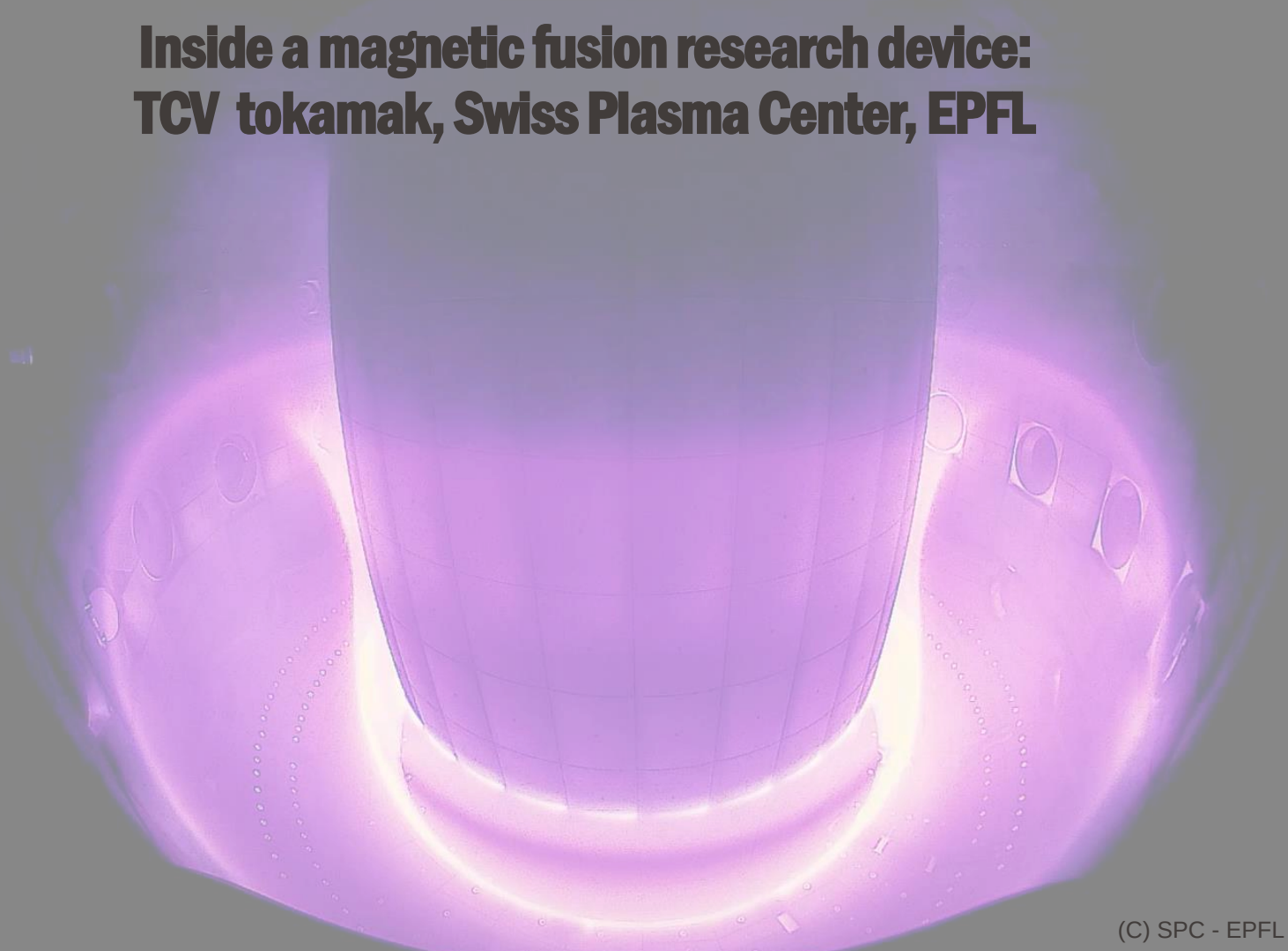
Nuclear Fusion: Status and Outlook

Laurent Villard
Swiss Plasma Center
EPFL

ICES Geneva 4 October 2024

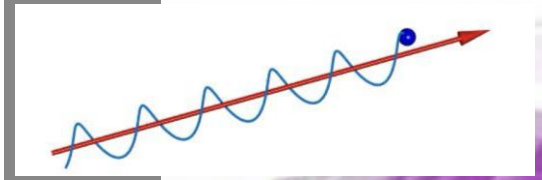
École polytechnique fédérale de Lausanne

Inside a magnetic fusion research device: TCV tokamak, Swiss Plasma Center, EPFL

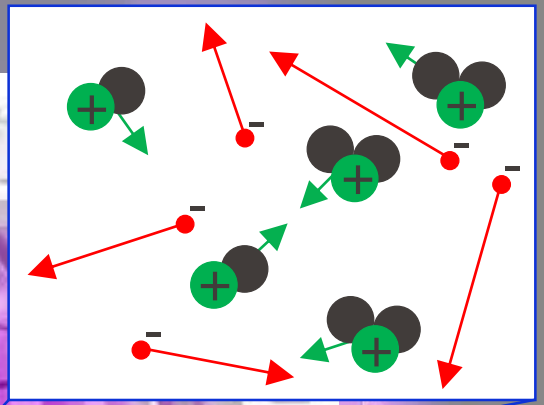


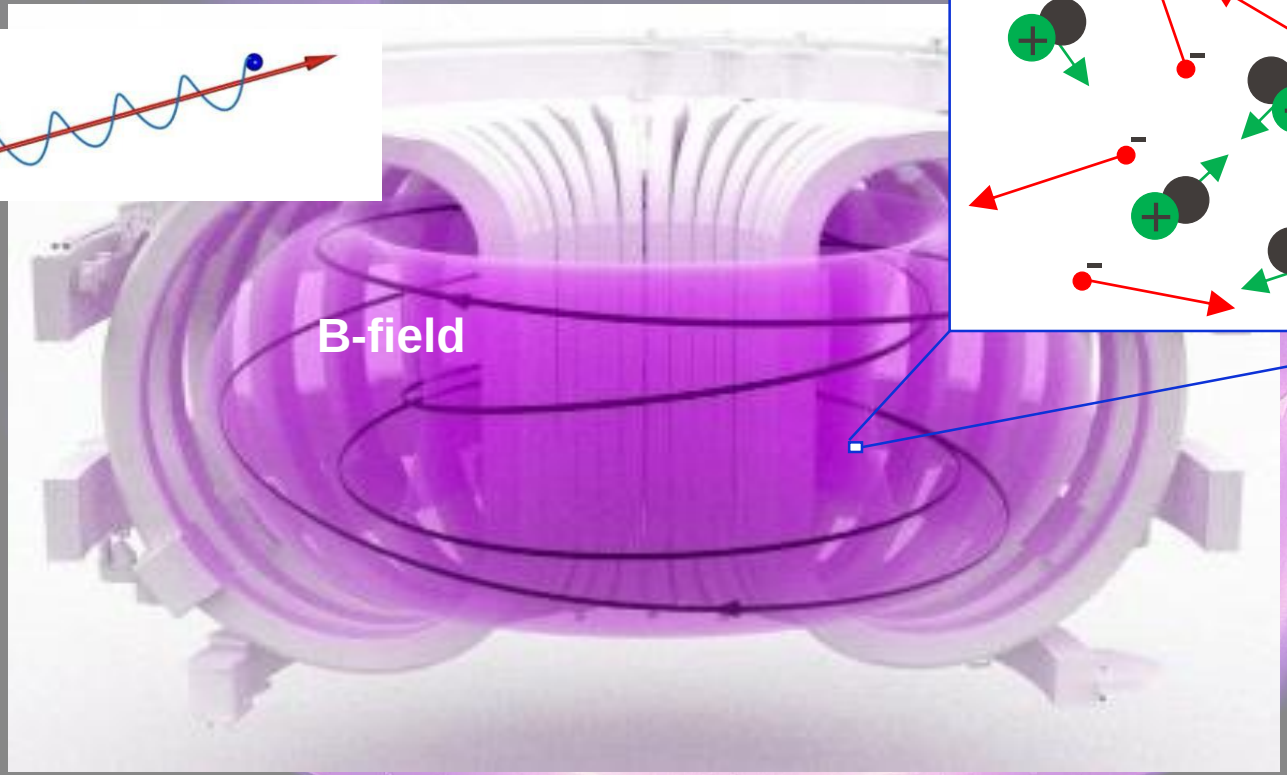
Magnetic confinement fusion – main idea

Charged particles
~follow B-field



Plasma

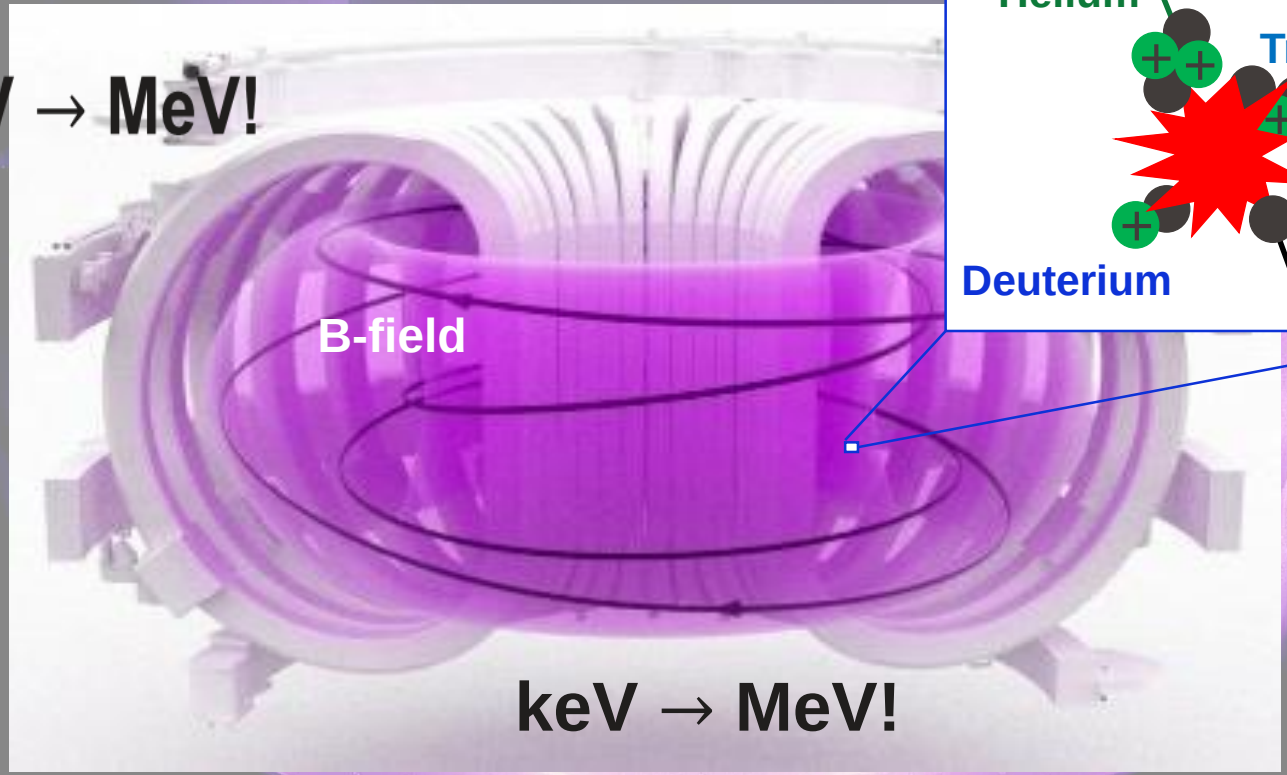


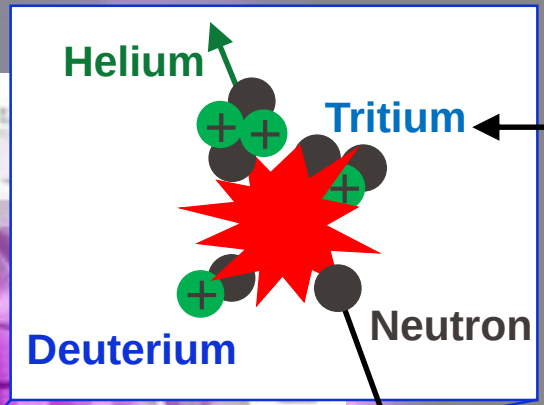


Magnetic confinement fusion – main idea

Charged particles
~follow B-field

keV → MeV!





^{6}Li

$^{4}He + T$

The quest for fusion power

The goal of the worldwide fusion research effort is to master fusion on earth and to develop a safe, clean and essentially inexhaustible source for baseload electricity

Lithium + Deuterium → Helium + energy

1 x 

+ 20 x 

≈ 50 x 

=7950 l

… + 19.997 litres of water

Fusion is taking a more and more visible role world wide

Results: JET DT, NIF

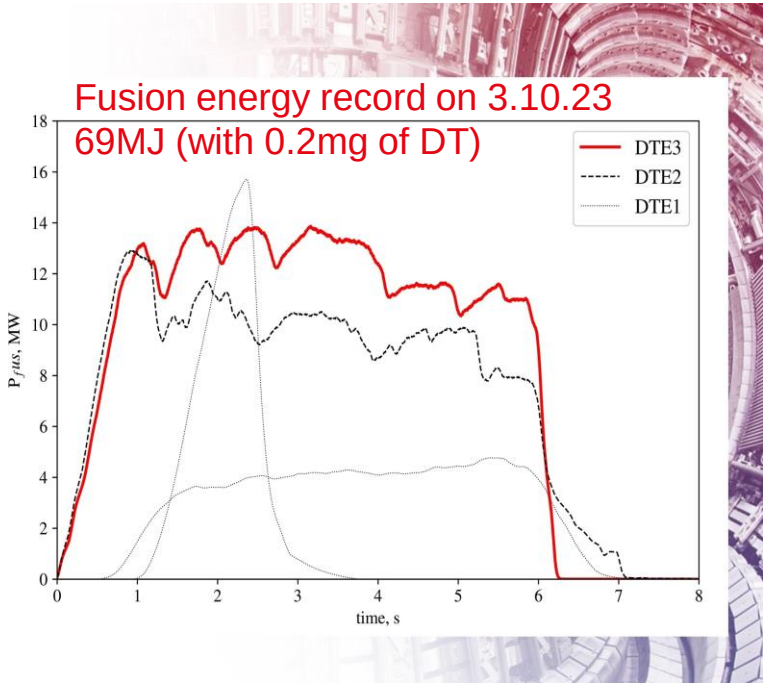


Image: UKAEA / Eurofusion

Image: LLNL / NIF

Fusion is taking a more and more visible role world wide

Results: JET DT, NIF

Private involvement

Fusion Companies Around the World

FUSION INDUSTRY ASSOCIATION

$6bn
Investment

https://www.fusionindustryassociation.org/

Fusion is taking a more and more visible role world wide

Results: JET DT, NIF

Private involvement

Political interest

Emmanuel Macron
President of France

The French president wants Europe to become a global leader by 2030 in five strategic sectors including fusion energy

25 April 2024

Christian Ehler
Member of the European Parliament

The Net-Zero Industry Act was approved by the plenary of the European Parliament and includes fusion energy as a strategic technology.

25 April 2024

Kadri Simson
EU Energy Commissioner

Energy Commissioner said in a conference in Strasbourg: "The time is right to discuss what a possible EU Fusion Strategy could look like."

23 April 2024

Ursula von der Leyen
President of the European Commission

The Commission President visited the Max Planck Institute for Plasma Physics and stressed the need for a European fusion alliance and a clear regulatory framework for fusion.

11 April 2024

April

G7 Meeting on Energy

Turin
29-30 April 2024

Fusion is taking a more and more visible role world wide

Results: JET DT, NIF

Private involvement

Political interest

Very large developments in some countries – e.g. China, UK

CRAFT centre at ASIPP Hefei. Source: CRAFT.

Future Culham Centre For Fusion Energy ©UKAEA

ITER - site at end of 2023

Image: ITER

ITER – ongoing repairs – vacuum vessel

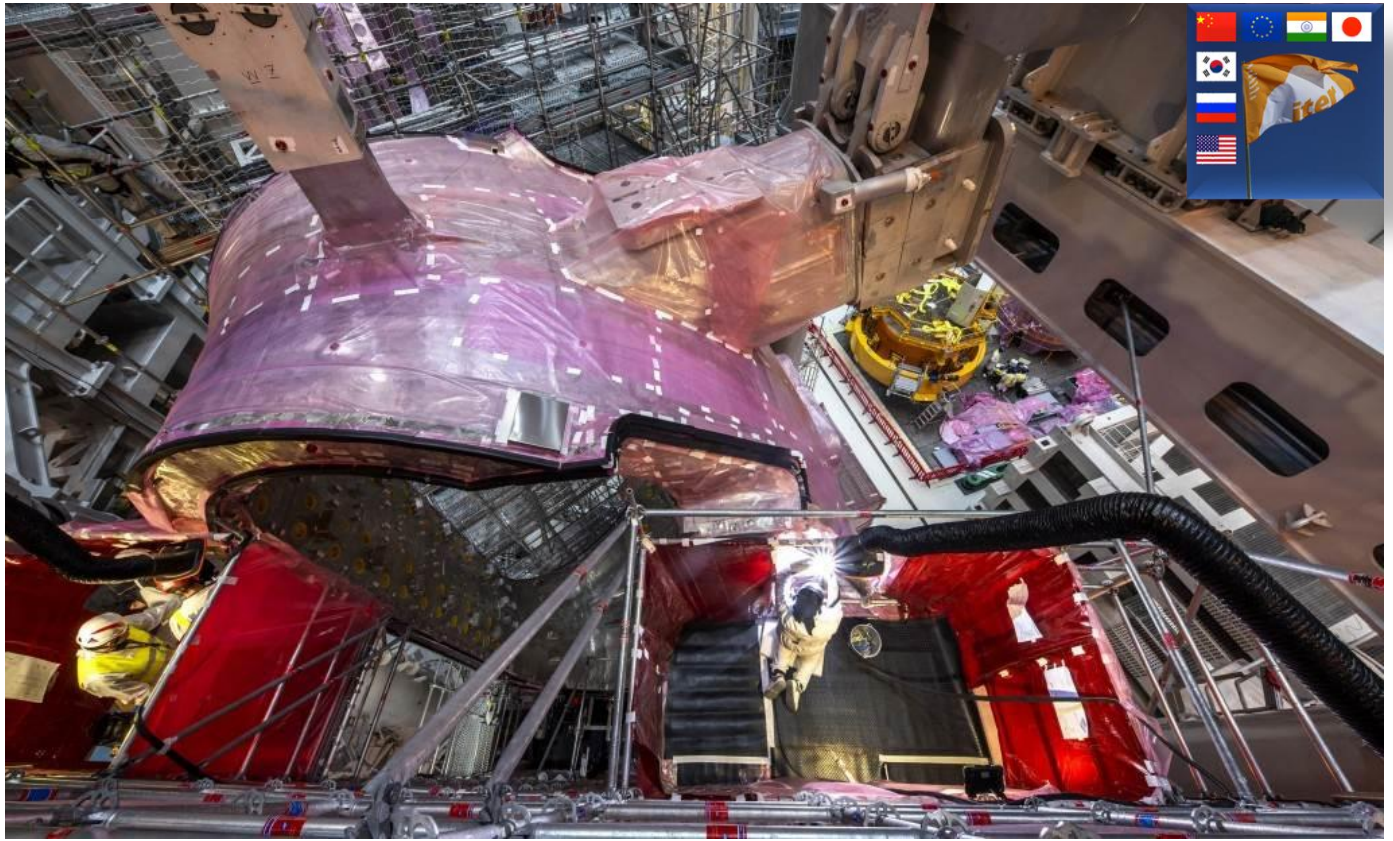


Image: ITER

Metal build-up on the regions of the sector 7 bevel affected by dimensional non-conformities

ITER – ongoing repairs – thermal shield

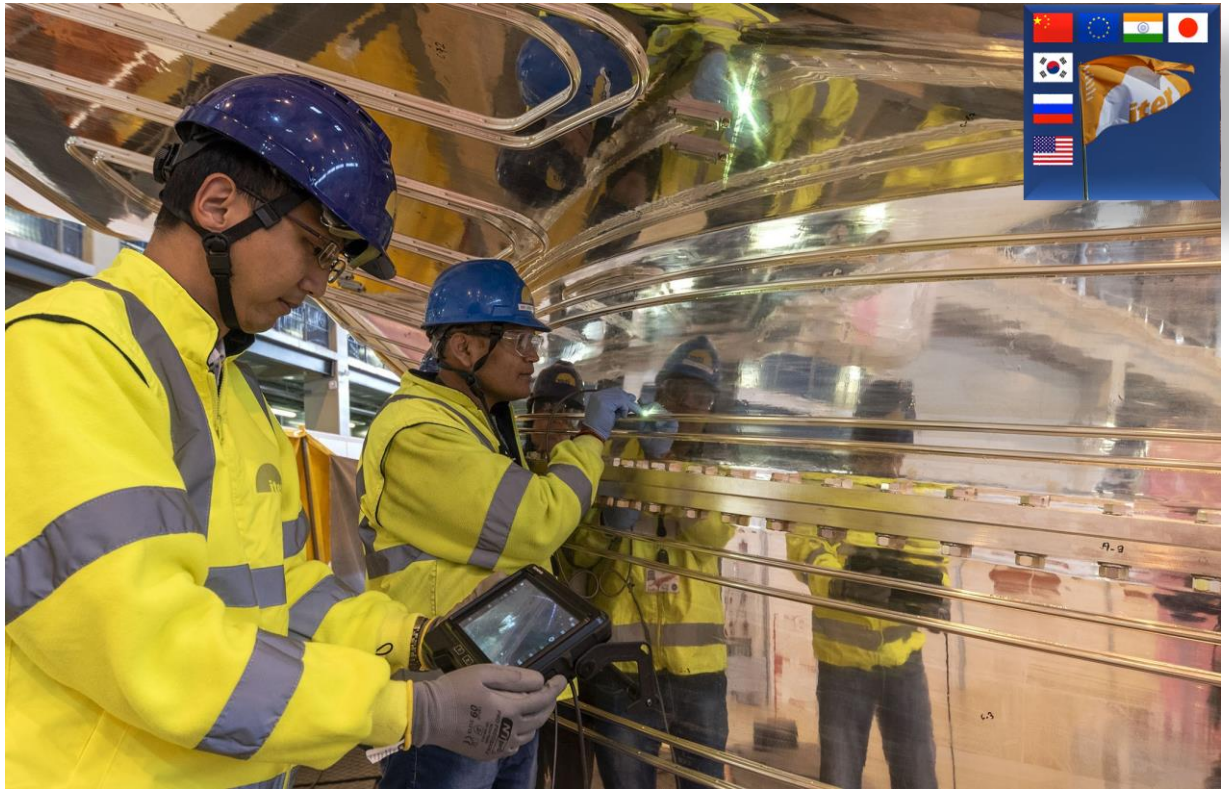


Image: ITER

Thermal shield sets inspected on site and tested for corrosion cracking. The panels with superficial defects are shipped to India for repair (5 out 9 so far).

ITER and Fusion for Energy - ex. of successful EU procurements

PROJECT PROGRESS

Tritium building completed (December 2023)

PROJECT PROGRESS

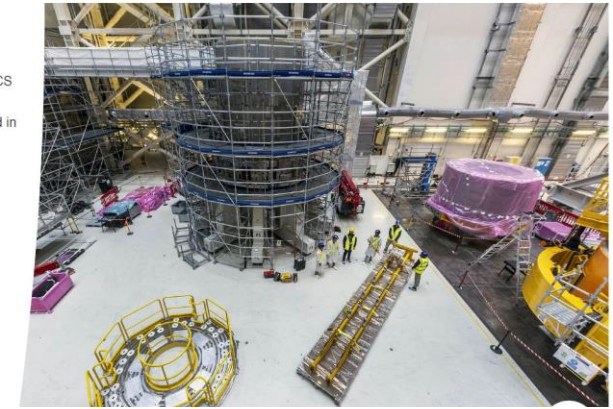
Last TF coil delivered (December 2023)

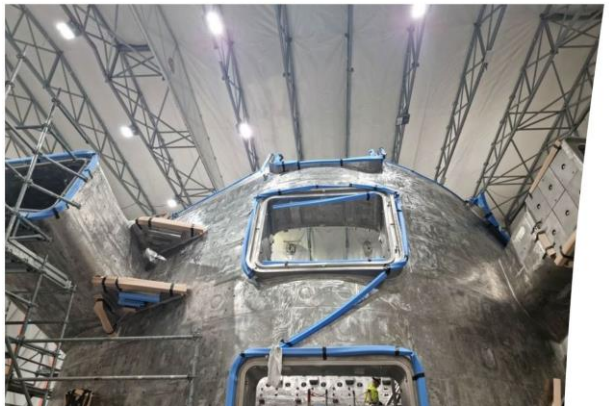
IO-DA celebration to take place on 15 April.

PROJECT PROGRESS

In process of stacking 3 CS modules (29 Feb 2024)

Fourth CS module arrived in December





EU VV MANUFACTURING

First European vacuum vessel sector passed its leak test (February 2024)

Images: F4E / ITER

The EUROfusion consortium

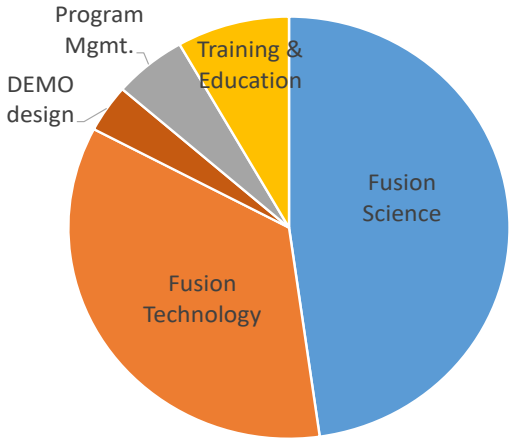
29 countries

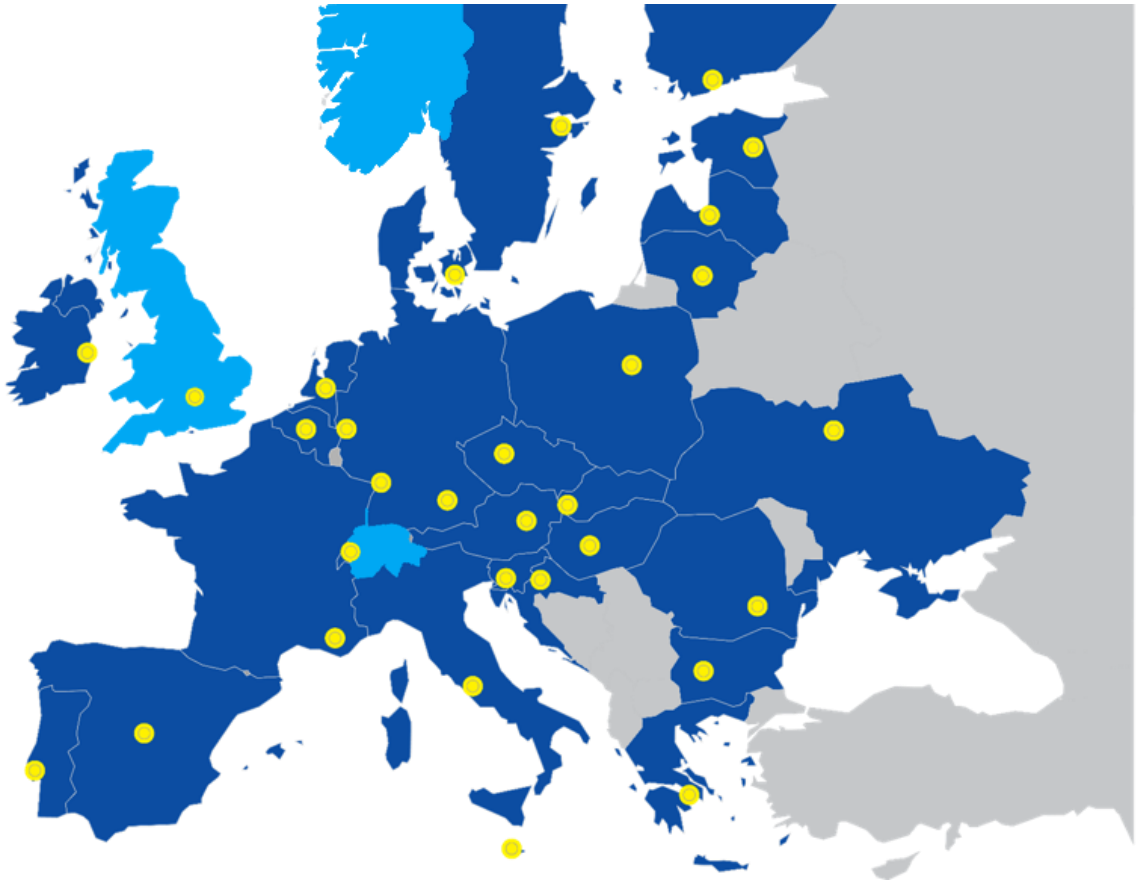
31 Research Institutions

150 Universities

5000 Staff

800 students





EUROfusion

Swiss Plasma Center

JET has ended its operations after 40 years

Standing Ovation for JET Inventor

March 7, 2024

Member news, UKAEA (U.K.)

“JET has created a real fusion community”

! March 11, 2024 " EUROfusion news

Largest tokamak now: JT60-SA, Japan (+Eurofusion)

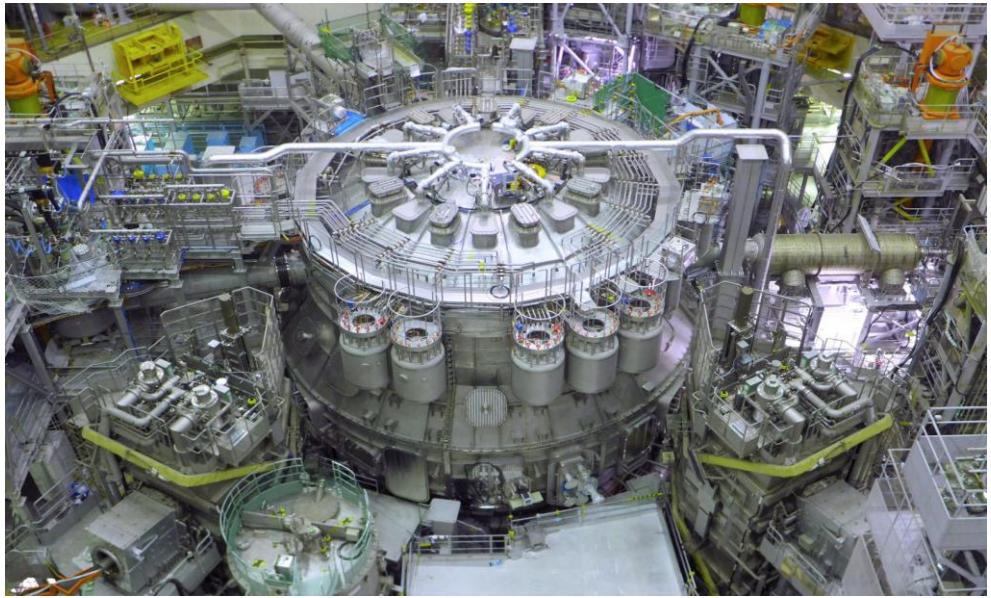


Image: JT60-SA

JT-60SA is officially the most powerful Tokamak.

Europe and Japan celebrate breakthrough in paving the way for fusion energy

01.12.2023 | Broader Approach | JT-60SA

Our Roadmap

Plasma Scenarios, Transients, Exhaust & Burning Plasma Regime


JET


ASDEX UPGRADE


WEST


JT-60SA

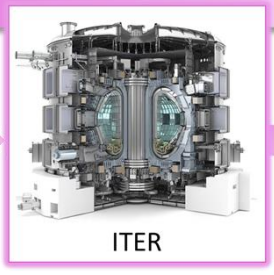

COMPASS UPGRADE


TCV


MAST UPGRADE


WENDELSTEIN 7-X


DTT

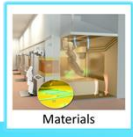

ITER

DEMO


Linear Facilities


Neutron Sources


Tritium & Fuel Cycle


Materials


Tritium Breeding Blanket


Divertor & HHFCs

High Performance Computing


Heating & Current Drive


Remote Maintenance


Materials Test Reactors


Magnets


IFMIF-DONES

Breeding Blanker, Remote Handling, Materials, Magnets

FUSION POWER PLANT

EUROfusion

The DEMO step

Demonstration of commercial feasibility, net electricity production (~300MWe for >2h), self-sufficient fuel cycle, safety & waste production

ITER shall validate DEMO physics and part of technological basis but DEMO schedule should be resilient to changes in ITER schedule

Other machines, will play a role for DEMO in reducing uncertainties in physics and technology

Conceptual design of DEMO (tokamak configuration) conducted in EUROfusion

Target: operations ~20 years after kick-off

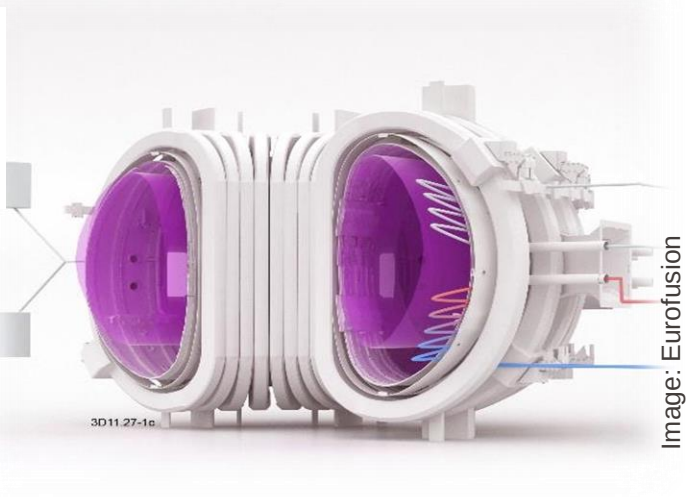


Image: Eurofusion

The Swiss Plasma Center and its mission

National laboratory with international facilities in an academic environment

Aim: make ITER a success

develop the science and technology basis of DEMO

prepare the ITER/DEMO generations of scientists and engineers

exploit plasma and fusion spinoffs for industry and society

The TCV tokamak - a EUROfusion facility

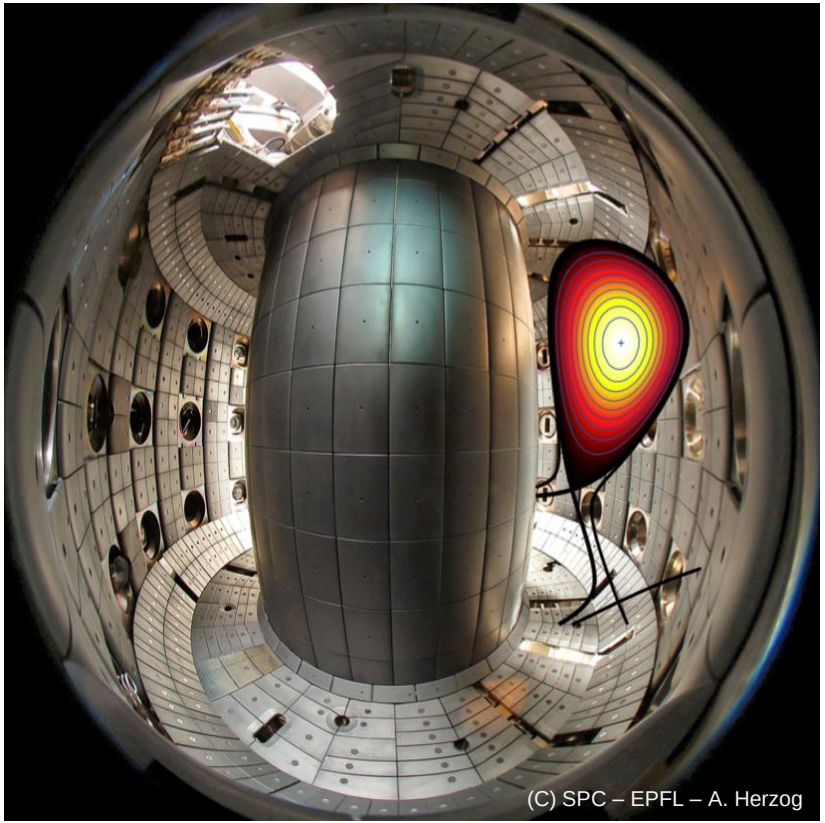
Swiss Plasma Center

Important role in revised Roadmap

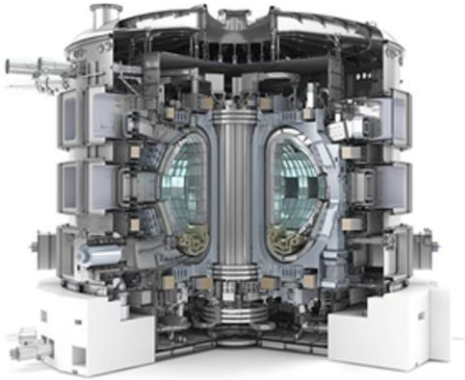
Facilities Review report

«*TCV's value to the EUROfusion and world's fusion programmes is high in proportion to its relatively inexpensive cost of operation. It has important roles in* ***workforce development*** *and international collaboration, where it continues to develop original techniques and configurations that can be further developed at larger facilities* »

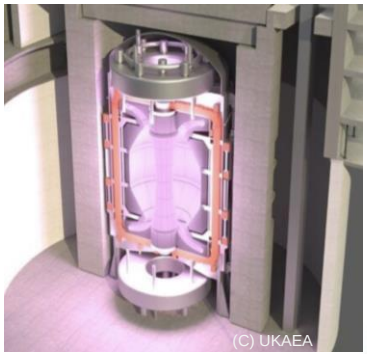
SPC is currently training 52 PhD students and employs **33 Post-Docs**



Key initiatives worldwide (magnetic fusion only)

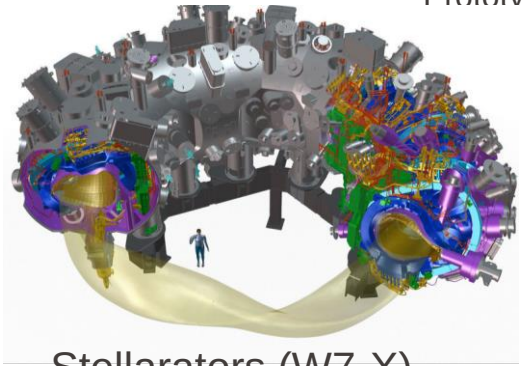


ITER



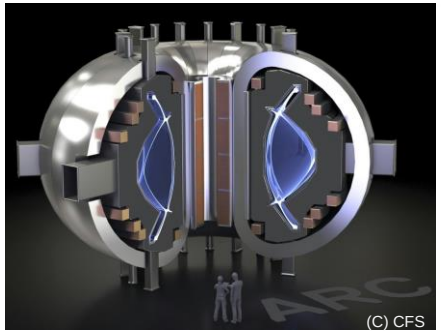
STEP (UK)
Prototype power plant
(2040)

Chinese Fusion Roadmap
[Y.Song, Fus.Eng. Des. 2022]



Stellarators (W7-X)

Private initiatives
e.g. CFS (USA)



HTS magnets
SPARC (Q>2) (2025)
ARC (commercial
power plant) (2030's)

See e.g. Theiler et al., "*State of fusion technology and main actors*", Ch. 10 of SFOE report on Technology Monitoring of Nuclear Energy – 2024, available online

Conclusions

- There has been a tremendous acceleration of the worldwide effort to make fusion energy a reality.
- This has been triggered by recent milestone successes in public-funded research.
- The private sector is raising substantial funds. Several companies have been created, of which at least some are serious contenders on the race to fusion and/or will contribute substantially to the development of the required technology.
- Publicly funded fusion research has received a huge boost in some countries (China, UK in particular).
- Our roadmap objectives remain essentially the same, but increasingly will rely on public-private partnerships.

Will fusion energy help to save the planet?

Yes, it will

When will this happen?

Nobody knows for sure, but recent developments make it a very realistic perspective by ~2050

Thank you for your attention!