IAEA-CN301-132

DETERMINATION OF FUEL RETENTION IN TOKAMAKS BY ACCELERATOR-BASED METHODS

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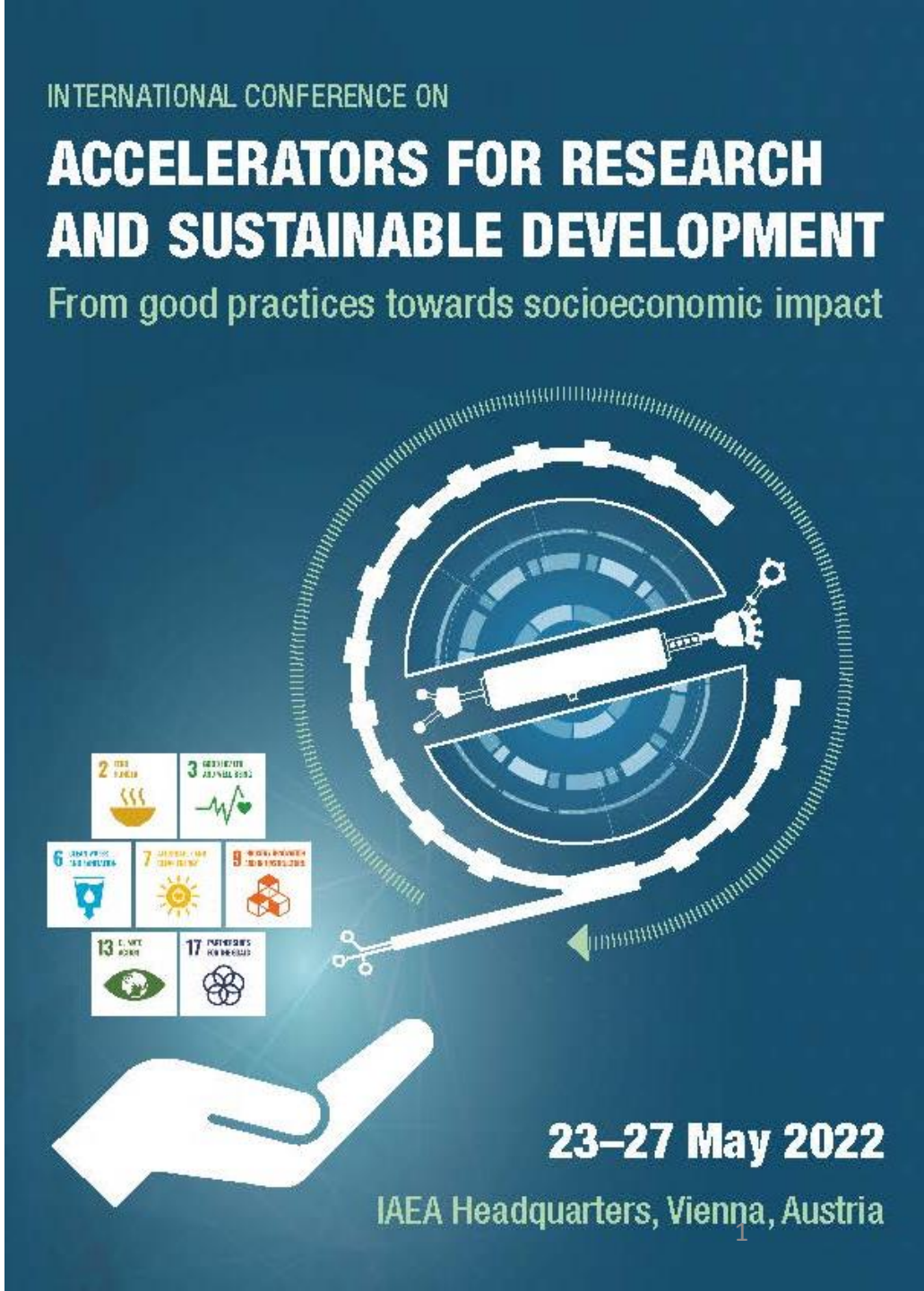


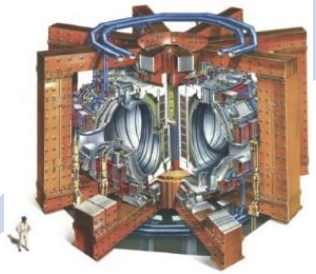
Outline

- Fusion power development
- Fusion materials challenges
- Use of accelerator based techniques in fuel retention analysis

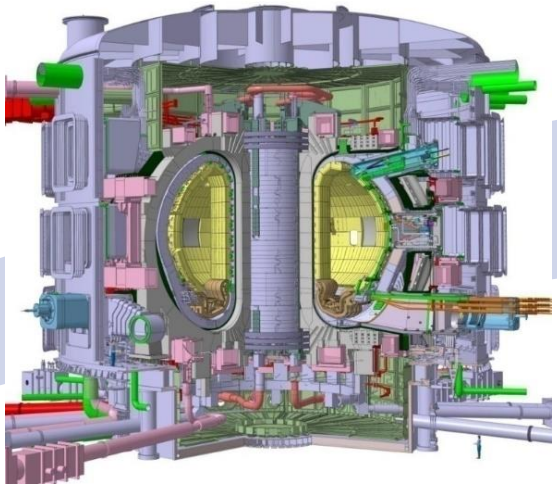
Nuclear Fusion: research for future sustainable energy source

- Nuclear fusion offers a potential future *Net Zero* energy supply
- Worldwide research with this aim in mind

JET, UK
(Joint European Torus)
Fusion Energy
Record 2021



Current
Experimental
Nuclear Fusion
Tokamaks



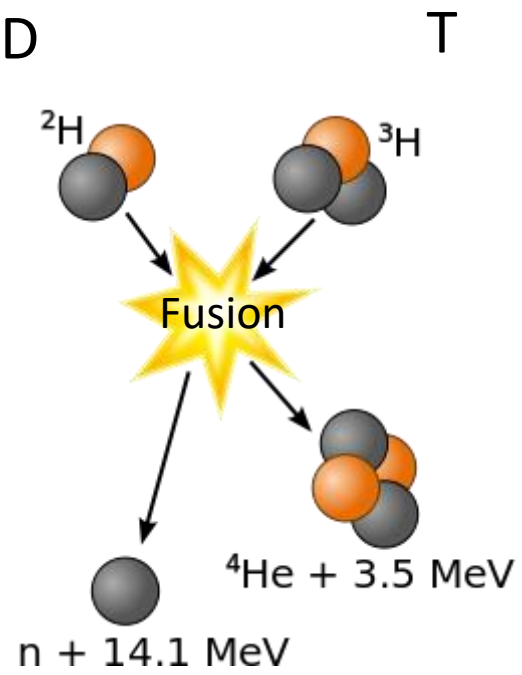
ITER, France
(**I**nternational **T**hermonuclear
Experimental **R**eactor)

Next Phase
Experimental
Nuclear Fusion
Reactors

Demonstration
fusion power
plants

Fusion
power
plants

Fusion reaction

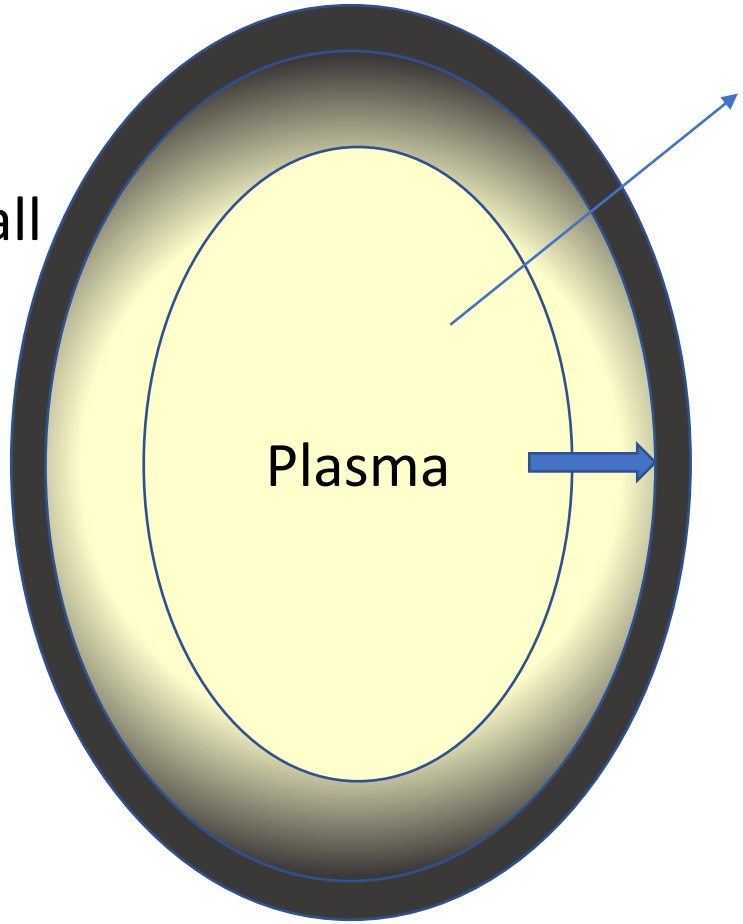


Fusion fuel: T and D

- The reaction of primary interest for fusion devices involves two isotopes of hydrogen – Deuterium (D) and Tritium (T)
- To initiate the fusion reaction, a plasma of deuterium and tritium is formed by heating to over 100 million K
- Majority of the energy released as 14.1 MeV neutrons
- Most experimental work is carried out in non-nuclear phases using Protium (abundant Hydrogen), Deuterium and Helium

Materials challenges

Harsh environment leads to interactions between the wall and the plasma *"Plasma Wall Interaction"* and neutron irradiation damage.



Neutron leaving plasma

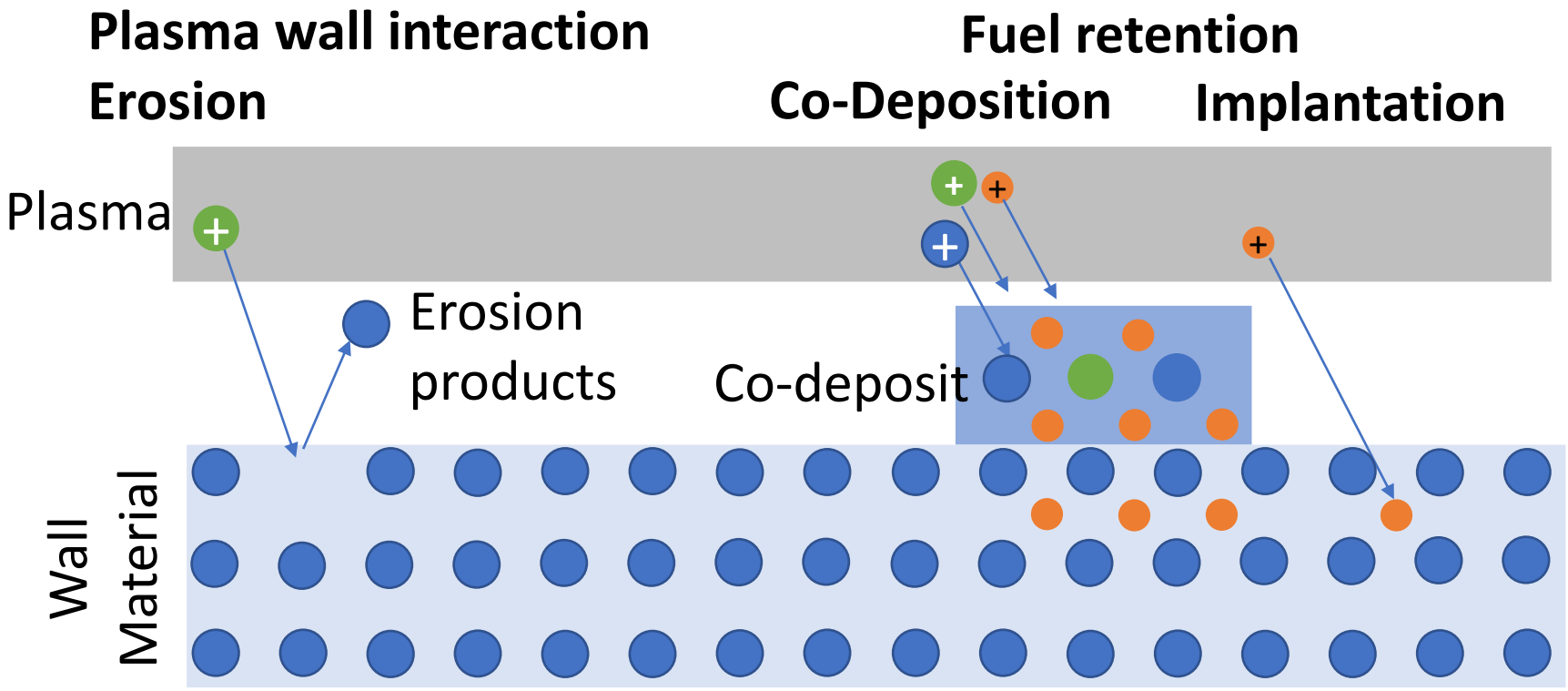
- Energy transfer
- *Radiation damage*

Impurity ion leaving plasma

- *Plasma Wall interaction*
- High heat & particle loads
- Erosion/material migration/deposition
- **Fuel retention**

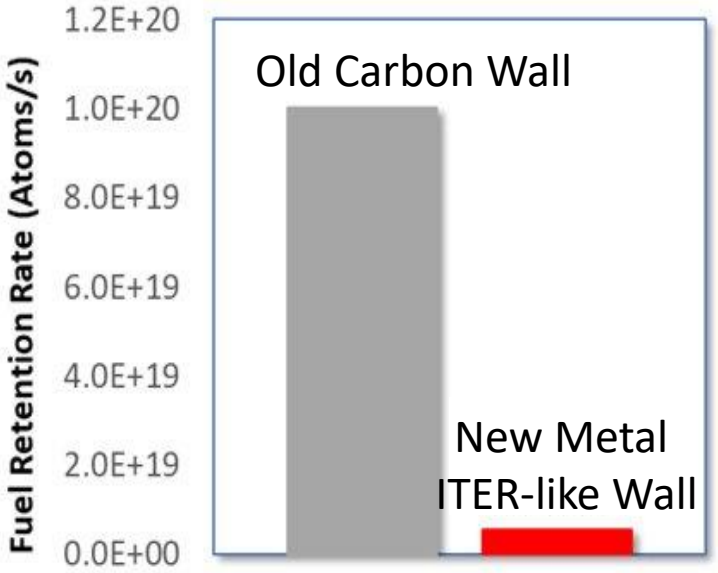
Plasma Wall Interaction and Fuel Retention

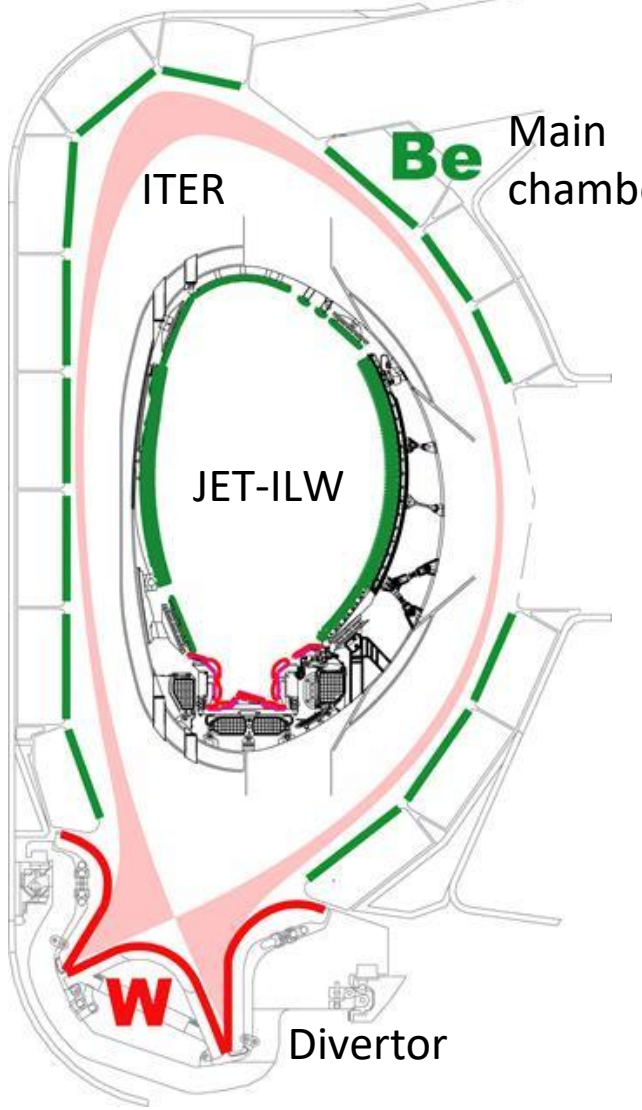
Fuel retention occurs through **co-deposition** of hydrogen isotopes with erosion products and direct **implantation**



JET ITER-like Wall (JET-ILW)

- Change from carbon interior to all metal *ITER-like* wall in 2010
- Motivated by need to reduce fuel retention wall materials
- Demonstrated > x10 reduction in fuel retention in metal wall
- Ion beam analysis of wall components important





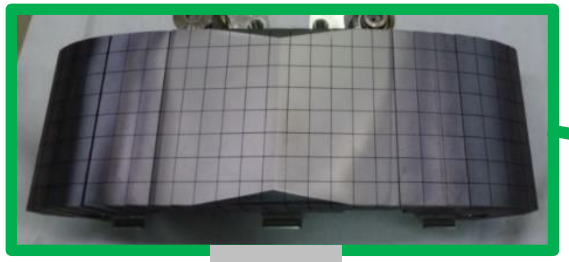
G.F. Matthews, et al. Phys. Scr. T145 (2011) 014001.
https://doi.org/10.1088/0031-8949/2011/T145/014001.

S. Brezinsek, et al.,Nucl. Fusion. 53 (2013) 083023.
https://doi.org/10.1088/0029-5515/53/8/083023.

JET-ITER like wall (JET-ILW) vessel components

- Many large complex assemblies need to be handled

Bulk beryllium (Be)
Castellated structure

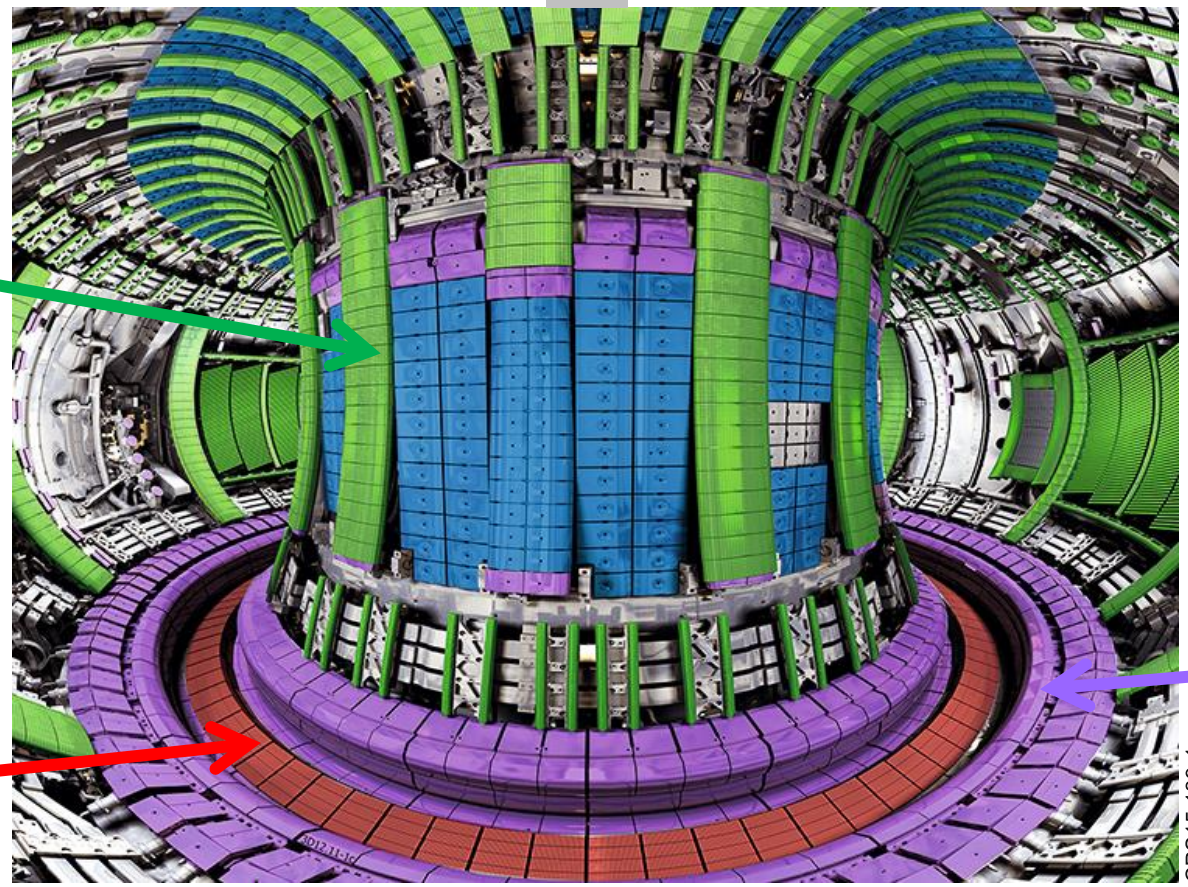


30 cm

Bulk tungsten (W)
Lamellae structure

40 cm, 80 kg

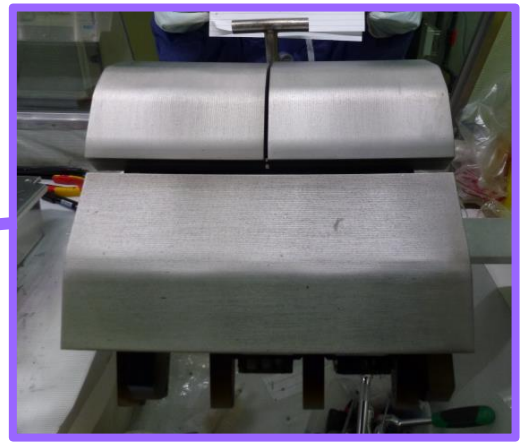
6 m



CPS15.139-1c

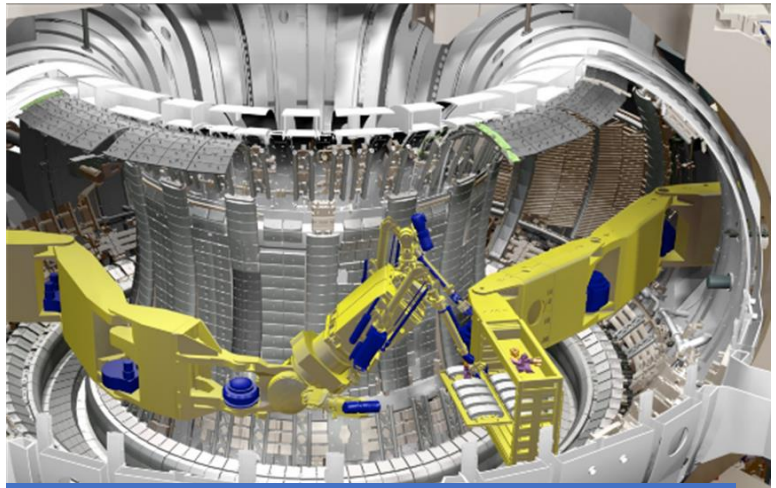
Bulk Be PFCs
Be- coated inconel PFCs
Bulk W
W- coated CFC PFCs

Tungsten coating on carbon-fibre composite (W-CFC)



40 cm

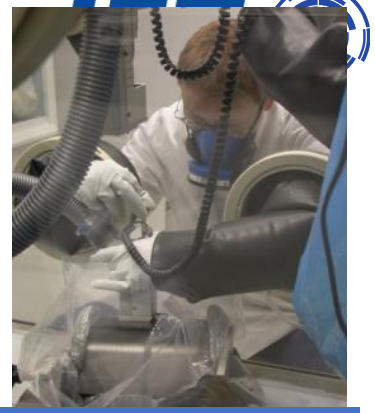
Sample journey from JET to analysis



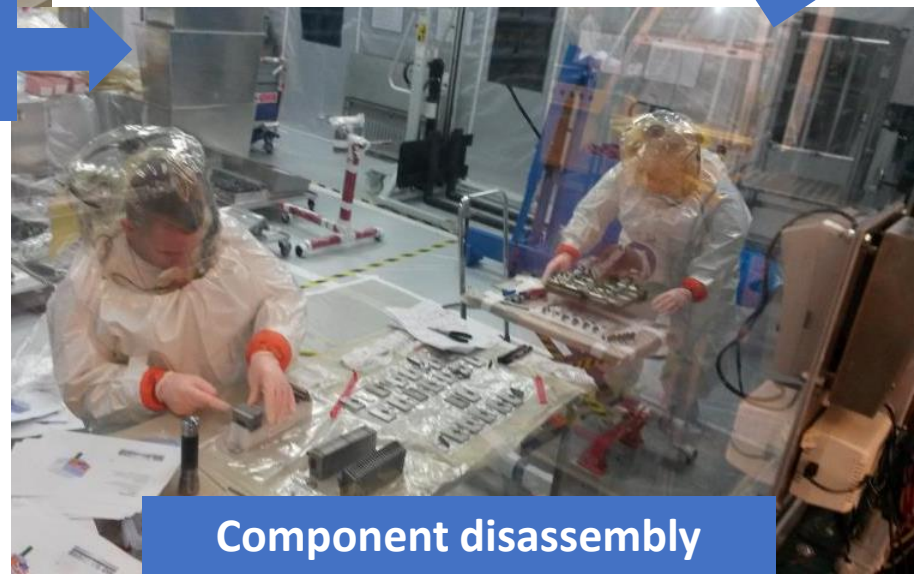
Component removal using remote handling

https://www.youtube.com/watch?v=hg6MnjG7m6U

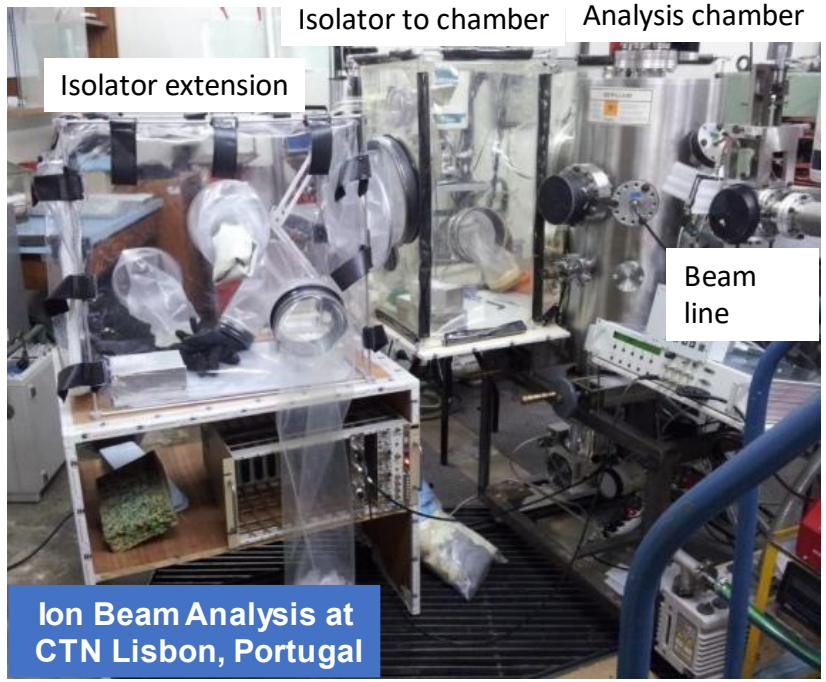
Handling of beryllium and tritium contaminated components



VTT, Finland: Sample preparation



Component disassembly

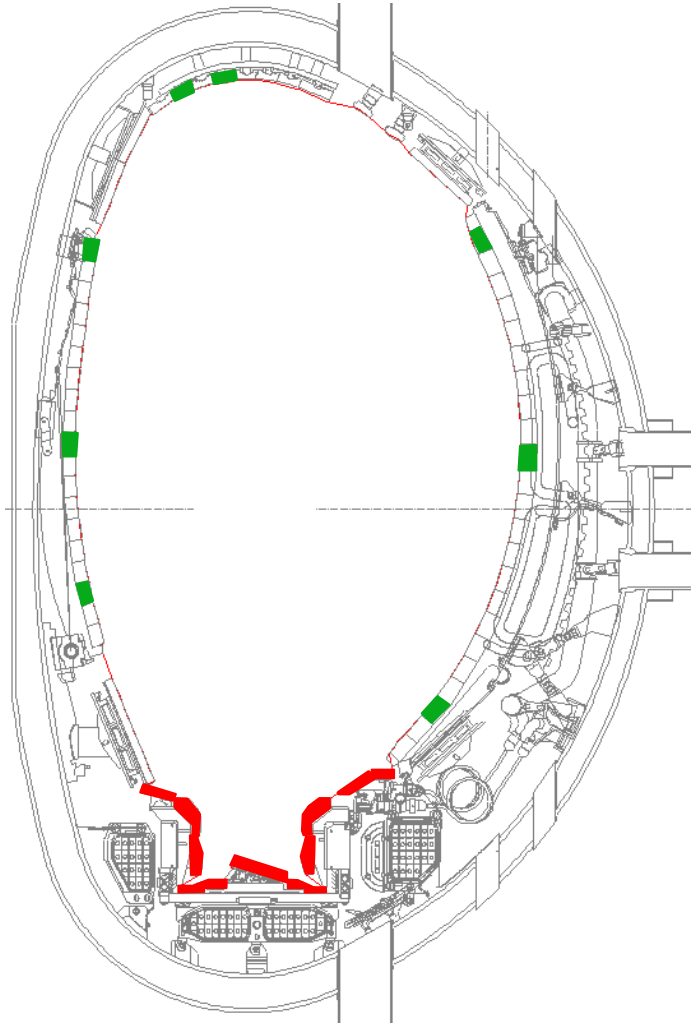


Ion Beam Analysis at CTN Lisbon, Portugal

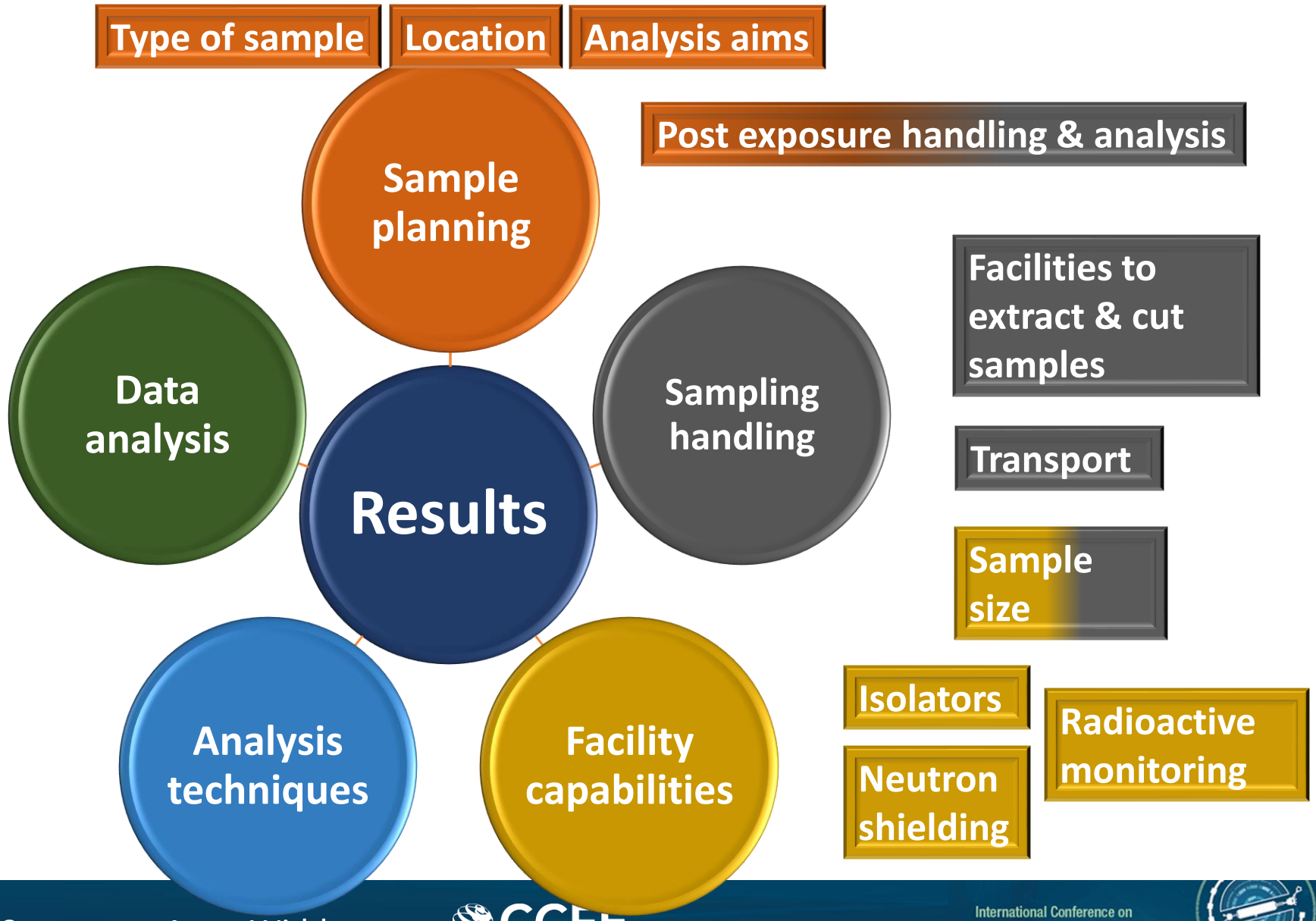
Component analysis programme on JET-ILW

- Cycle of plasma operation followed by intervention to remove components for analysis and carry out maintenance
- 100s of samples and 1000s of measured and analysed points
- Large international effort - EUROfusion Work Programme & EU-Japan Broader Approach

Techniques used in fuel retention analysis **More than 20 types altogether….**
Ion beam analysis techniques **NRA, ERDA, SIMS, µbeam**
Thermal desorption techniques **TPD/TDS, LIDS**
Tritium analysis **Dissolution & liquid scintillation, total combustion, desorption**



Holistic approach for analysis



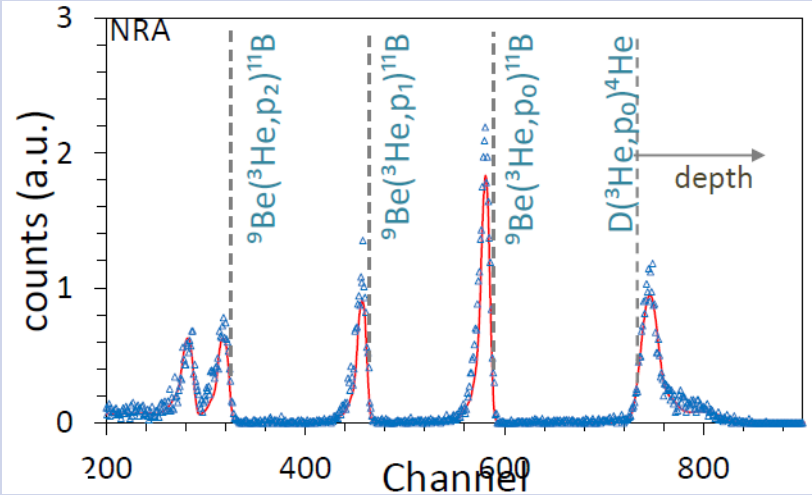
Accelerator based techniques for fuel retention analysis

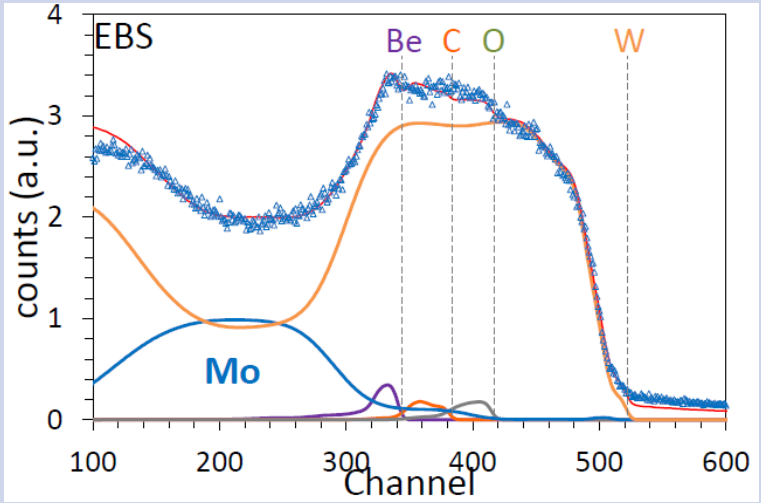
Component	Accelerator Based Techniques	Analysis Result	Implications/ Conclusion
Beryllium tiles Tungsten tiles	**Nuclear Reaction Analysis** **Back Scattering** **Elastic Recoil Detection Analysis**	Fuel Inventory (hydrogen isotope) Co-deposition with erosion products	Lifetime Plasma Control Fuel Cycle Safety, Licensing, Regulation Decommissioning $\Rightarrow$ Economy of operation

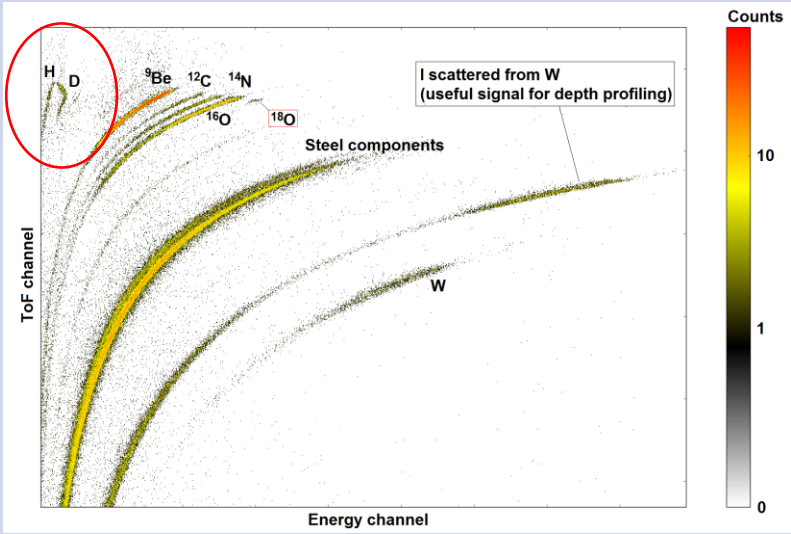
M. Rubel, et al, Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms. 371 (2016) 4–11. https://doi.org/10.1016/j.nimb.2015.09.077.

Ion beam analysis techniques

Nuclear Reaction Analysis	Backscattering techniques	Heavy Ion Elastic Recoil Detection Analysis
^{3}He beam -> Deuterium retention: ^{2}H(^{3}He,p)^{4}He Beryllium deposition: ^{9}Be(^{3}He,p$_0$)^{11}B	Proton beam -> Characterises impurities present with co-deposited hydrogen isotopes.	Iodine beam -> H & D (^{2}H) in one measurement Identifies fuel in co-deposits





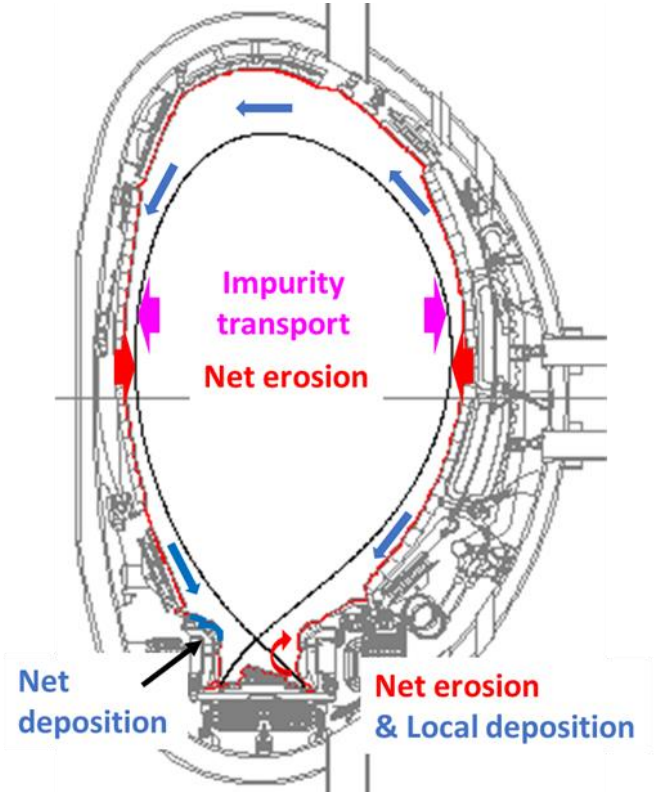


Fuel quantification & depth profile

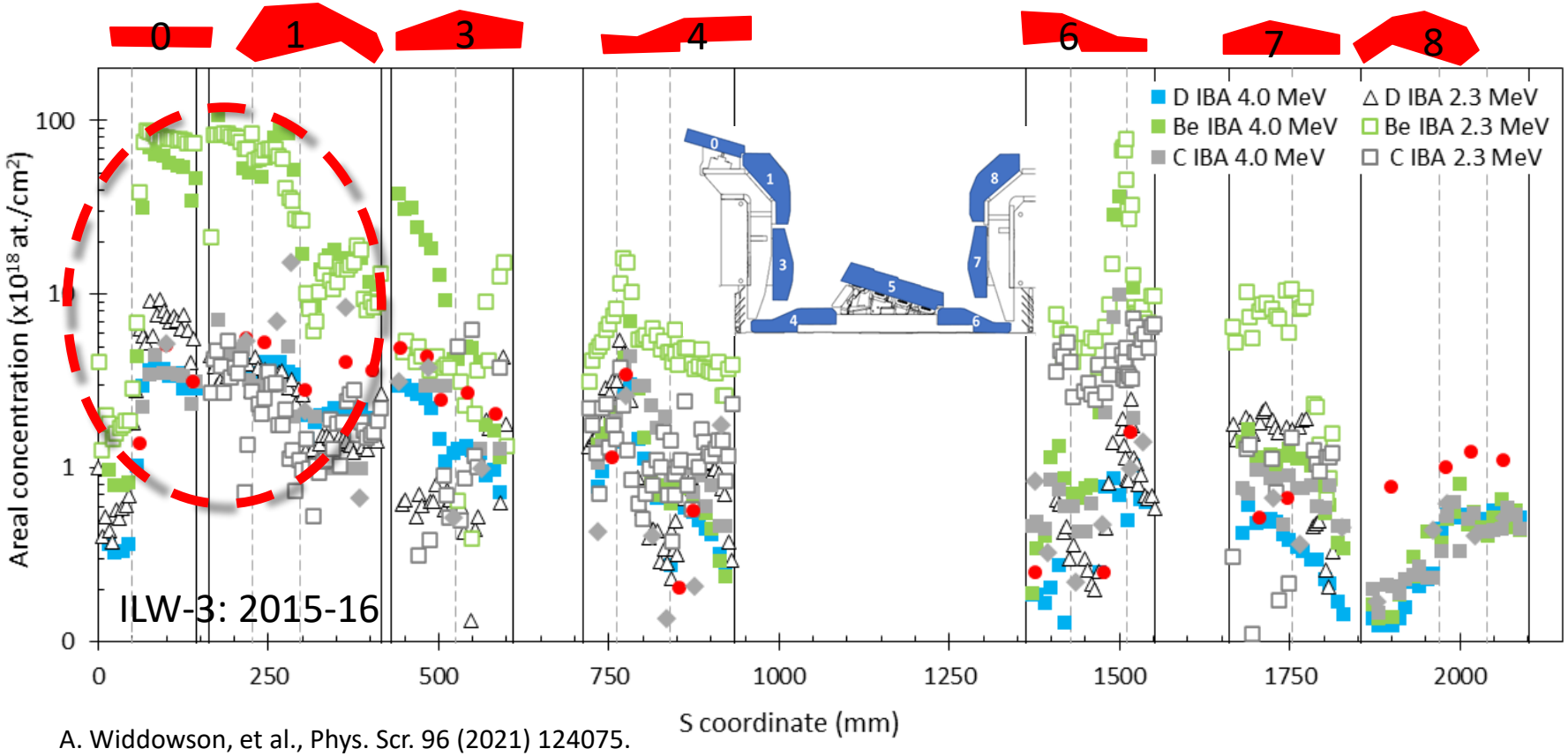
Co-deposition of fuel with impurities from plasma wall interaction

Fuel retention in JET

- 100s of samples and 1000s of measured and analysed points
- Conclusion: Fuel retention dominated by co-deposition mainly at upper inner divertor



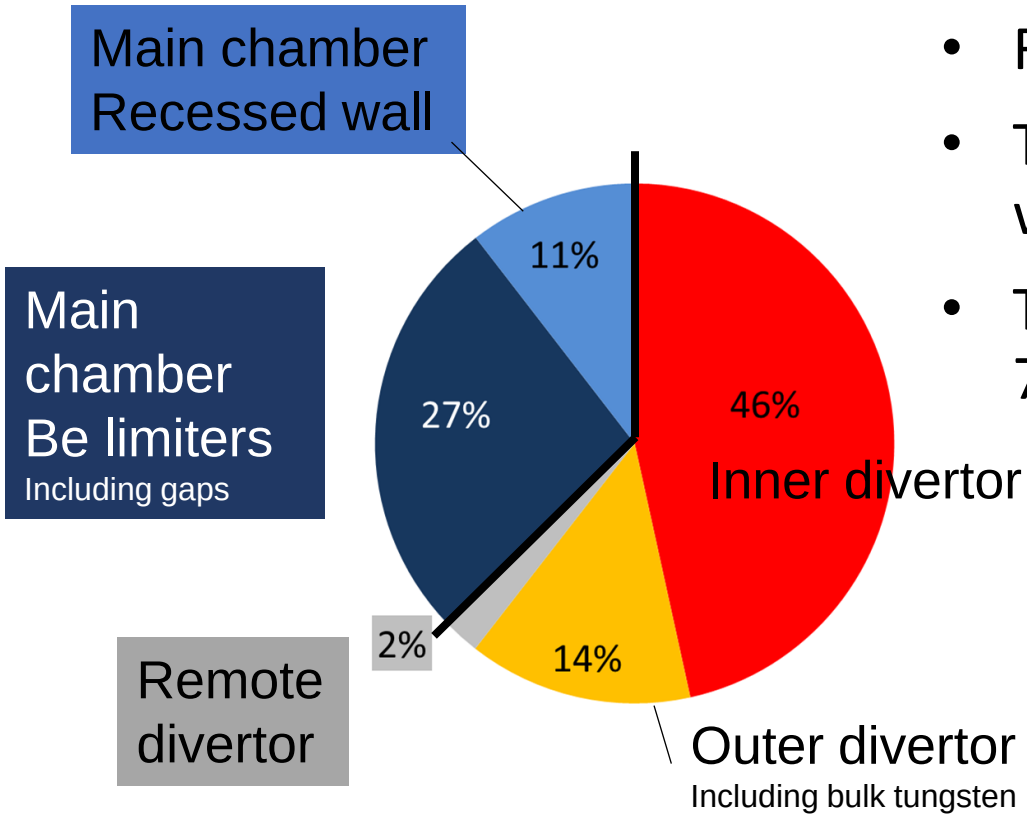
S. Brezinsek, et al., Nucl. Fusion. 55 (2015) 063021.
https://doi.org/10.1088/0029-5515/55/6/063021.



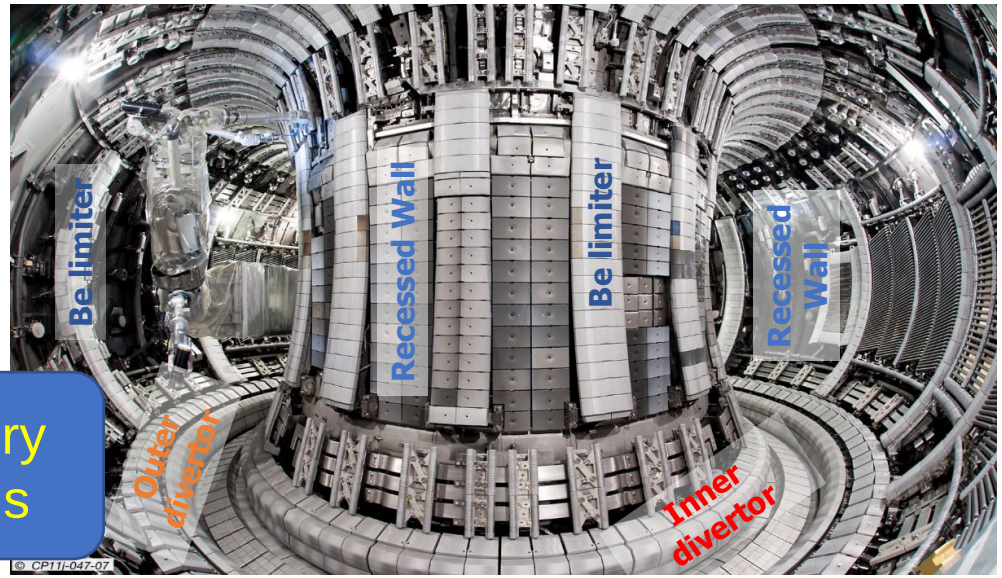
A. Widdowson, et al., Phys. Scr. 96 (2021) 124075.
https://doi.org/10.1088/1402-4896/ac3b30.

Global fuel inventory JET ILW

- Extrapolation from analysis of samples around the vessel
- Fuel retention fraction in JET-ILW is 0.2 % of injected fuel
- Tritium (T) inventory can be estimated when operating with DT in nuclear phase
- T retention in JET at end of 2023 after DT operations 7.5×10^{22} T atoms [0.38 g T, 134 TBq]



Total fuel inventory
42×10^{22} D atoms



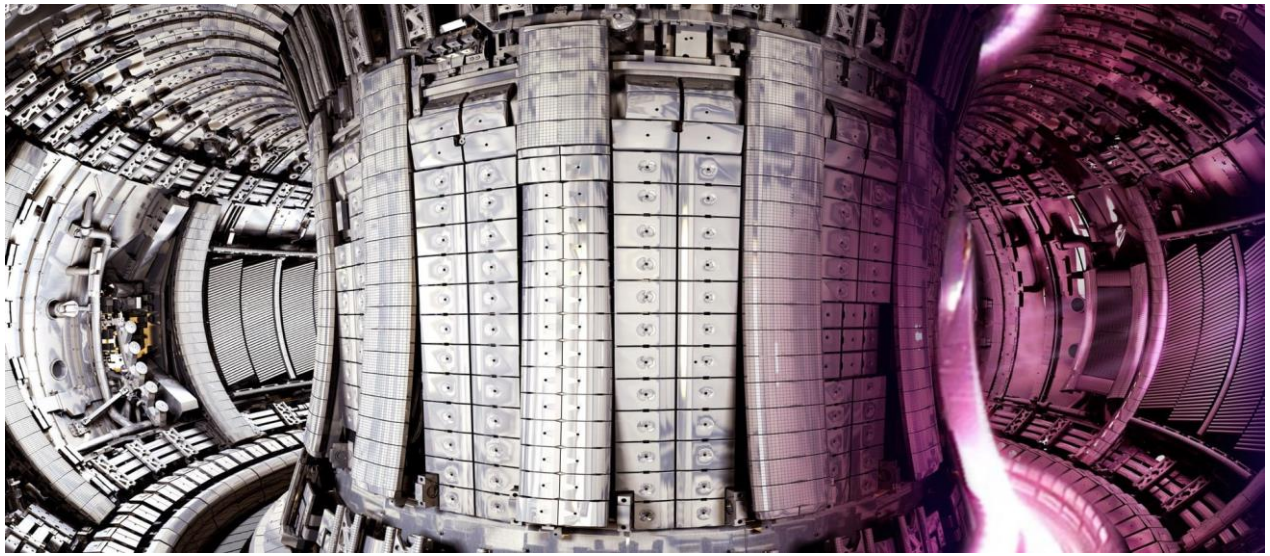
A. Widdowson, et al., Phys. Scr. 96 (2021) 124075. https://doi.org/10.1088/1402-4896/ac3b30.

Summary

- Accelerator based techniques play a crucial role in evaluating fuel inventory in fusion materials
- Results have implications for plasma control, fuel cycle, regulation, decommissioning
- Important for economy of operation in the development of sustainable fusion power

Record-breaking 59 MJ of sustained fusion energy achieved at JET

https://ccfe.ukaea.uk/fusion-energy-record-demonstrates-powerplant-future/
https://www.youtube.com/watch?v=H99hvPlC4is&t=2177s



Chief Executive of the UK Atomic Energy Authority, Professor Ian Chapman, discussed the progress in production of fusion energy, stating *"this is a landmark event that moves researchers closer to conquering one of the biggest challenges in science. It exceeded the previous mark of just under 22 megajoules of total energy achieved in 1997" (multiple).*

The Programme Manager of the EUROfusion group, Tony Donne, said that the JET scientists had made huge progress, and were *"on the right path".* He also added that *"if we can maintain fusion for five seconds, we can do it for five minutes and then five hours as we scale up our operations in future machines"* (*Daily Mail Online*).

Joe Milnes, Head of JET operations, identified the development of JET experiments as *"a step closer to fusion power".* Additionally, he said *"we've demonstrated that we can create a mini star inside of our machine and hold it there for five seconds and get high performance, which really takes us into a new realm"* (*BBC*).

George Freeman, the Minister for Science, Research and Innovation, discussed the advancement of fusion energy and said *"these milestone results are testament to the UK's role as a global leader in fusion energy research. They are evidence that the ground-breaking research and innovation being done here in the UK, and via collaboration with our partners across Europe, is making fusion power a reality"* (*MSN UK*).

Fernanda Rimini, CCFE Plasma Scientist, made a number of high profile broadcast appearances, including BBC One's Sunday Morning Show and LBC. She discussed the potential of the technology as an energy source stating it's "*green, and doesn't produce greenhouse gases and could replace some of the big power plants we have now"* (*BBC*).

Thank you

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