UK Atomic Energy Authority

EUROfusion

Overview of progress towards maintainable architectures for fusion devices

Oliver Crofts

RACE

ISFNT-15 | 12th September 2023

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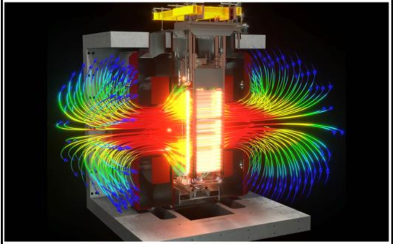
Introduction

Remote Maintenance is Device Defining and Mission Critical

- Oliver Crofts - Work Package Leader for WPRM developing Remote Maintenance for the EU DEMO
- The team comprises 10 Research Units across Europe
- UKAEA is the lead beneficiary for remote maintenance on DEMO
  - Leading the system design and technology development

ROBOTIC HANDLING IN RACE



TEST COMPONENTS IN FUSION TECHNOLOGY TEST FACILITIES (FTF)

POWERPLANT DESIGN STEP AND DEMO

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

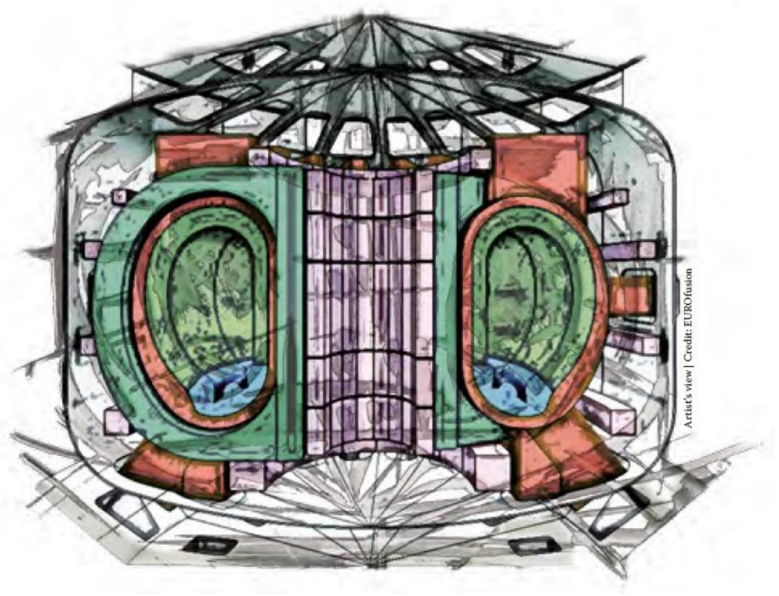
IPPLM – Institute of Plasma Physics and Laser Microfusion, Poland

Introduction

Remote Maintenance is Device Defining and Mission Critical

- Progress towards maintainable architectures
  1. Supporting the DEMO Central Team
  2. Support for plant designers
  3. Developing the Remote Maintenance Equipment
  4. Technology development work
- Drivers for remote maintenance
  - Cost, including electricity production
  - Efficient maintenance
  - Minimise plant down time
  - Influence the architecture of the plant
- DEMO pre-concept design review concluded that:

  'Remote maintenance needs to be addressed as part of the entire plant and the individual components from the very beginning with the leadership of the DEMO Central Team' [1]

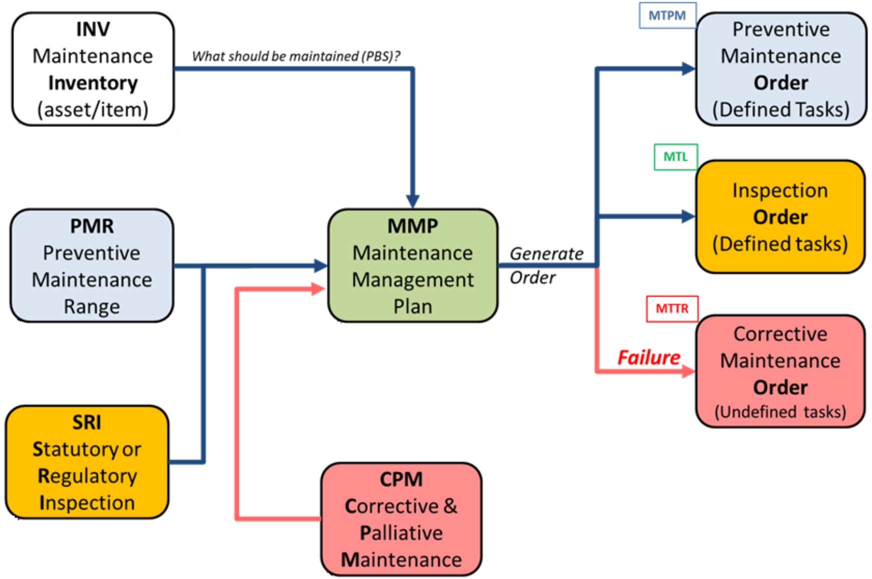


[1] EU DEMO Remote Maintenance System development during the Pre-Concept Design Phase, O. Crofts et al., Fusion Engineering and Design 179 (2022) 113121

Support for the DEMO Central Team

Remote Maintenance input to the architecture selection

- Studies on alternative architectures
- Remote Maintenance System Design Lead
  - Marc Torrance
  - ‘Bottom-up’ equipment development
  - Candidate Remote Maintenance Equipment
  - Equipment Catalogue – in the DEMO Baseline
- Maintenance Transverse Function Lead
  - Didier Chauvin
  - ‘Top-down’ Maintenance Specification development
  - Development of the Maintenance Management Plan

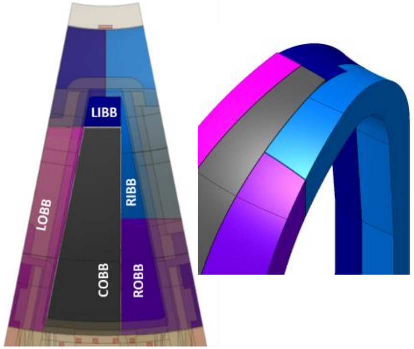


Remote Maintenance Equipment Catalogue
- Data sheets
- Space reservations

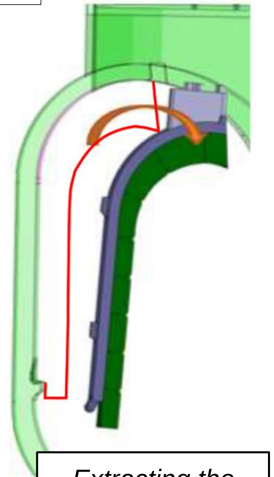
Alternative Architecture Studies

Alternative blanket configurations could significantly improve plant maintenance

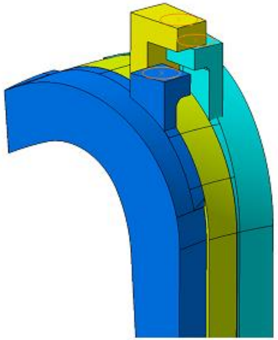
1) Puzzle blankets
2) Overlapping lifting points – new blanket design
   – L. Poszovecz et. al., PS3-126 ISFNT-15 poster
3) Single inboard blanket – larger port required
4) Combined inboard and outboard blanket



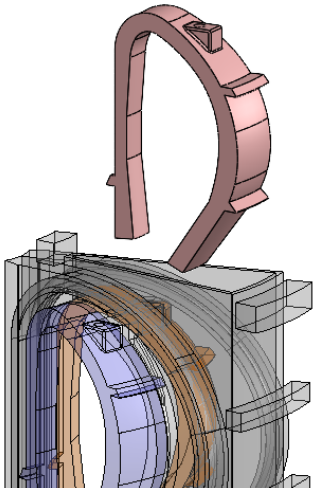
1) Puzzle blankets (UKAEA RACE)



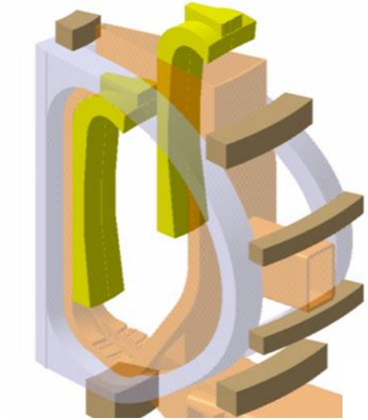
Extracting the first of two inboard blankets



2) Three inboard blankets with overlapping lifting points (EK-CER)



4) Combined inboard and outboard (VTT – LUT)

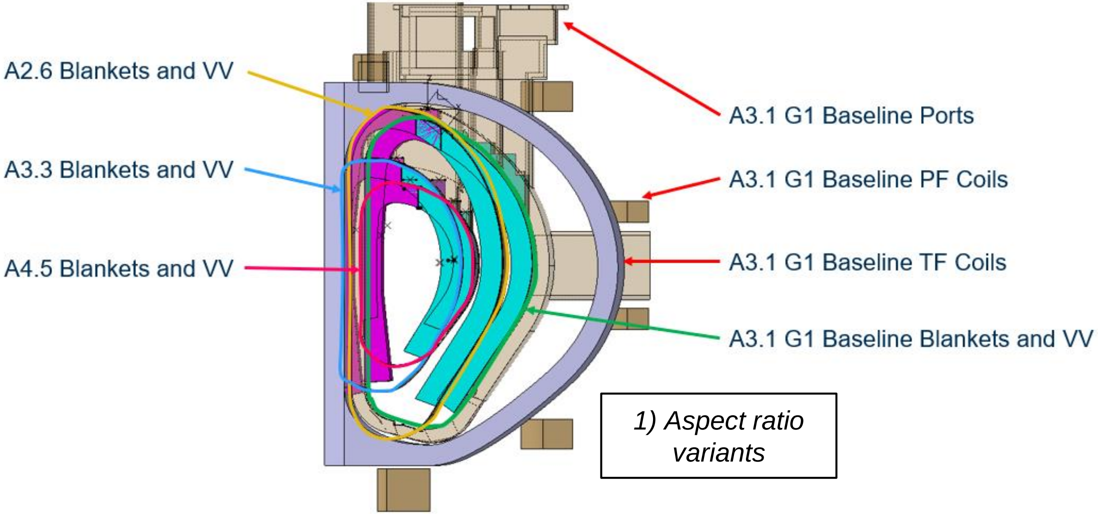


3) Single combined inboard blanket (UKAEA – RACE)

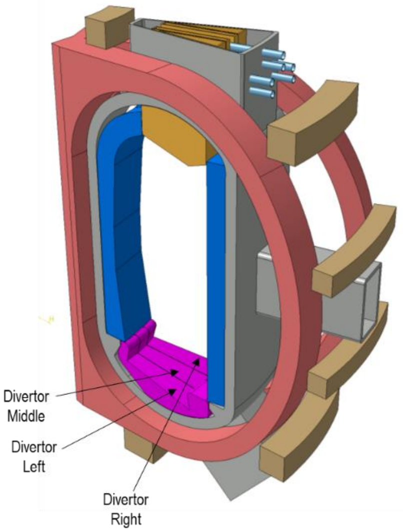
Alternative Architecture Studies

Alternative tokamak configurations could significantly improve plant maintenance

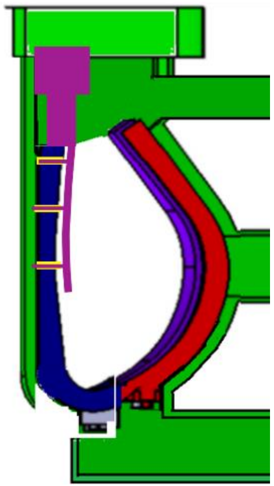
1) Aspect ratio variants – more space
2) Major radius variants – more space
3) Simplified blanket architecture – impacts vessel and plasma
4) Inverted DEMO – impacts the magnets and plasma



1) Aspect ratio variants



3) Simplified blanket architecture



4) Inverted divertor

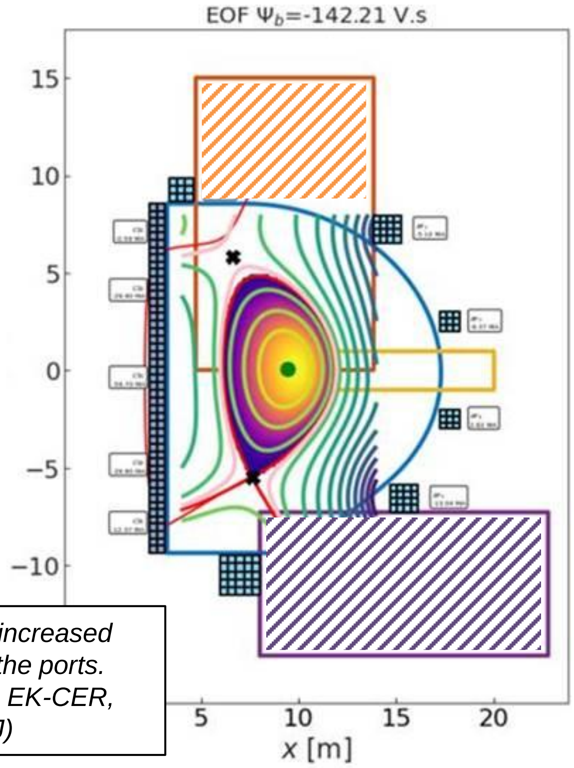
Computational assessments

Design codes allow an initial check of the magnet and plasma viability

- PROCESS and Bluemira codes
  - Move Poloidal Field Coils to increase the space for the ports
  - Check viable magnet and plasma configurations
  - Result of the first assessment shown in the figure

- Promising architectural changes
  - Enlarge the vacuum vessel to accommodate a single IBB
  - Reduction in dominate handling loads by ~65%

- More space allows simpler maintenance

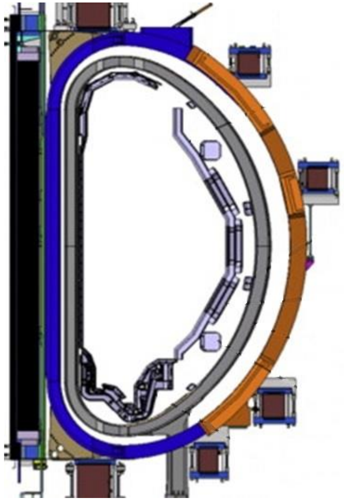


Bluemira output with increased accessible space at the ports. (UKAEA/RACE, VTT, EK-CER, IPPLM/NCBJ)

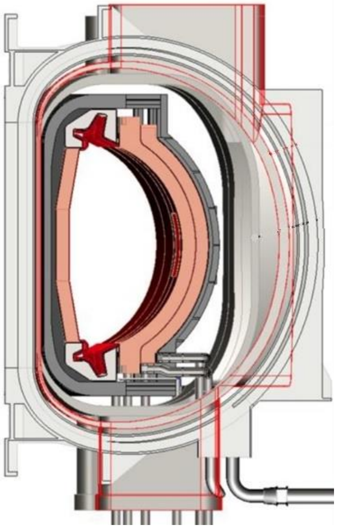
Space behind the blankets

Different balance between space, cost and plasma configuration

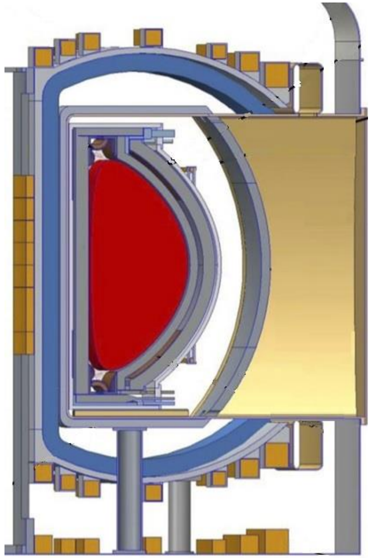
CFETR - China
Space between VV & BB



JT-60SA - Japan
Space between VV & BB



K-DEMO - Korea
Space between VV & BB

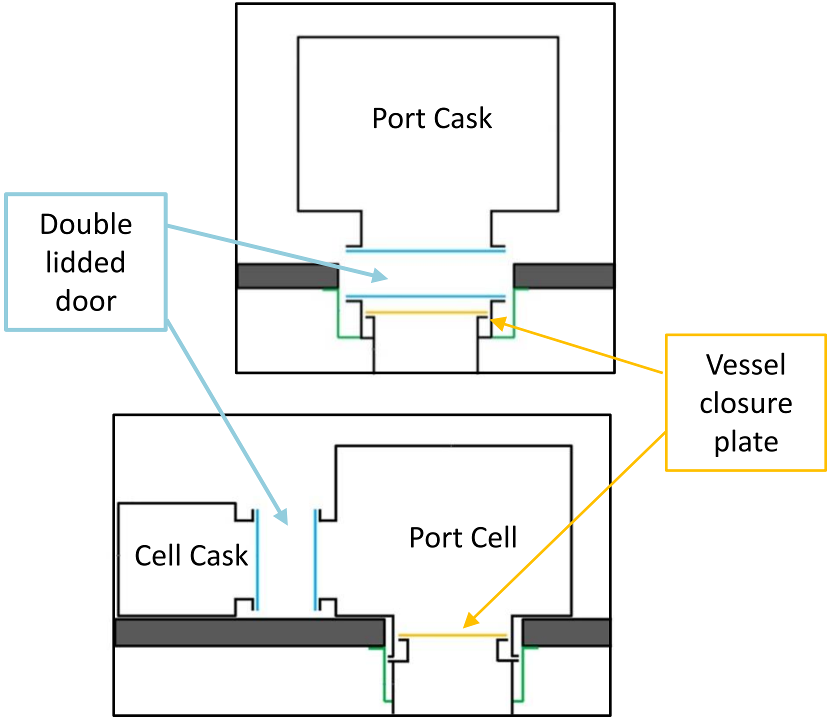


ARIES-ACT2 - US
Horizontal BB replacement

Port Cask vs Port Cell

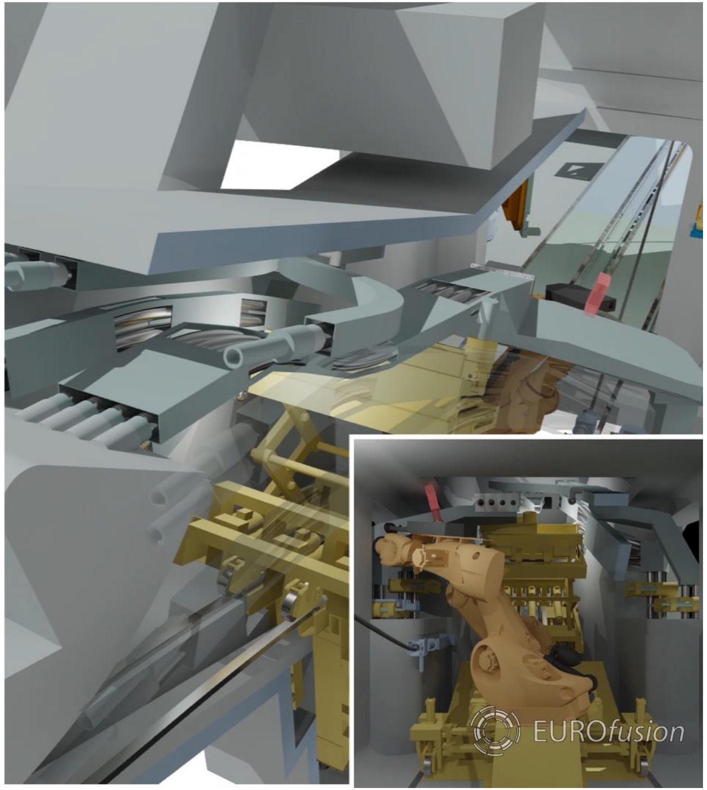
Ex-vessel layout is critical to efficient maintenance operations

- Transfer casks can either dock directly to the port, or dock to a port cell around the port
- Advantages of a Port Cell
  - Space to assemble and store equipment and plant
  - Reduces the cask size and number of transfers
  - Reduced plant downtime
- Advantages of docking casks directly to the port
  - Reduced volume connected to the vessel
  - Increased ex-vessel space when not in maintenance
  - Can reduce ventilation and decontamination requirements



Divertor Port is likely to need a Port Cell

Complex handling and transport systems required

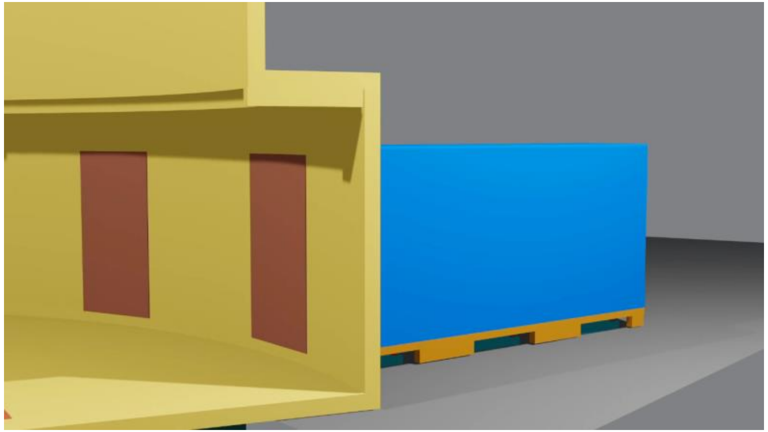


Upper Port Architecture

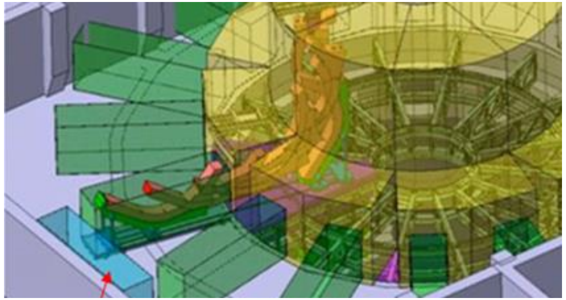
Upper Port could use Port Casks or a Port Cell

- Port Cell advantages
  - Speeds up maintenance
  - Reduces amount of remote maintenance equipment
  - Smaller cask size and number of transfers
  - Can rotate the blankets to a horizontal orientation
- Port Casks are a possibility
  - Vertical transfer of equipment can be done by crane
  - Deployment of manipulators would be an advantage

Crane deployed upper port equipment (UKAEA/RACE)



Blanket rotation (G.Teixeira – IST)

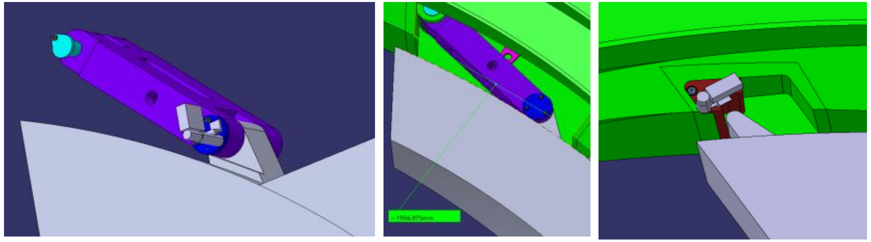


Upper Port Cell (UKAEA/RACE)

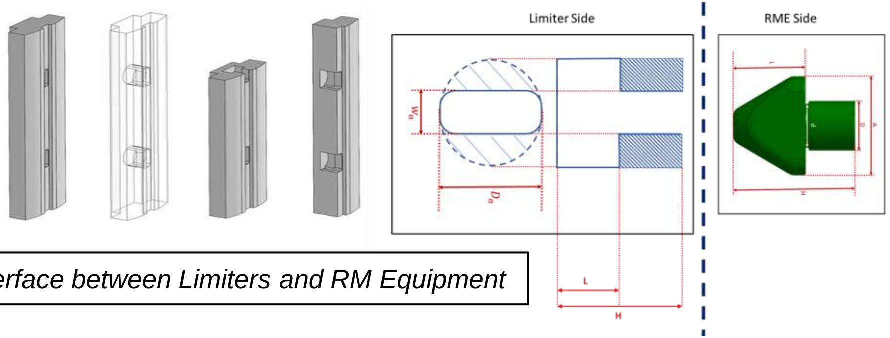
Support for Plant Designers

Plant designs must be compatible with remote maintenance

- Breeding blankets
  - Size, stiffness, clearance, mass
  - Attachment to the vacuum vessel
- Limiters
  - Maintenance of service connections
  - Access to attachment to vacuum vessel
- Divertor
  - Positioning accuracy and handling
- Heating and current drive
  - Simplified maintenance
  - Line replaceable units
  - Modular transmission lines



Assessing Tool Access for Manipulation

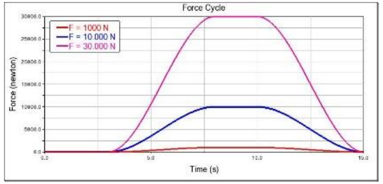


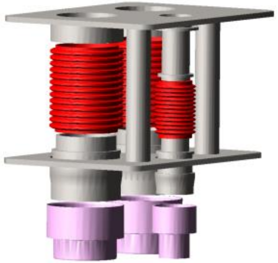
Interface between Limiters and RM Equipment

Service Joining Tools

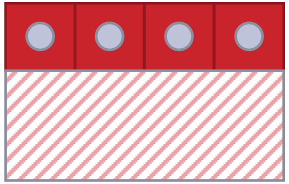
Proposed architectures require novel in-bore pipe cutting and welding

- In-bore pipe tools are critical to maintenance
  - Not enough space for orbital tools
  - Develop candidate tools
  - Assessment of technical maturity
  - Proof-of-principle testing
  - Understand feasibility and capability

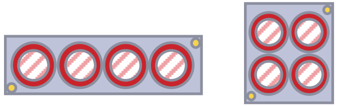




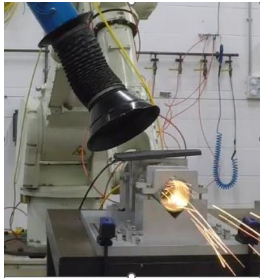
Alignment system testing and modelling (UKAEA/RACE and ENEA Polito)

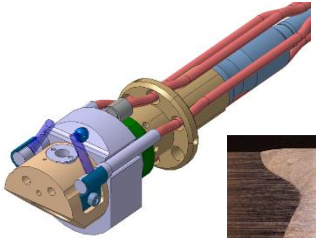


ITER pipe tool access



DEMO in-bore pipe tool access

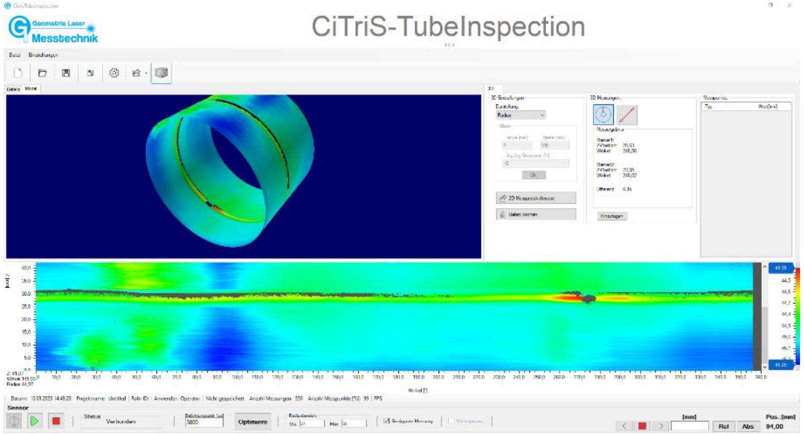




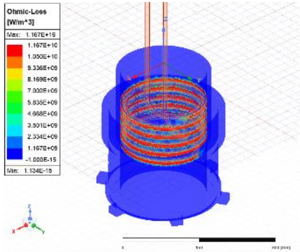
Laser in-bore cutting and welding tool development and testing (UKAEA/RACE)

Service Joining Tools

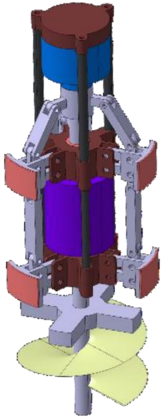
Proposed architectures require novel in-bore pipe cutting and welding



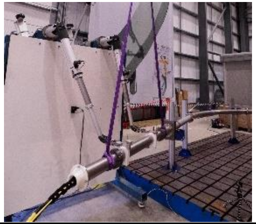
In-bore pipe non-destructive examination (KIT – Azman Azka)



Brazing induction heating trials (EK-CER – Jeno Kadi)



Mechanical cutting (ENEA/Unibas)



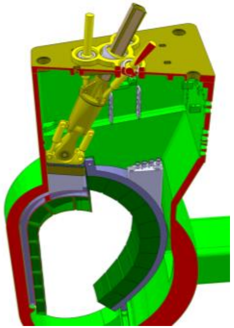
In-bore deployment tool testing (UKAEA/RACE)

- Findings of this work
  - No fundamental issues identified but risks remain
  - Architectures with tight pipe spacing look feasible

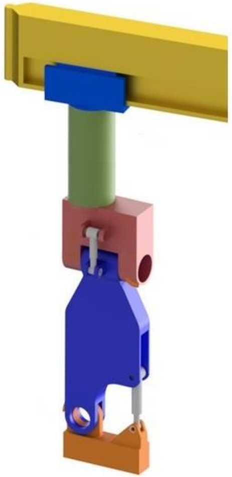
Blanket Handling Equipment

Novel and challenging handling systems are required for blanket maintenance

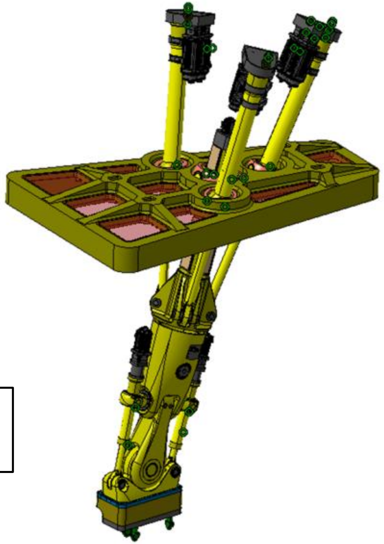
- Inboard Blanket handling
  - Narrow end of the port
  - Complex extraction path
  - Large force moment
- Position control
  - Handling of massive flexible payloads
  - Understand the system dynamics
  - Novel control systems



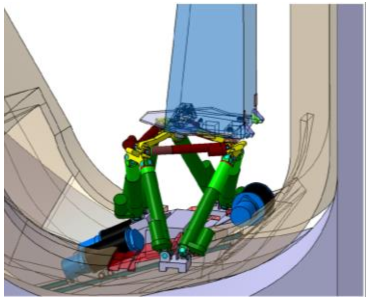
Inboard blanket handling



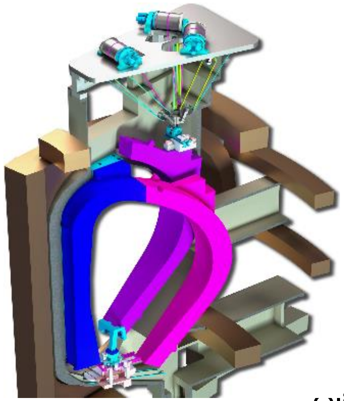
Rail-based series mechanism (UKAEA/RACE, IPPLM/NCBJ)



Hybrid mechanism (UKAEA/RACE)



Hexapod lower manipulator EK-CER – Marcell Málics – ISFNT 15 poster PS4-126

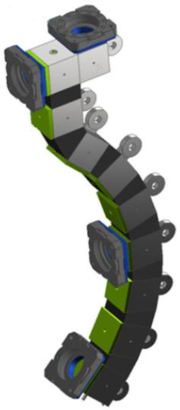


Two-port mechanism with cable driven upper manipulator (UKAEA/RACE, EK-CER, VTT, ENEA/LTCalcoli)

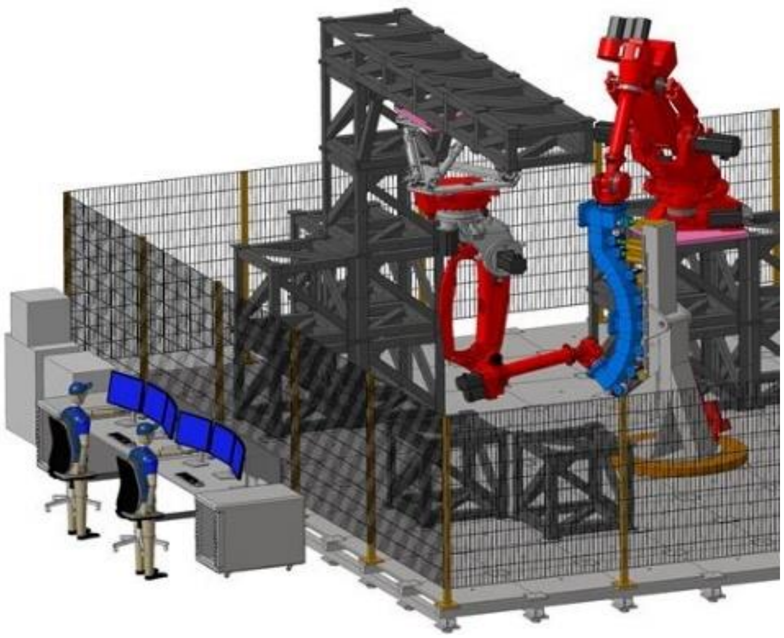
Remote Maintenance Test Facility

Vertical maintenance architectures require novel control systems to be developed

- Test technologies for handling massive flexible loads
  - Actuators, sensors, control algorithms
  - Feedforward control algorithms have been developed for handling flexible loads
- Series of Test Rigs that integrate into TR15
  - Reconfigurable layout
  - Test a range of parameters
- At the concept design stage
  - Smaller scale test rig is under construction
  - Initial test of control algorithms
  - De-risk the main test facility
  - Feedforward control algorithms have been developed for handling flexible loads



Reconfigurable test payload UKAEA/RACE



RMTF TR15 integrated test rig UKAEA/RACE

Application of optimal control for breeding blanket remote maintenance Sam Herschmann. ISFNT 15 presentation this afternoon

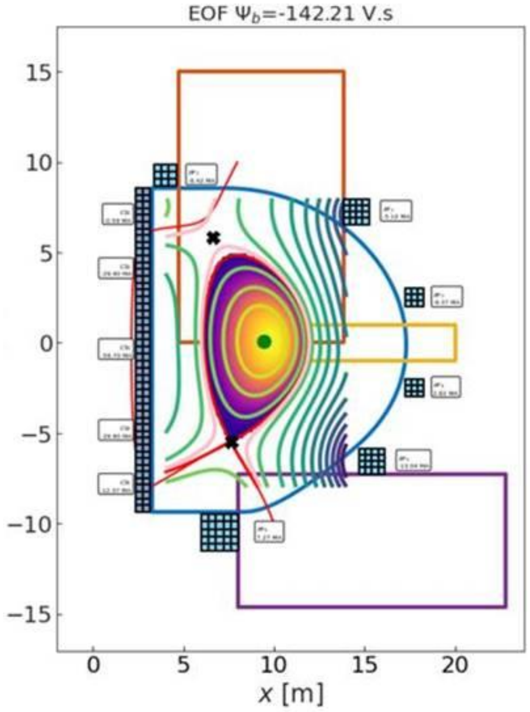
Summary

Architectures shown in this presentation are possible alternatives

- Early consideration of RM is critical
- Influencing architecture by:
  - Supporting the DEMO Central Team
    - Studies into Remote Maintenance benefits
  - Support for plant designers
    - Ensure maintainable concepts are proposed
  - Developing the Remote Maintenance Equipment
    - Inform designers of what is possible
  - Technology development work
    - Understand the feasibility of RM solutions

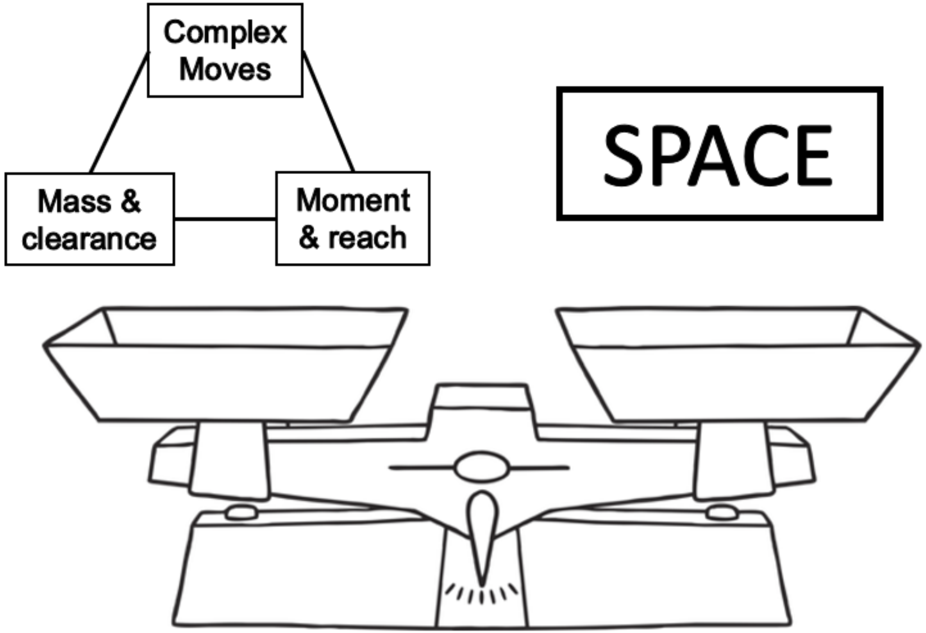
- Cost of Remote Maintenance reduces with more space

- These are proposals for alternative architectures



Conclusion

Give Remote Maintenance Space!



EUROfusion Ethos

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