EUROfusion

Maintenance of a Fusion Power Plant The EU Approach

IAEA-TECH-2/2

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RACE

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Contents

- The importance of maintenance
- The challenges of a tokamak architecture
- Service joining
- Precision handling of massive components
- Layout of the access ports
- New work planned for the next 5 years

Introduction

Powerplant economics

- Availability is a strong driver
- Maintenance duration
- Planned and unplanned

Maintenance requirements

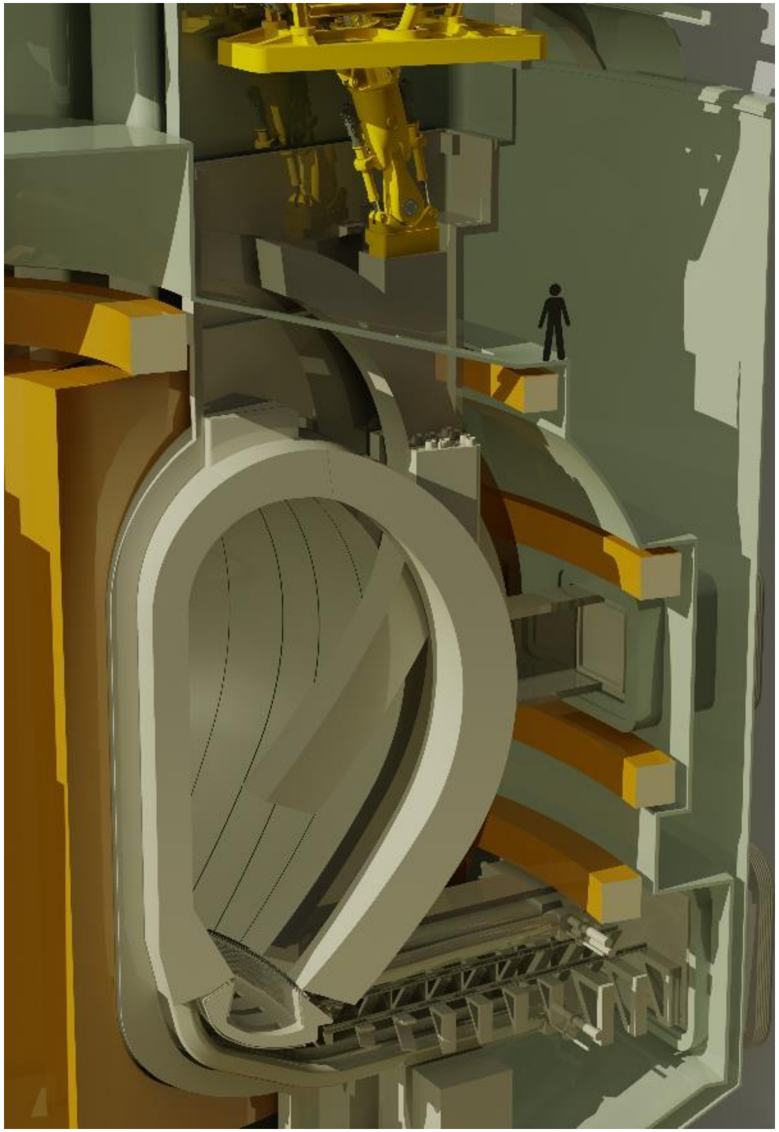
- Stronger than for existing machines
- Drive plant architecture
- Early integration of maintenance
- Consider the full lifecycle from the outset

An effective maintenance system

- Simple, safe, robust, rapid, flexible, recoverable, and low cost

EUROfusion DEMO Central Team

- Manages high level integration



The challenge

The tokamak architecture

Vessel surrounded with a magnetic cage, structural supports and thick shielding

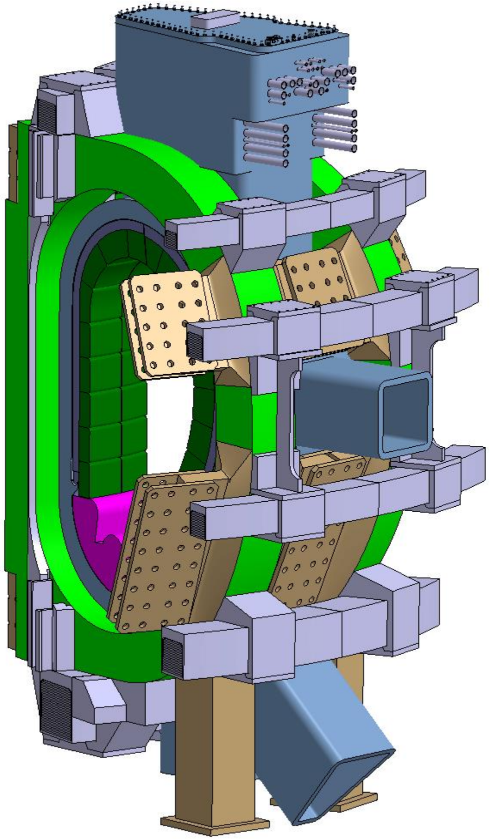
Long narrow ports through which to inspect, repair and exchange components

The EU approach is to work from the port

- Avoid the severe radiation in the vessel
- Simpler maintenance systems
- Better recovery options
- Precision handling of massive components

Non-EU proposals with simpler handling

- ARIES-ACT1 concept
  - Full sector maintenance
  - Larger magnets and maintenance corridor
- K-DEMO and CFETR concepts
  - Large vertical ports
  - Larger vacuum vessel and TF coils



Tokamak maintenance access is through long narrow ports

T. G. Brown, "Three Confinement Systems—Spherical Tokamak, Standard Tokamak, and Stellarator: A Comparison of Key Component Cost Elements," in IEEE Transactions on Plasma Science, vol. 46, no. 6, pp. 2216-2230, June 2018, doi: 10.1109/TPS.2018.2832457.

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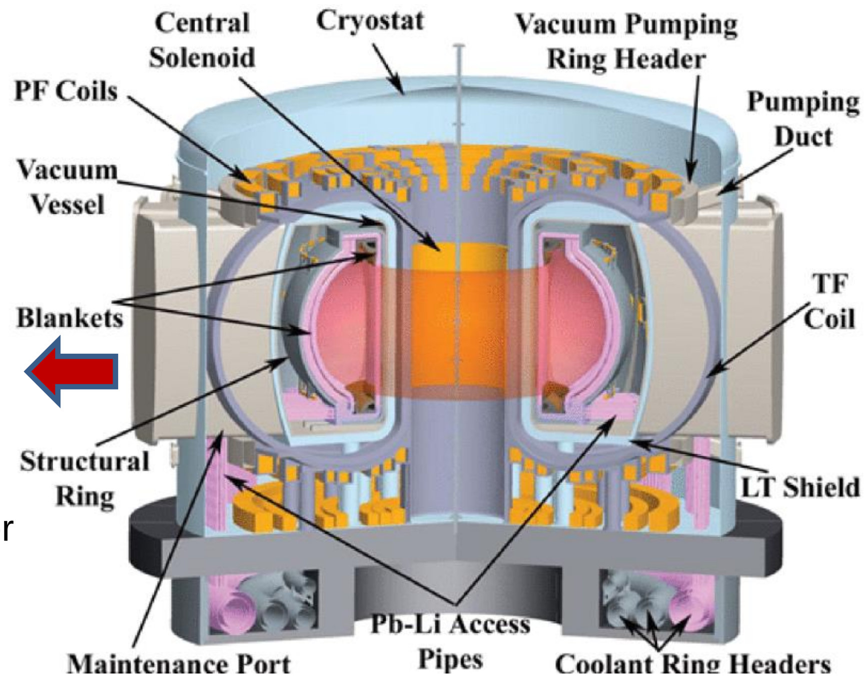

ARIES-ACT1 concept

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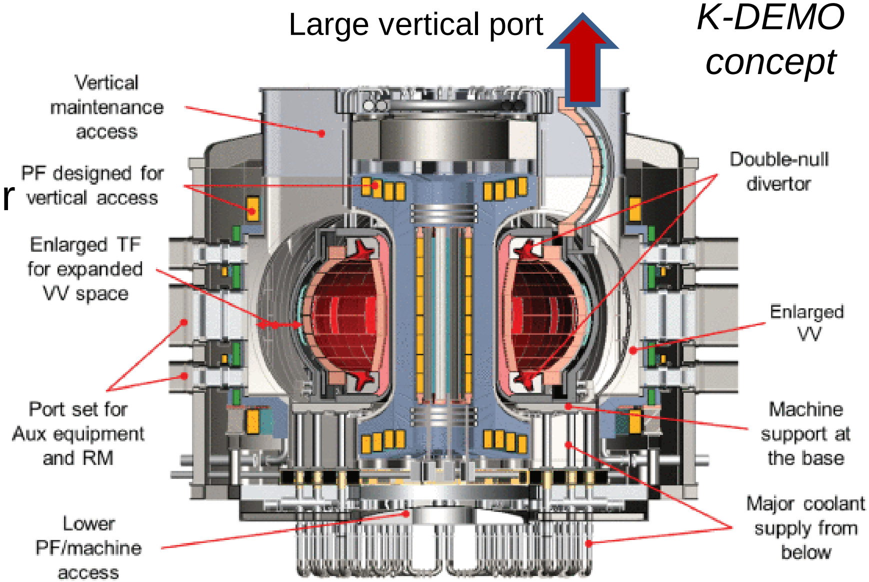

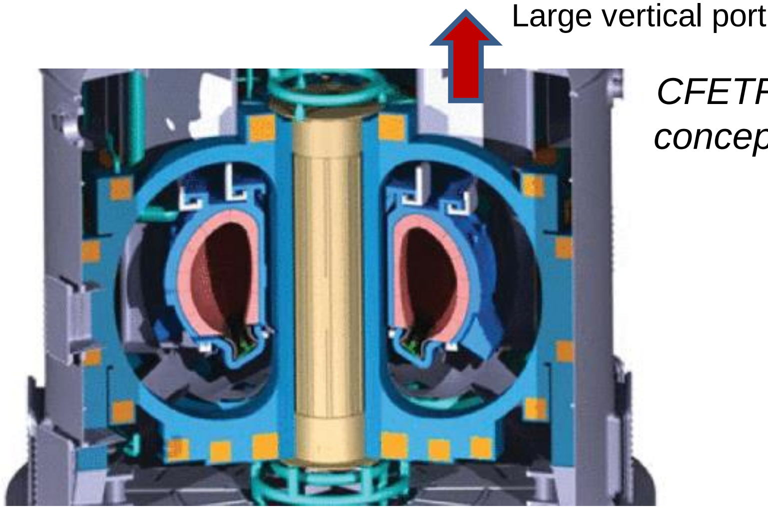

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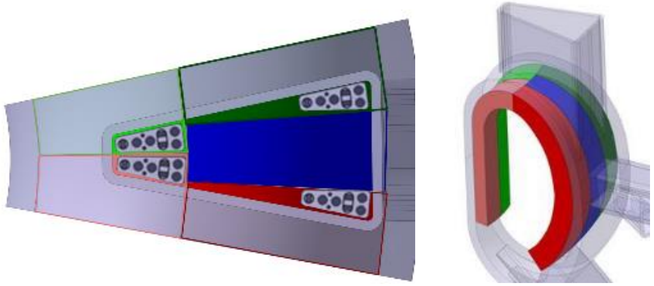
In-bore cutting and welding

Blanket segmentation

- Part of every blanket visible through the port
- Direct mechanical and pipe connections
- Small space around pipes for tool access

In-bore cutting and welding

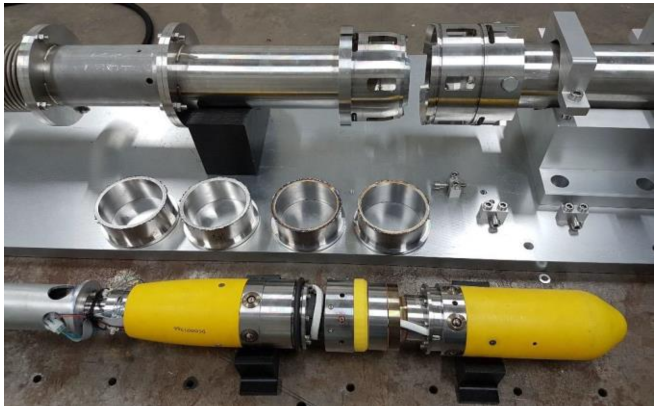
- Critical technology for the EU DEMO
- Arc cutting and welding has speed and recovery issues
- Laser better but technology immature
- Laser cutting and welding tests conducted successfully with industry involvement
- Risks remain to develop process that will satisfy a regulator



EU blanket segmentation

In-bore welding tool

Long distance deployment of in-bore tools



In-bore cutting tool and test rig

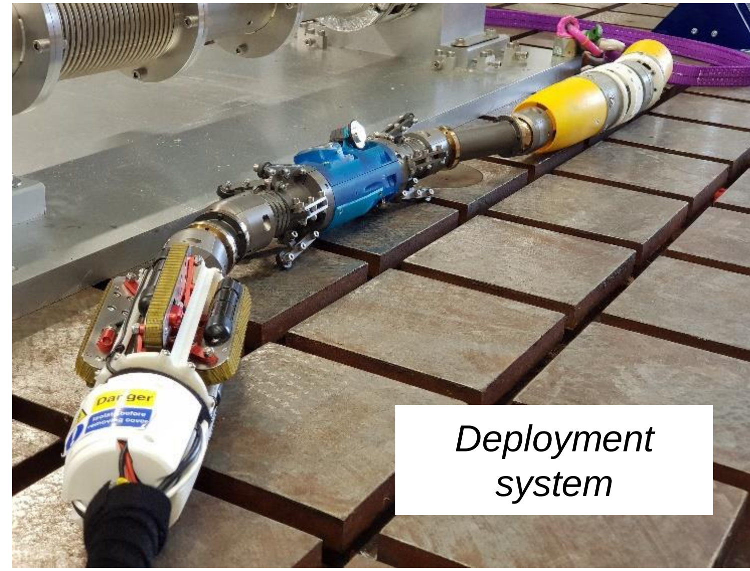
In-bore cutting and welding

Pipe alignment and deployment trials

- High alignment forces

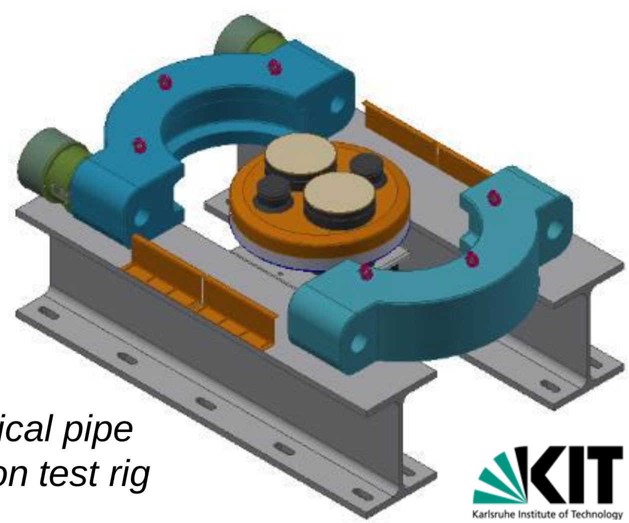
Mechanical pipe connection trials

- Preferred solution where space permits
- Testing to demonstrate leak and failure rates



Deployment system

Testing the alignment of multiple pipes



Mechanical pipe connection test rig

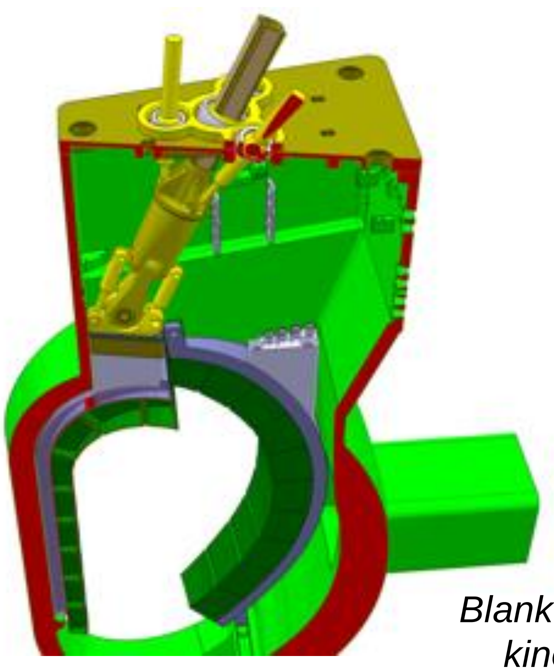
Precision handling

The EU DEMO blanket handling system

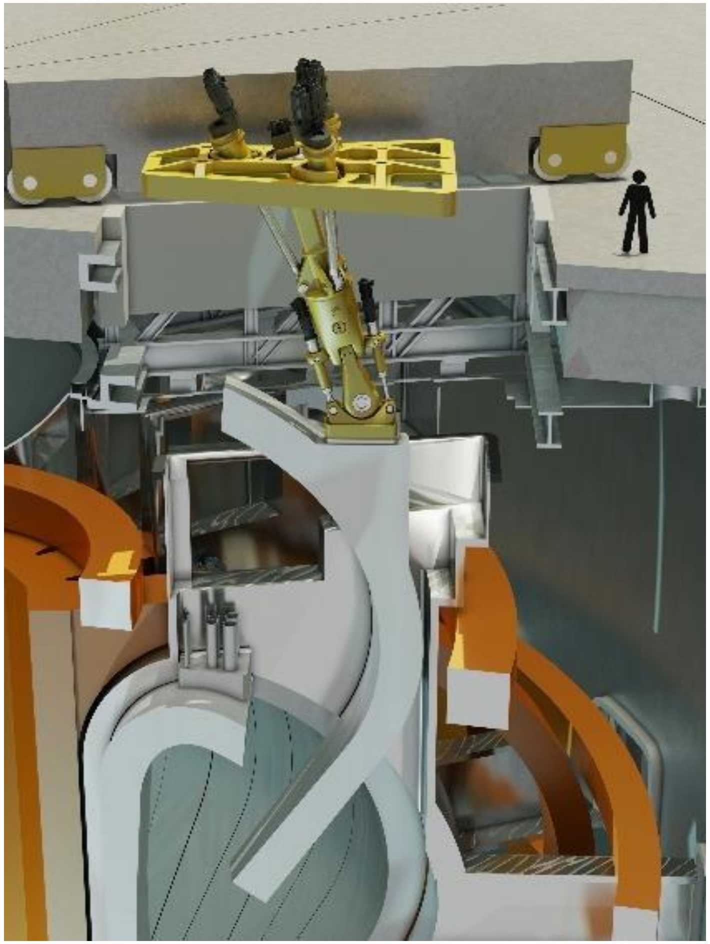
- Fit in the port space
- Manoeuvre the blanket below the port
- Handle 80 tonnes and accident conditions
- React loads through the port

Initial proposal

- Parallel kinematic mechanism for stiffness
- Structural reserve factors low
- Poor dynamic control performance



Blanket mover with parallel kinematic mechanism



Blanket and mover being lifted by the port crane

Precision handling

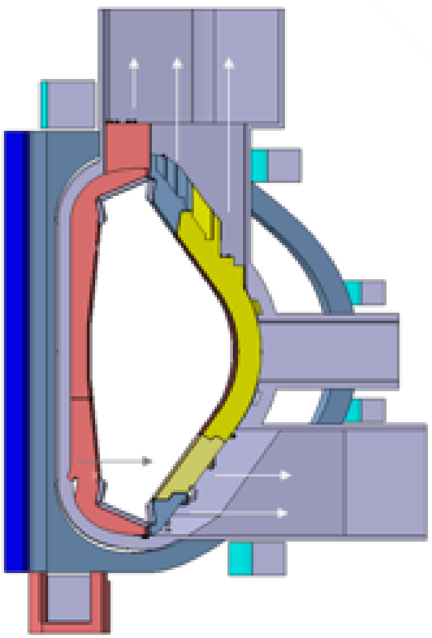
New blanket segmentation options

- Double null to improve kinematics
- Split blankets to reduce load

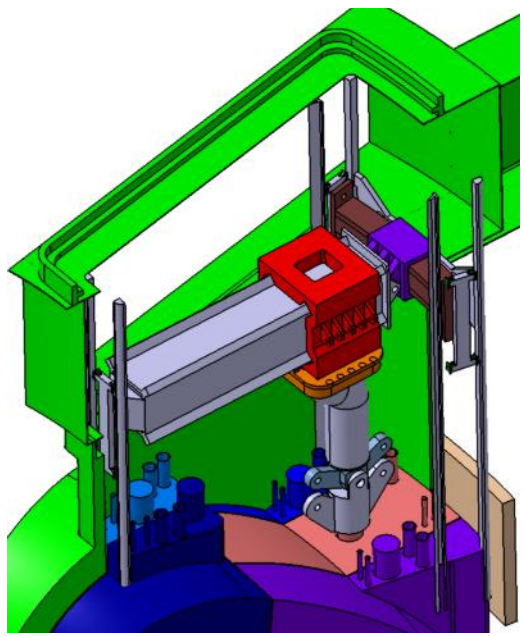
New blanket handling systems

- Rail and slideway based concept
- In-vessel guide from the bottom

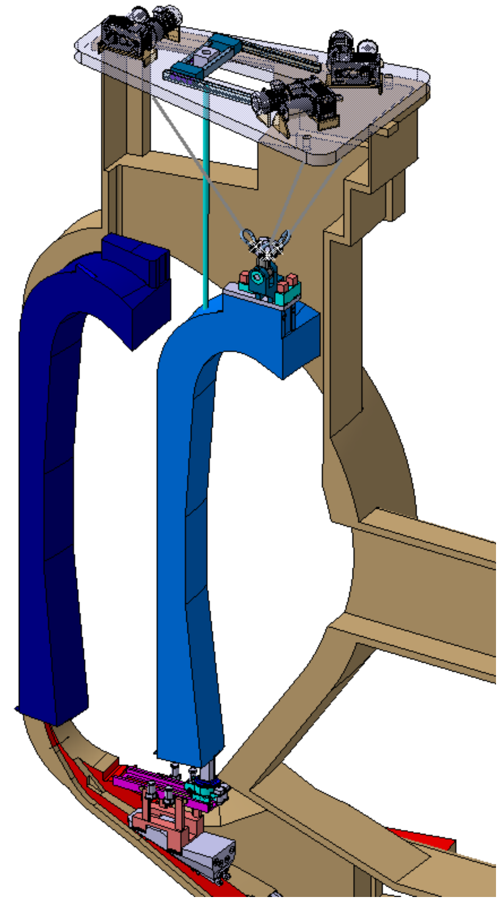
Design tool to optimise performance



Double null split blanket architecture



Rail and slideway mover



Guided blanket mover

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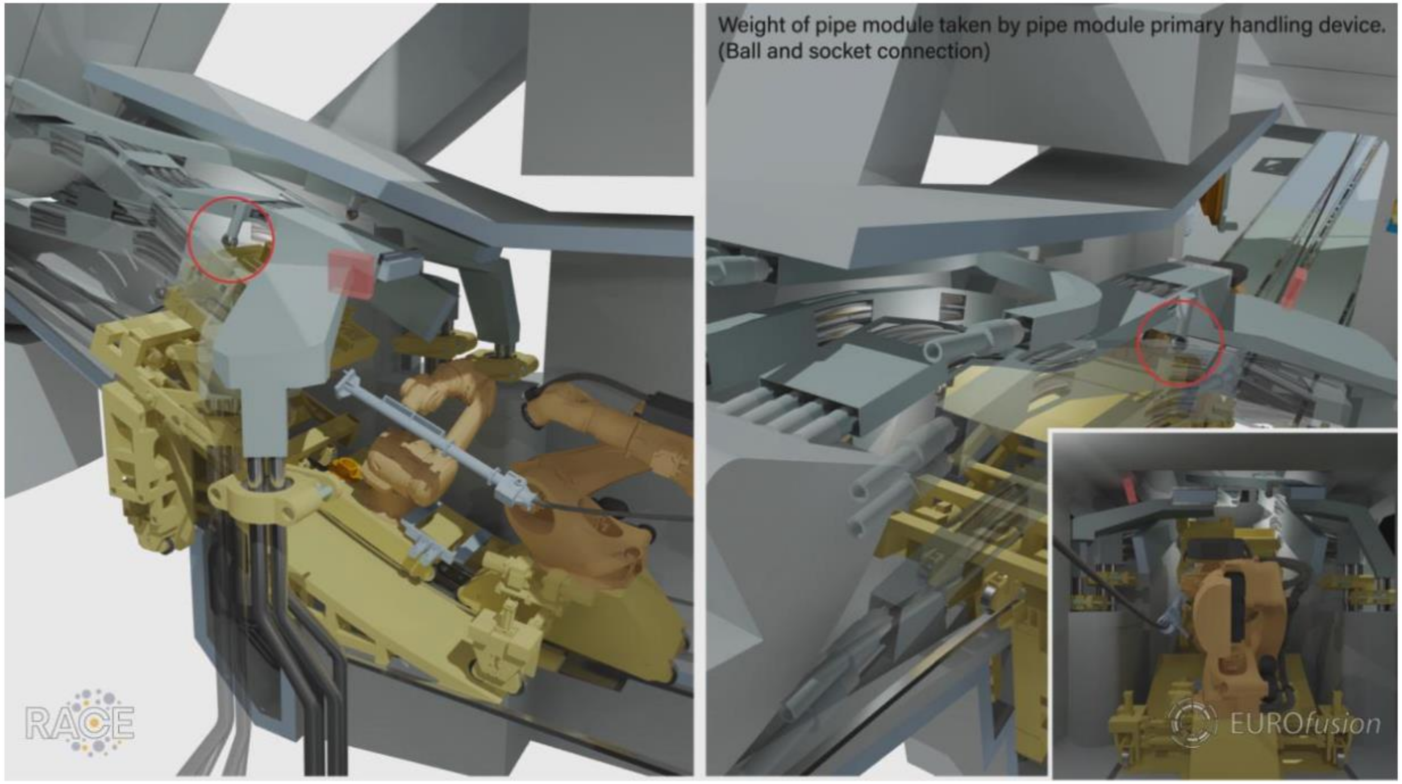
Port access

Port maintenance operations are highly space constrained

- Removal of bio-shield plug and vessel closure plate
- Install transfer system rails
- Remove pipes, heating systems, pumps and shields
- Install movers, remove plasma facing components
- Access operations take longer than component operations



Lower port maintenance

Port access

Animations showing representative sequence of operations are used to understand space constraints and the maintenance equipment and technology required

Upper port access

Lower port access

Modified industrial robots can be used for the main handling operations provided the main load is supported

Looking ahead

Remote Maintenance in Horizon Europe

Maintenance technical risks recognised

Develop integrated maintenance systems

Key maintenance risks addressed

Conduct tests on proof-of-principle designs

- Pipe connections
  - Laser bore joints
  - Mechanical connections
- In-vessel component handling
  - Handling interface
  - Component attachment – load transfer
- Port access systems
  - Pipe module handling
  - Contamination control doors

Contributors to the Remote Maintenance work package within Horizon Europe

RACE – Remote Applications in Challenging Environments, UK

VTT – Technical Research Centre of Finland

KIT – Karlsruhe Institute of Technology, Germany

CEA - Commission Energy Atomic, France

IST - Instituto Superior Técnico, Portugal

ENEA – Brasimone Research Centre, Italy

SFA – Slovenian Fusion Association, Slovenia

EK – Centre for Energy Research, Hungary

DTU – Department of Physics, Denmark

IPPLM – Institute of Plasma Physics and Laser Microfusion, Poland

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