



# **MOCK-UPS IN SUPPORT OF LONG-TERM REMOTE OPERATIONS IN CHALLENGING ENVIRONMENTS**

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**Fukushima Forum, 6 August 2018**

# The next few minutes...

## PURPOSE

To think about how mock-ups can be used to de-risk remote operations for long term fuel debris retrieval

## TOPICS

- RACE's use of mock-ups at UKAEA in support of remote operations at JET
- The methodology and principles that underpin use of RACE mock-ups
- Observations that may be relevant to 1F D-D

# UKAEA's mission

“To lead the commercial development of fusion power and related technology and position the UK as a leader in sustainable nuclear energy”

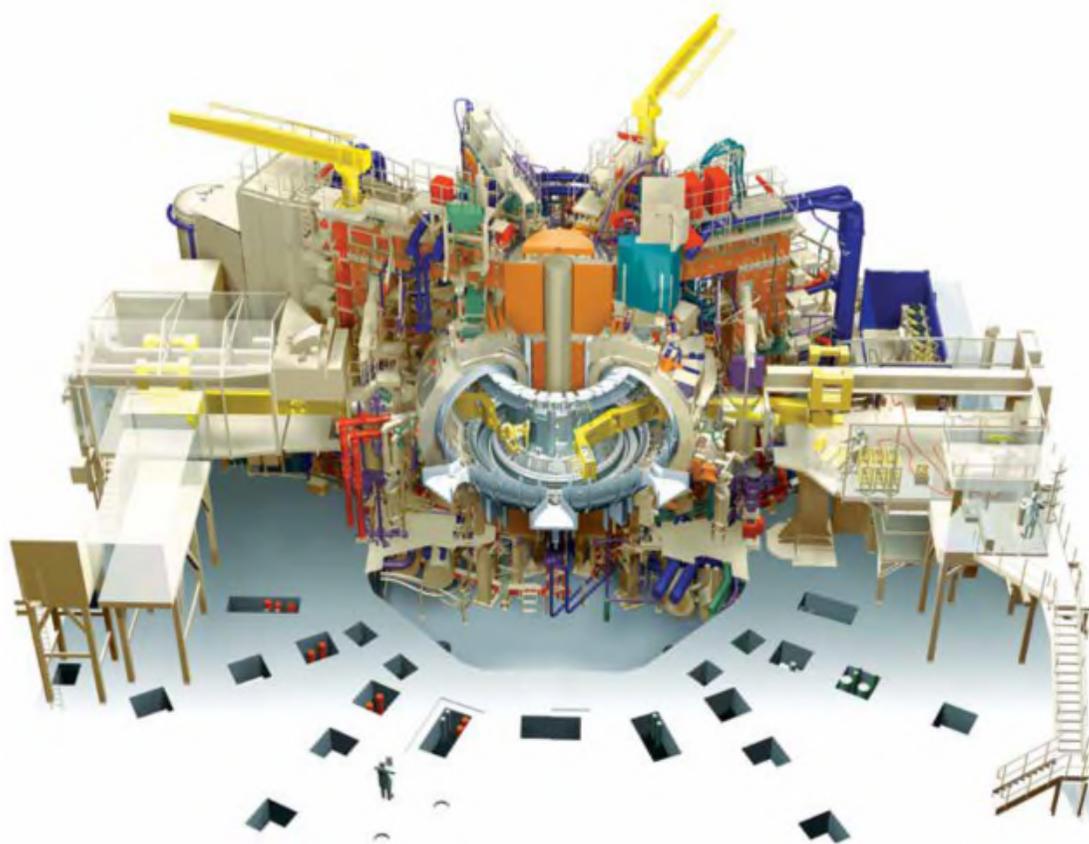
UKAEA hosts JET, the Joint European Torus

# RACE at Culham, Oxfordshire, UK



RACE is the UKAEA's centre for  
“Remote Applications (=Robotics) in Challenging Environments”

# JET Remote Handling System



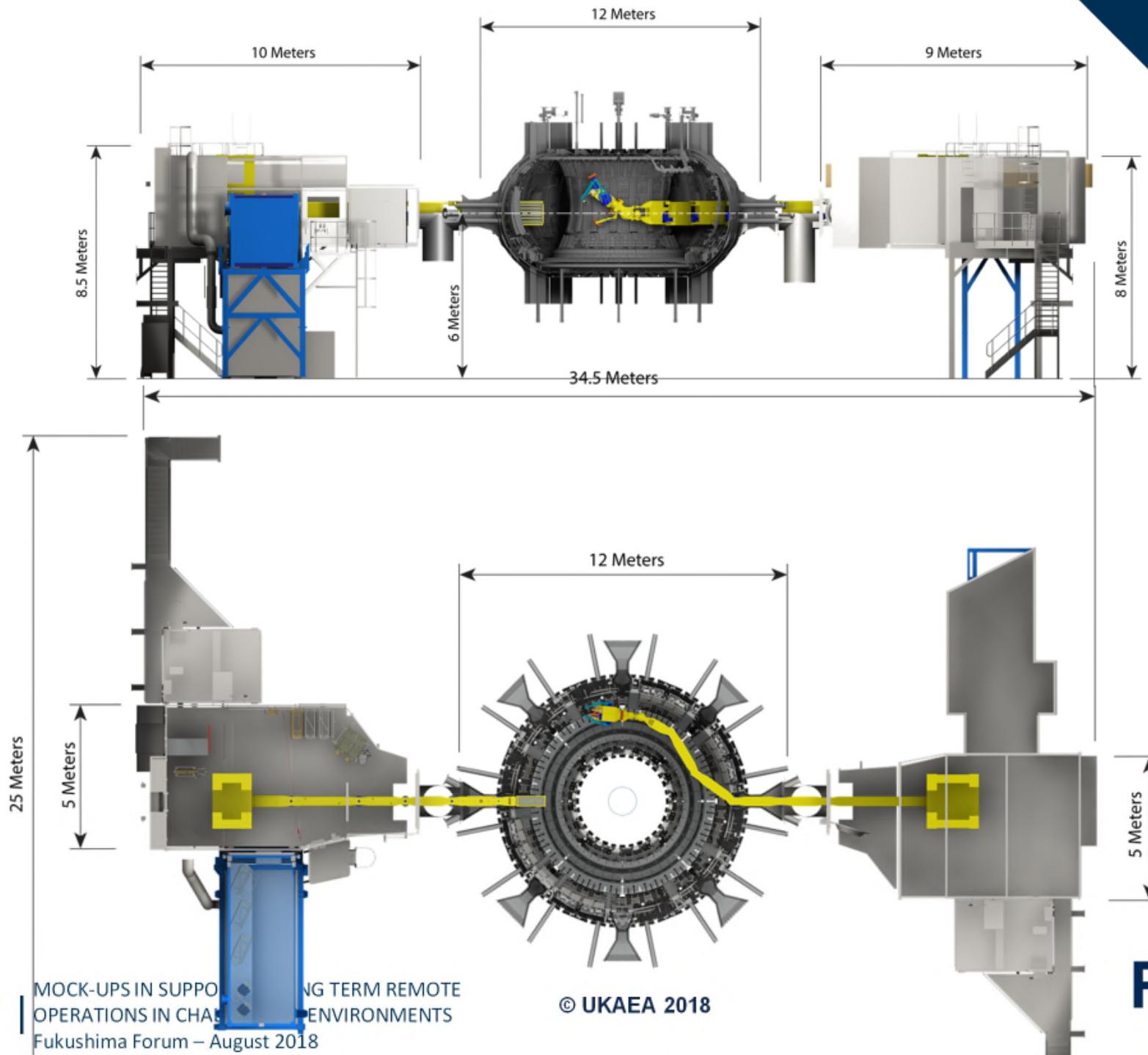
UKAEA has been at the forefront of remote handling systems technology for the past two decades, using and upgrading state-of-the-art remotely operated and robotic systems, validated using long term mock-ups.



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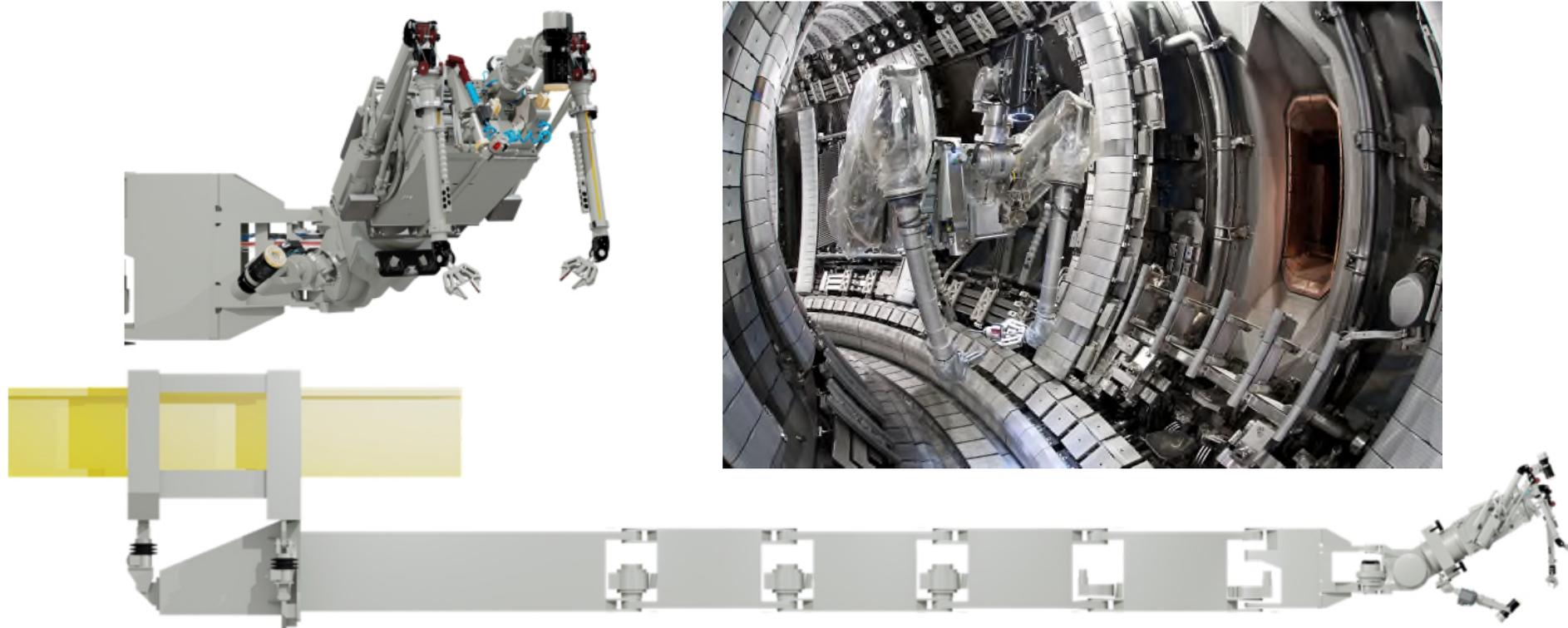
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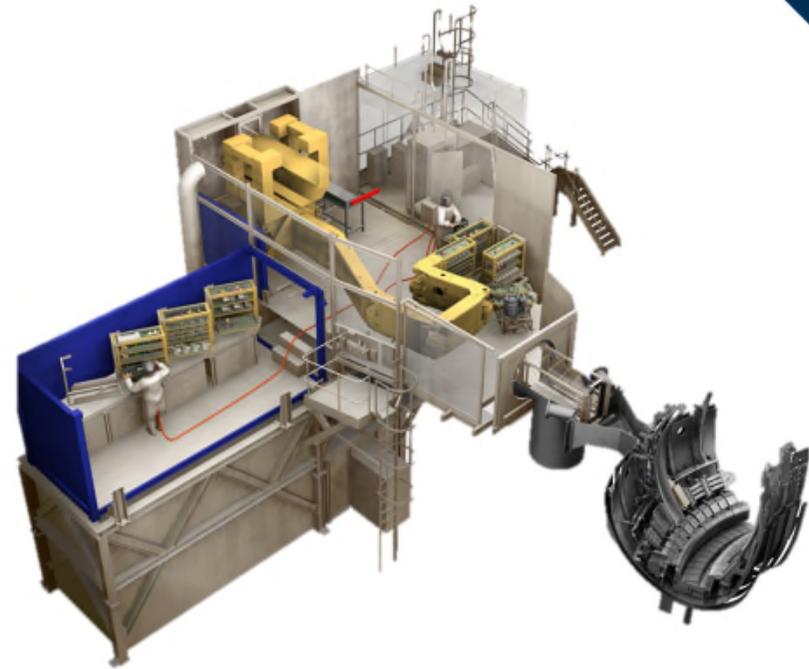
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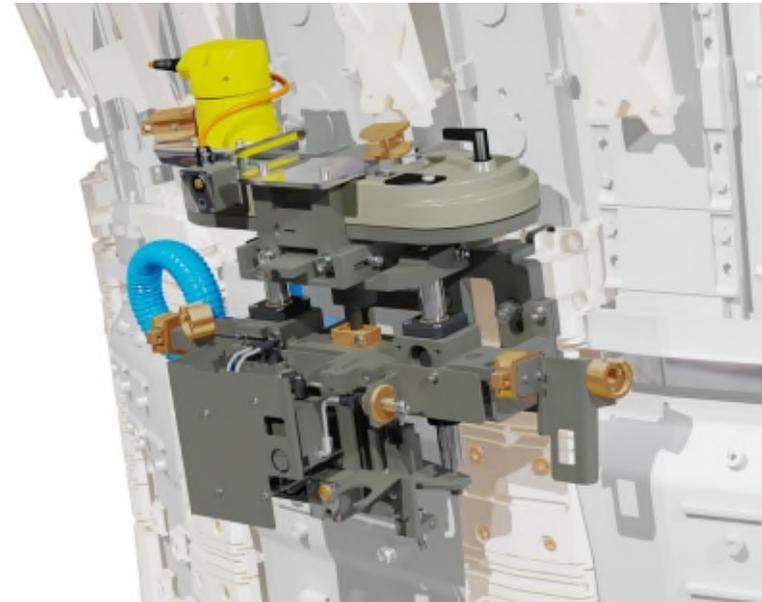
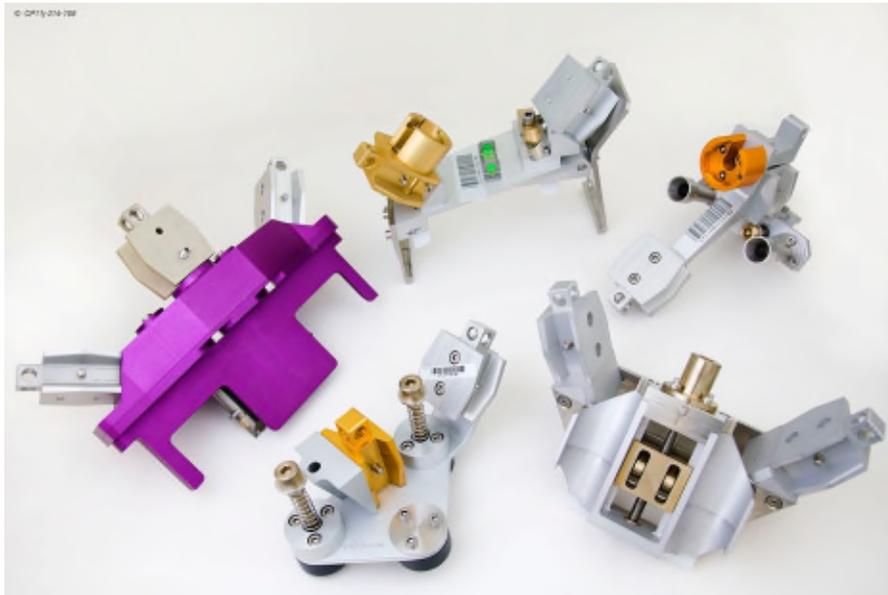
# Octant 5 Boom and MASCOT



# Octant 1 Boom

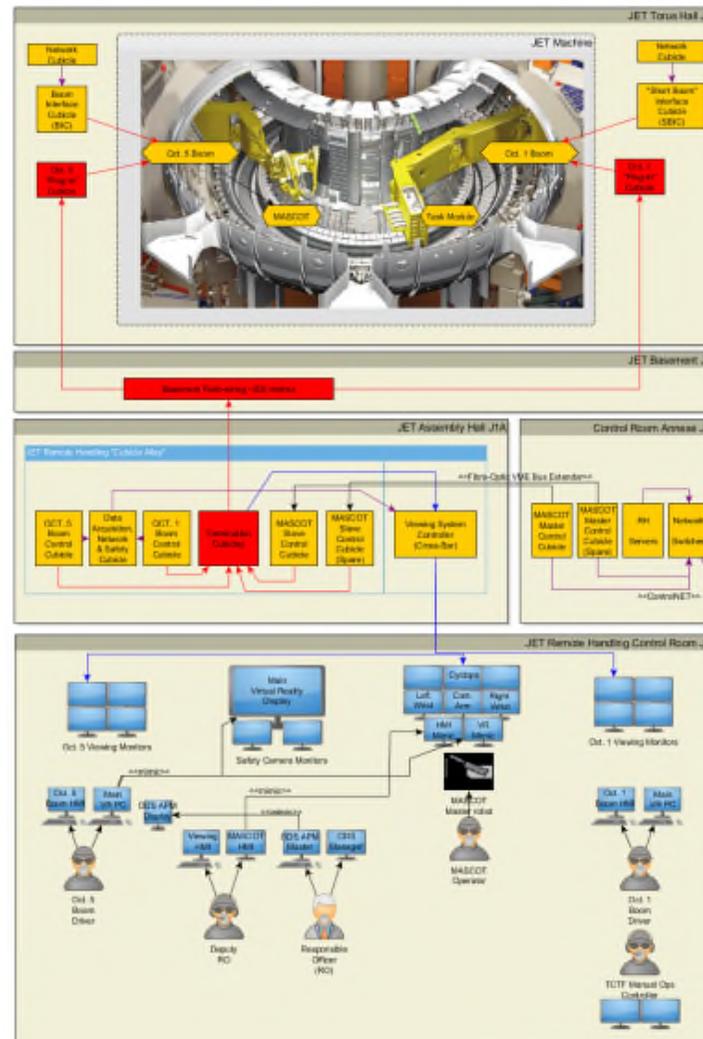


# Tools



# Control room

- 5 Operators
  - 1 Mascot driver
  - 1 Camera and Mascot support
  - 2 Boom drivers
  - 1 Responsible officer
- Master manipulator
- Control HMIs
- Camera suite
- VR system
- Operations Management System



# Warning!

JET is not 1F

JET is highly managed

JET is clean

JET is low radiation

JET is smaller

JET Remote Handling System is still unique

It has been used, maintained and upgraded for 20 years

# Mock-ups are important

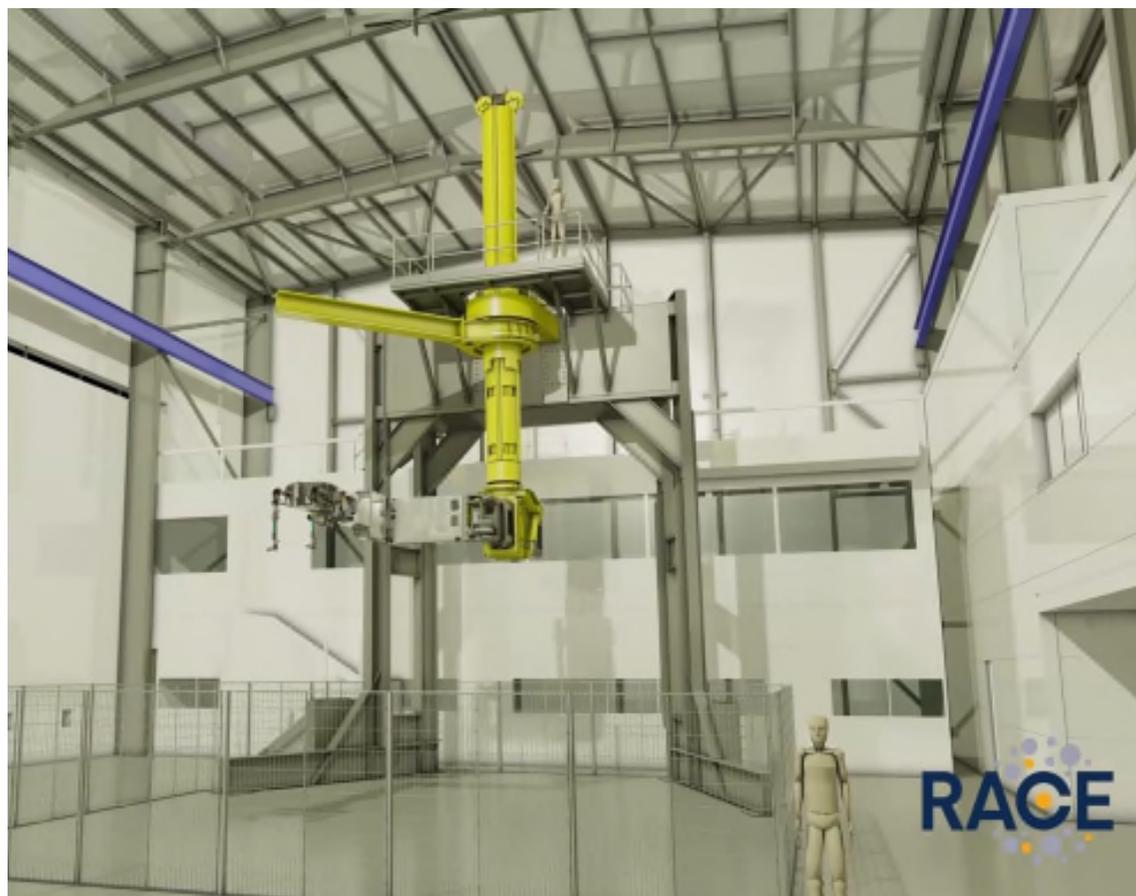
Why?

**Building trust**

**In-Vessel Training Facility (IVTF)** *that has been used for two decades in support of remote operations at JET.*

**Telescopic Articulated Remote Manipulator (TARM)** *is a unique hyper-redundant, slender, high payload robotic system that is a physical mock-up for the testing of software and control systems.*

# Telescopic Articulated Remote Manipulator



- Development of active position control system to manipulate large loads with low relative stiffness to ~10mm precision
- Two test end effectors
  - passive low frequency response to motion
  - active controllable oscillatory motion
- Trials of multiple, redundant sensing
- Longer term use as a generic test platform

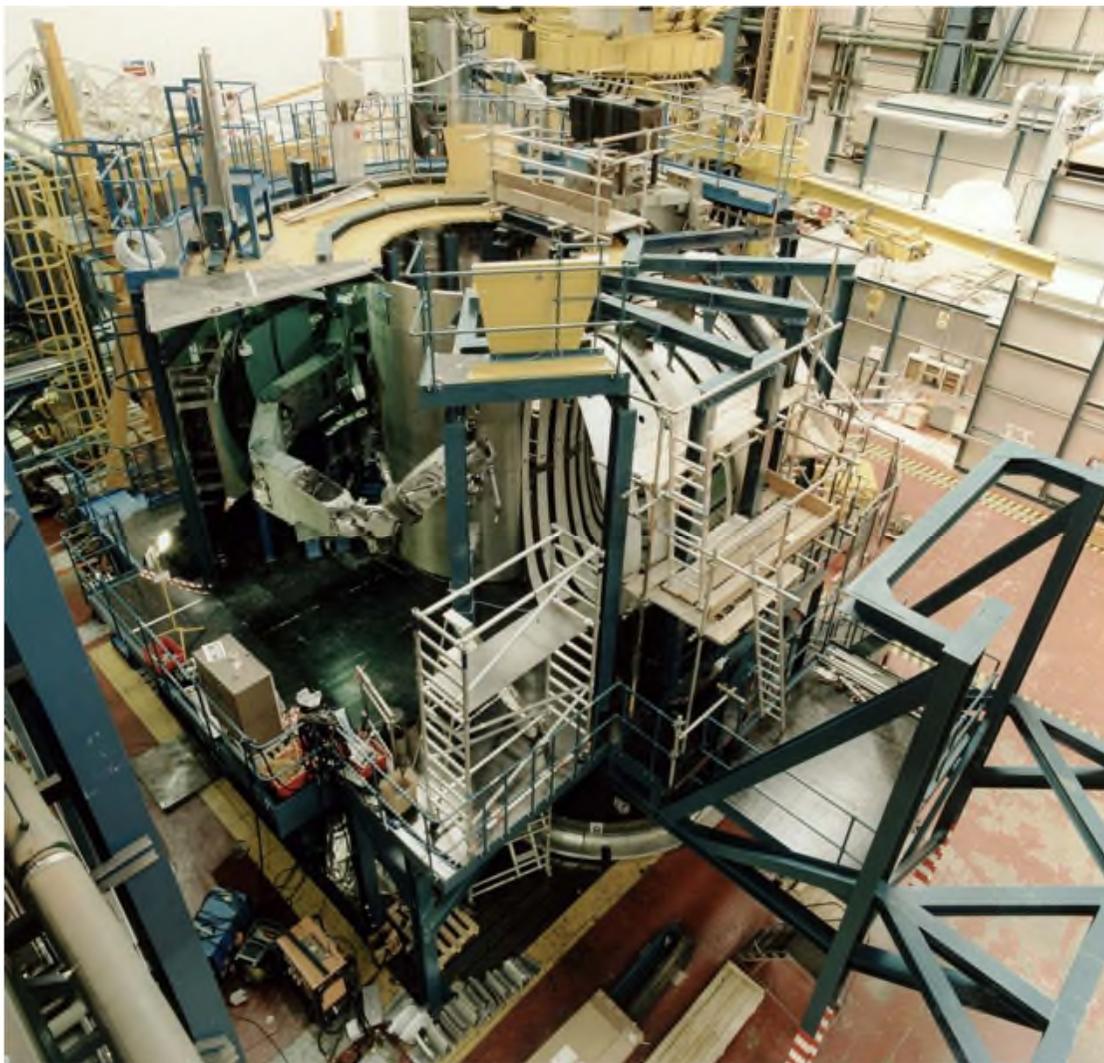


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# In-Vessel Training Facility



The IVTF has been an essential component of the JET remote handling system for the last 20 years.

Incrementally developed and constantly adapted

A critical and invaluable facility in developing the remote handling system and processes:

- Safe
- Proven
- Efficient (cost effective)
- Timely
- Field-oriented

# In-Vessel Training Facility

## Equipment development

- RHS tooling development and validation
- Component feasibility studies, development verification and validation

## Task development

- Component manipulation and handling trials.
- Task generation, verification and validation
- Failure and recovery scenario verification
- Boom teach file verification.

## Training

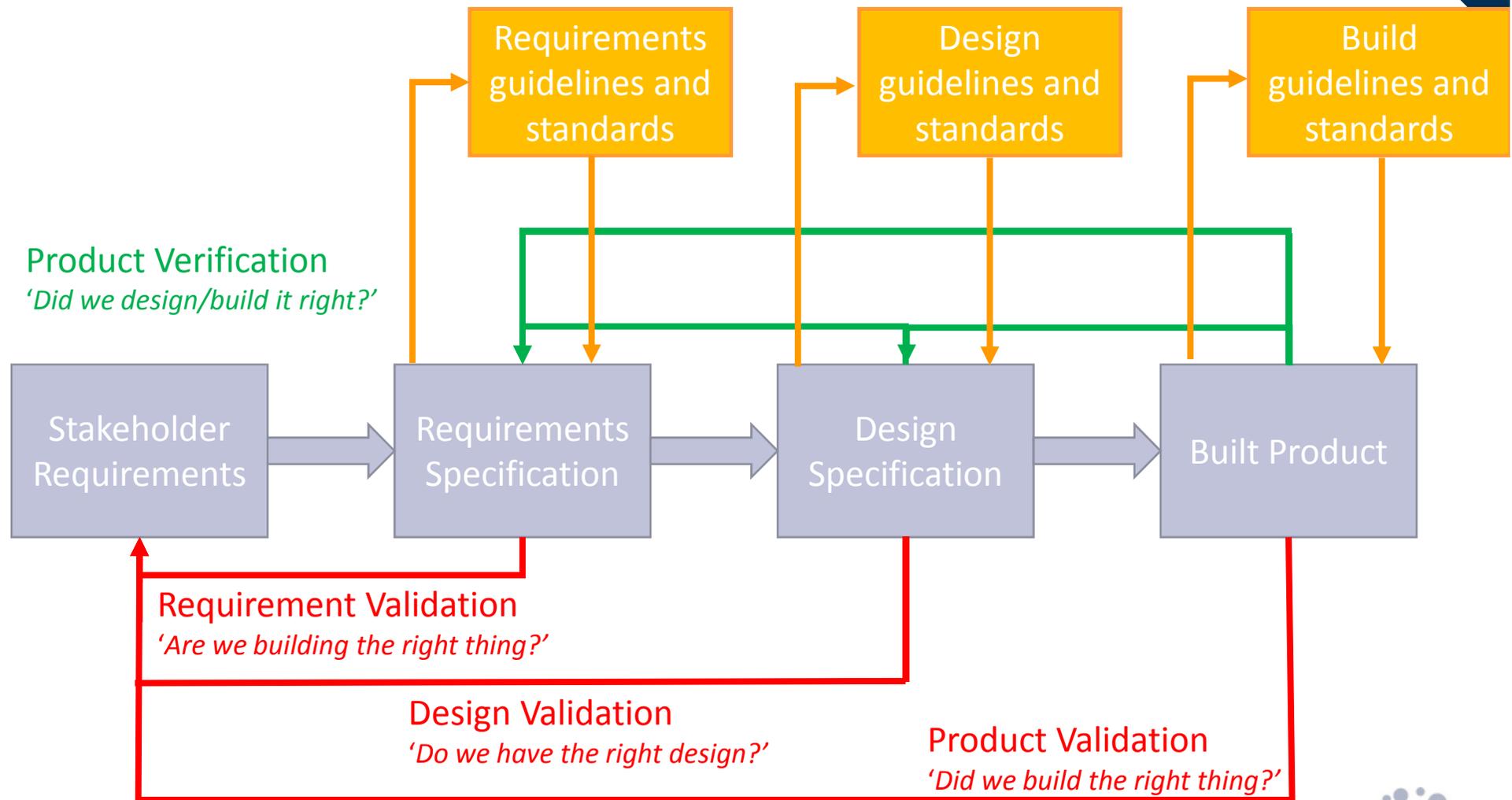
- Operator selection interviews
- Operator training
- Operator skill retention
- Operator assessment

## Operations

- Anomaly understanding and investigation



# Validation and Verification



# Stakeholder Engagement

**Invested observers.** *Anyone who is interested in the activity itself but who is unlikely to know the details of particular operational plans, hardware or specific operational procedures. An invested observer is most likely to be interested in the outcome of an activity.*

**Regulators.** *This group has been separated from invested observers and approvers to indicate their separate regulatory function.*

**Approvers.** *We assume that there is an independent group of approvers who should know the details of particular hardware or specific operational procedures so that they can make an informed independent assessment of operational plans.*

**Operation's management.** *This is the group of suitable qualified and experience people (SQEP) who should be expected to know the details of particular hardware and specific operational procedures with oversight of operations.*

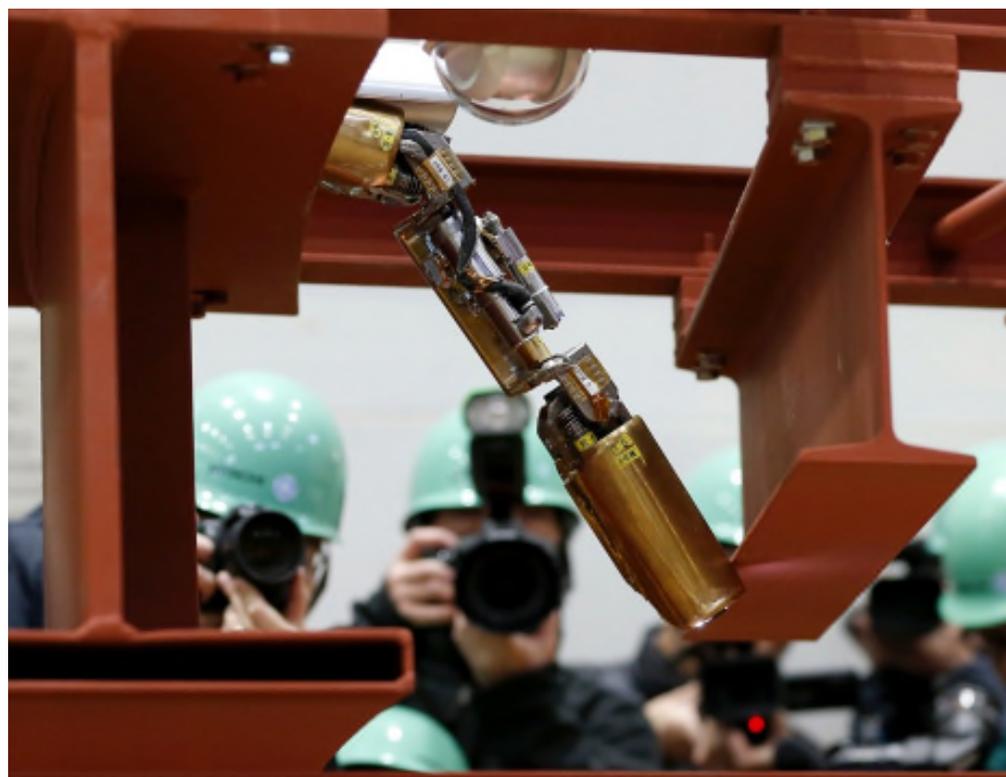
**Operators.** *This is the group of SQEP who should be expected to know the details of particular hardware and specific operational procedures and be able to operate the hardware.*

**Developers.** *This includes the original equipment design team and developers involved in modification, upgrade and ancillary system developments.*

# The Purpose of Mock-Ups

## Stakeholder engagement

- Approval of complex high risk projects such as fuel debris retrieval at 1-F require authorisation at high levels from financial, political and regulatory stakeholders.
- Physical demonstration communicates the completeness and thoroughness of a solution succinctly and accessibly in a way that complex paper studies will find difficult to match.



# Mock-Up Types

**Functional mock-ups** seek to test the functionality of the system or sub-systems

- Usually shorter term
- Replicates only immediate interfaces
- Usually used in earlier project phases
- Used by development team for focused technology and design development

**Environmental - operational mock-ups** seek to replicate the environment in which a system will work

- Usually longer term
- Replicates wider environment
- Usually used in later project phases to support operations
- Used by a wide range of stakeholders for demonstration, validation and training
- Allows broad investigation including unintended consequences and human factors



# The Purpose of Mock-Ups

## Integrating operators

- Build confidence in an uncertain environment
- Identify where operator uncertainty occurs and test mitigations
- Identify and improve specific usability issues
- Identify and prevent operator 'work arounds'



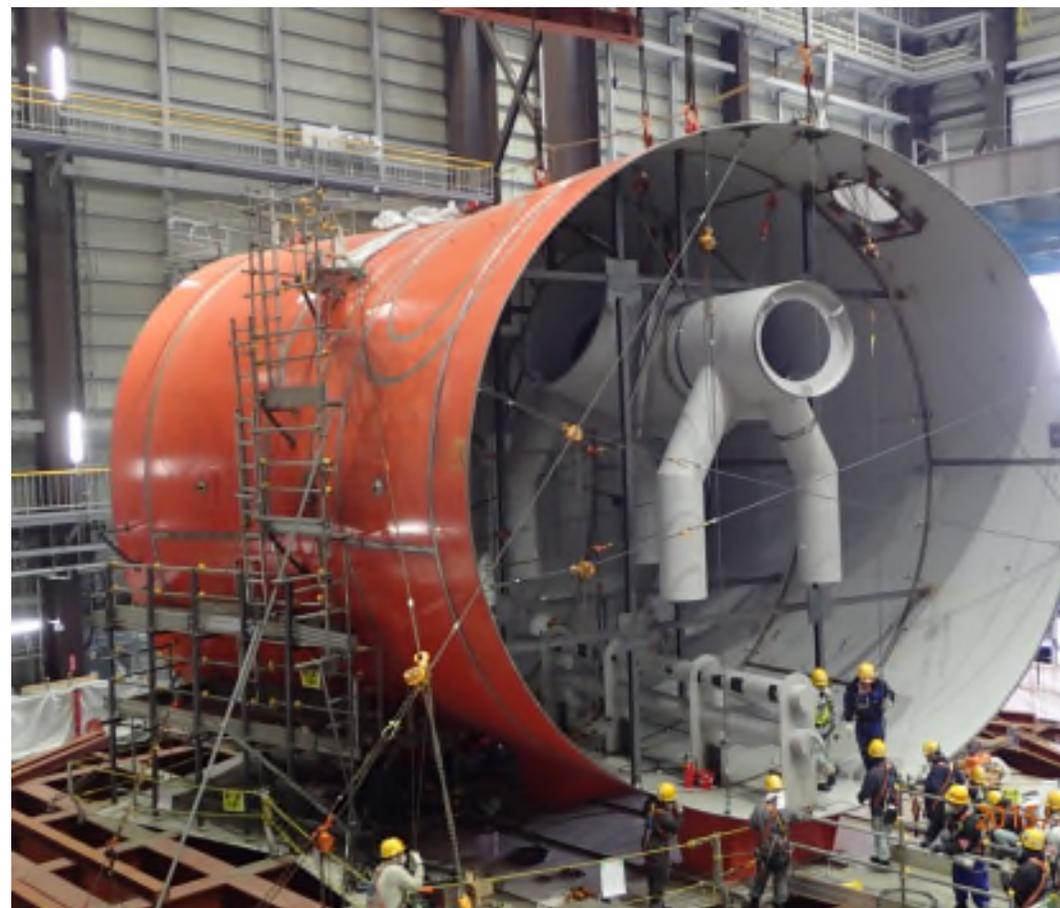
# The Purpose of Mock-Ups

## Unknown unknowns

The 1F PCVs will present a large number of unknowns and uncertainties

Mock-ups play a significant role in reducing these as well as understanding and improving collective reactions and responses

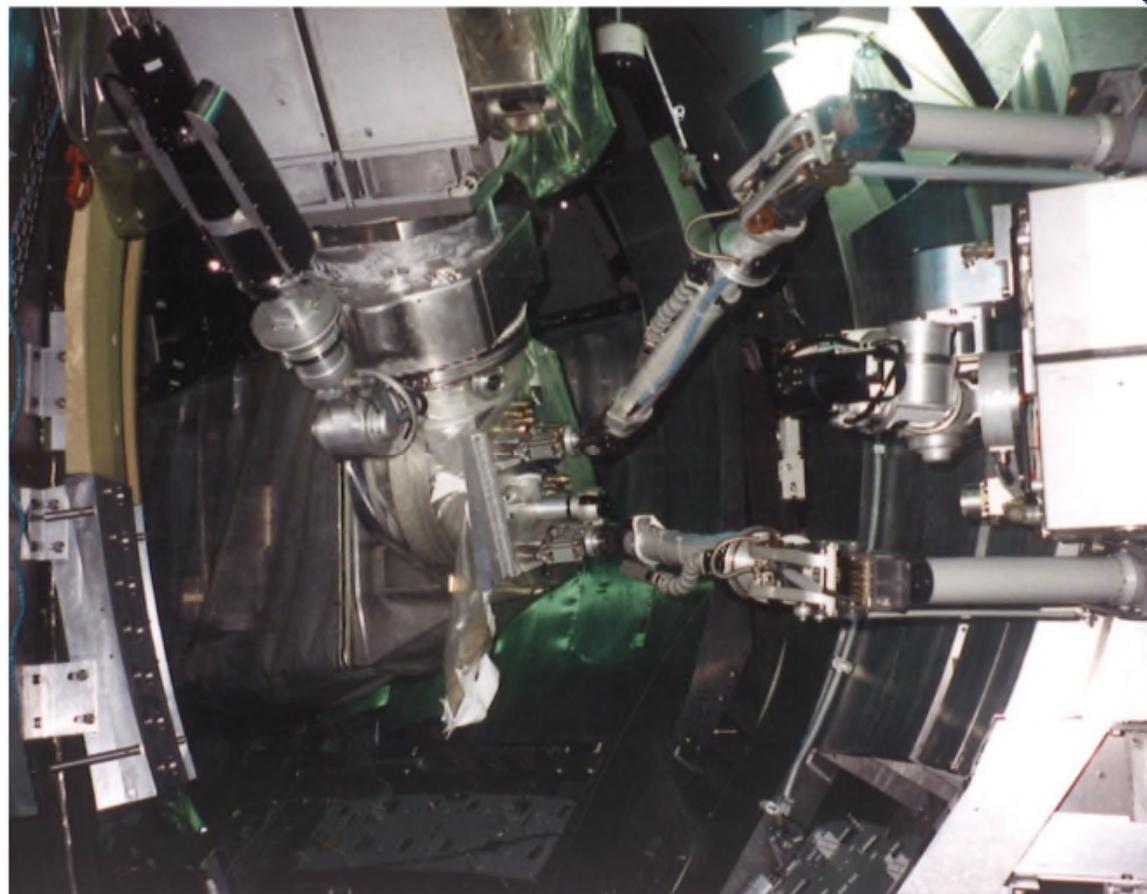
- Known Unknowns
  - Identify failure modes
  - Practice and develop recovery and rescue sequences
- Unknown Unknowns
  - Intentionally introduced anomalies allow testing of operator response
  - Capture first try 'failure'
  - Unknown unknown process



# The Purpose of Mock-Ups

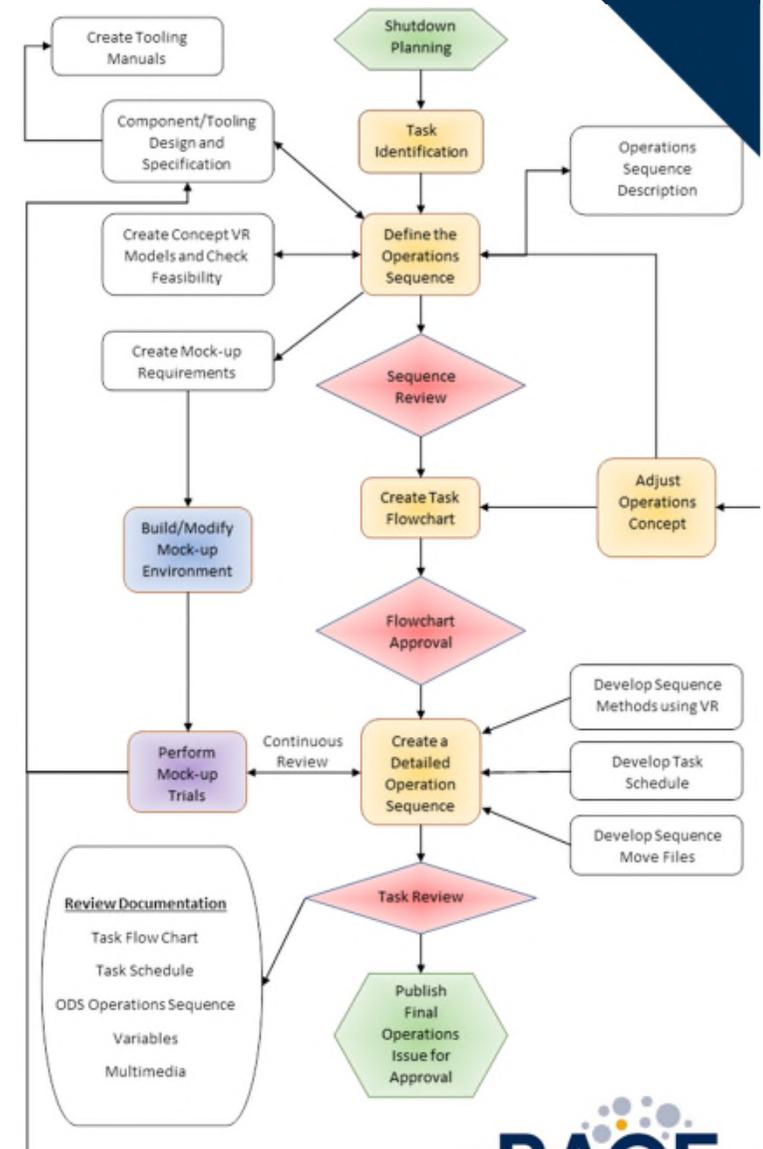
## Recovery from failure

- Extensive trialling of all identified failure scenarios occurs within IVTF
- Testing of tools which have the inherent risk of becoming attached to the environment or stranded is vital
- Although 1F's reactors are already inoperable, unrecoverable equipment increases the waste inventory, incurs cost, and potentially hinders further operations
- 'Getting out is more important than getting in'



# Making Mock-Ups Work

- Have and maintain clear objectives
  - A structured, risk-based approach should be used to determine objectives.
  - Use of mock-ups should be results led, flexible and agile since intermediate results may require changes.
  - It is important to match the real operations schedule and facility schedule.
  - A lower resolution output at the right time may be better than an exact answer that is too late.
  - Let objectives dictate structure, depth and materials
- Location
  - To build shared confidence accessibility of a particular stakeholder may be important:
  - Functional tests close to developer
  - Long term operational test and development close to operator



# Clean and Contaminated Systems

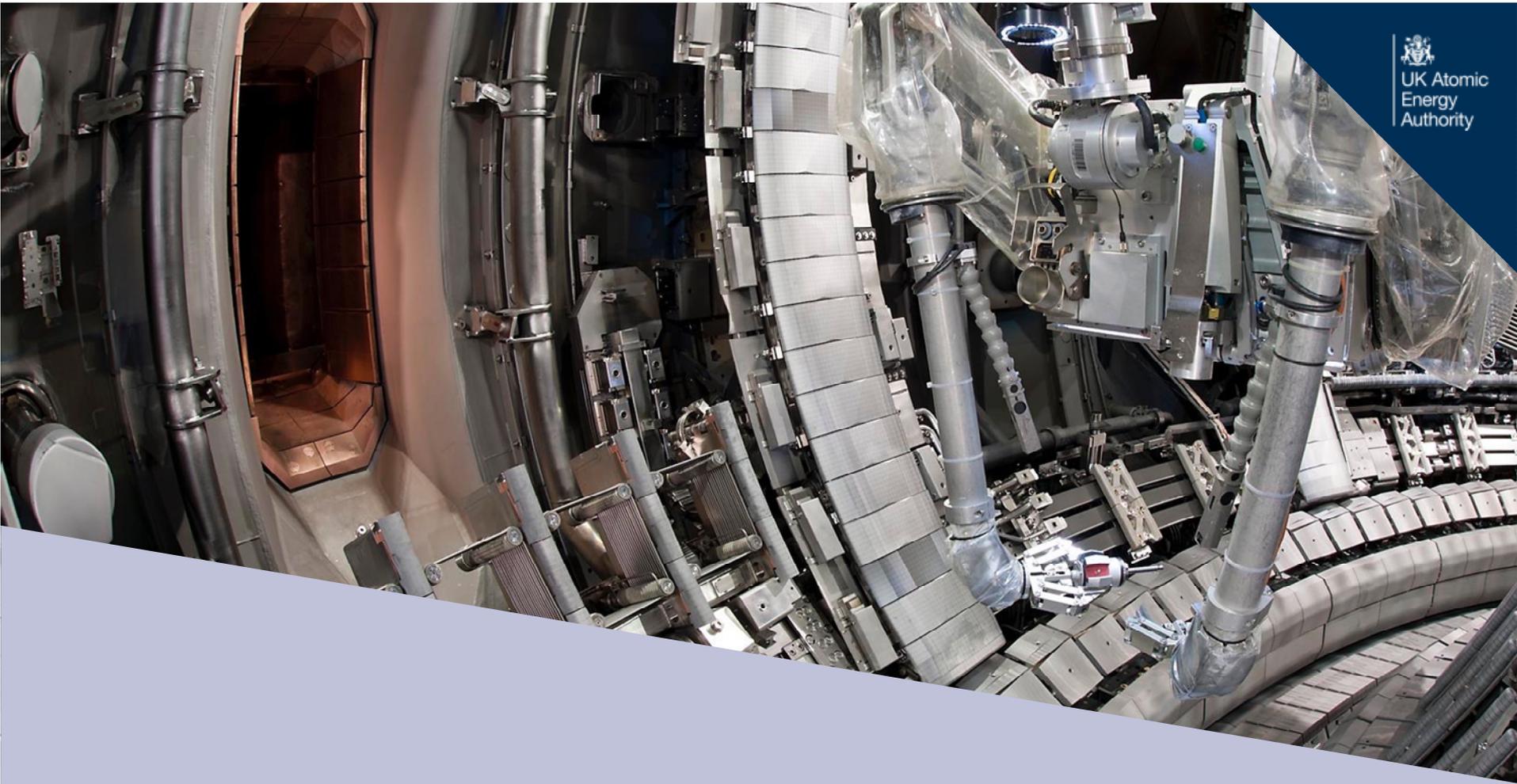
- At JET the actual equipment can be used for training in the IVTF mock-up due to the low level of contamination
- At Fukushima the equipment is likely to become highly contaminated
  - Equipment will need to be maintained, checked and re-validated and this may mean moving equipment from the reactor to a separate facility
  - If operations equipment is not available for training, additional systems will be needed
  - Simulators may provide an alternative for some elements of the training
- As a minimum, there is a need for four activities:
  - Assembly and test of clean machines, including stores and workshops
  - Testing of clean machines within mock-ups
  - Maintenance of contaminated machines, including stores and workshops
  - Testing of contaminated machines
- Each of these spaces will need to be managed and maintained, ideally by the same team

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# Summary

Long term physical mock-ups enable efficient response to changes in through-life operational requirements. Mock-ups enable hardware to be improved and skills to be enhanced and maintained.

First interventions into the 1F reactors will be hard to approve because the unknown-unknowns mean that it will not be possible to mitigate all the risks. In this context, the principle purpose of early physical mock-ups is to build shared stakeholder confidence that enables a collective decision to start.



**Thanks for listening!**

**Any questions?**