	HTC, Liquid metal blanket	~70M USD
MiRESSO	Japan	Beryllium production	-	Low temperature Beryllium production	~50M USD
LINEA Innovations	Japan	FRC & Mirror	Early 2030s	Electromagnetic compression tech, Direct electricity convetor.	~12M USD
Starlight engine	Japan	Tokamak	2030s	Tritium breeding, System integration	no public data

Sep. 2025 Japanese investors invested 750M USD in CFS (USA)

2026-2028, The Japanese government will provide 380M USD in support for domestic ventures

Contents

Japanese Fusion Energy Innovation Strategy

April 2023 -

Japan

Maximizing ITER/BA achievements and emerging technologies
to demonstrate fusion power in the 2030s
and build a fusion industrial ecosystem.

(1) Developing the Fusion Industry
Industry

- Strengthen J-Fusion collaboration
- International standards & supply chains
- Safety and regulatory framework
- Accelerate commercialization

(2) Fusion Technology
Technology

- Accelerate prototype reactor R&D
- Strengthen public-private innovation
- Leverage ITER/BA core technologies

(3) Implementation Framework
Promotion

- Government-led coordination
- Innovation hubs (QST, NIFS, ILE)
- Human resource development
- Public engagement & communication

Academia

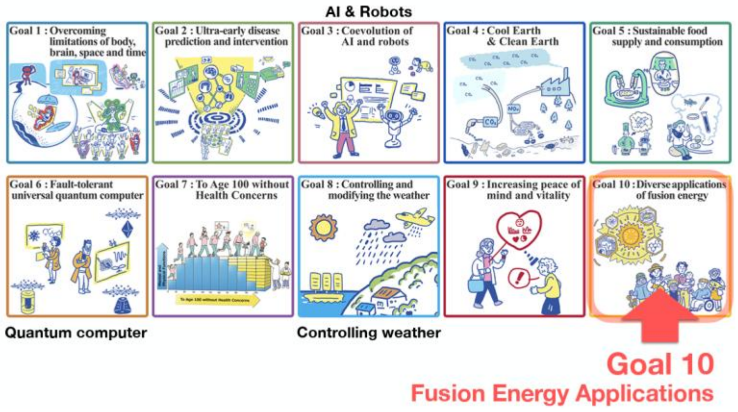
FOSTER@UKAEA
(Fusion Opportunities in Skills, Training, Education and Research)

Several support programs, including ***Moonshot Goal 10***, are currently underway !

Moonshot Goal 10: Fusion Energy Applications

Japan

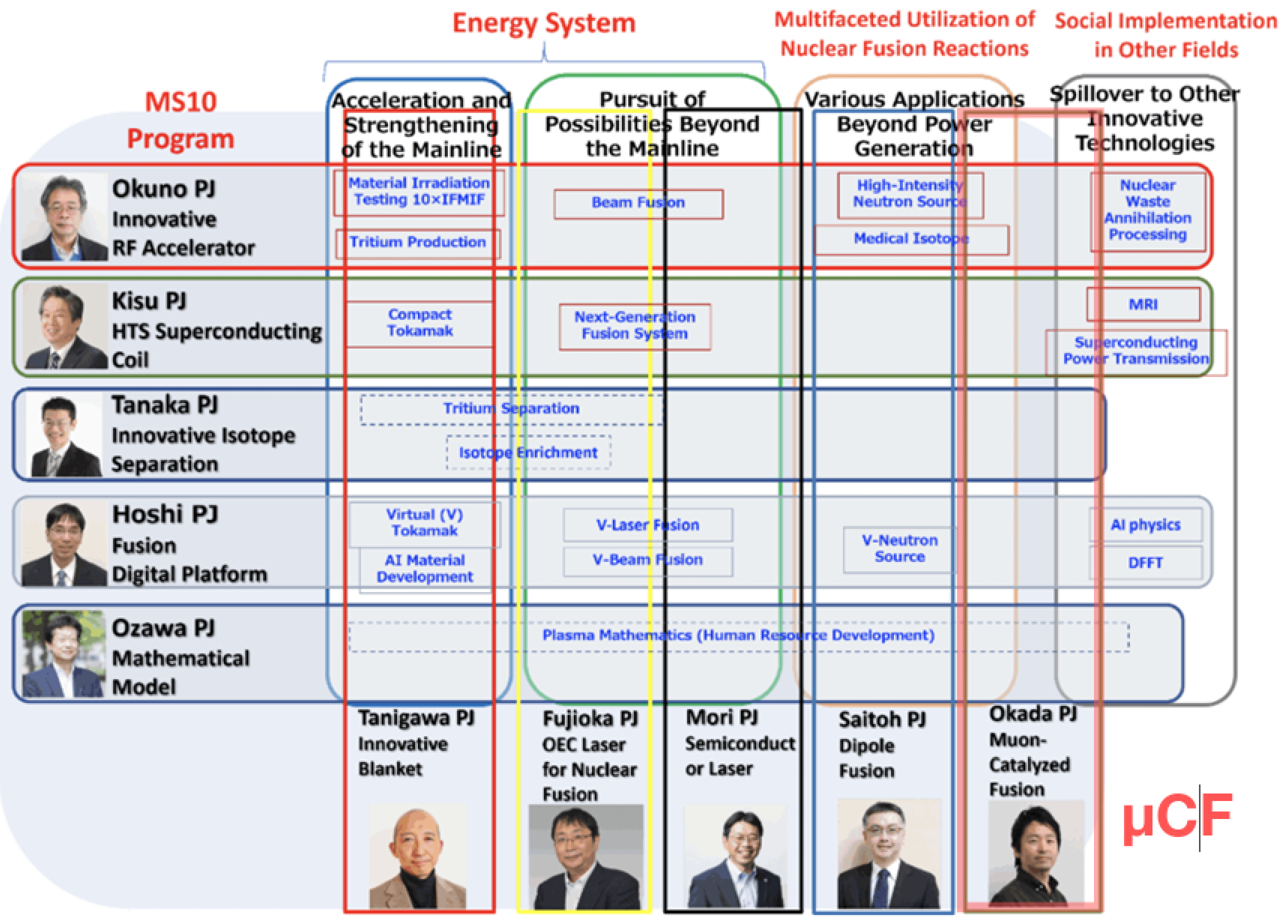
10 National Grand Challenges for Society by 2050



- ✓ Beyond conventional fusion
- ✓ Toward practical implementation
- ✓ Interdisciplinary innovation

➡ **μCF is one of the novel fusion concepts envisioned in Goal 10.**

Moonshot Goal 10 comprises ten research projects spanning the entire fusion landscape —from mainstream technologies to **novel concepts such as μCF**



S. Okada in this WS : https://indico.ph.liv.ac.uk/event/2421/contributions/10927/attachments/5281/7456/20260702_LiverpoolWS.pdf

Summary

- A dramatic transformation is underway in fusion energy research
- NIFS launched a new project named “MCPoP”
- The private sector is a new stakeholder
- The Japanese government strongly supports fusion energy based on its innovation strategy
- MS10 supports μCF researches led by S. Okada