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VIPER Virtual Integration Platform for Engineering & Remote Handling

A testbed for Fusion devices components validation under ALARA requirement

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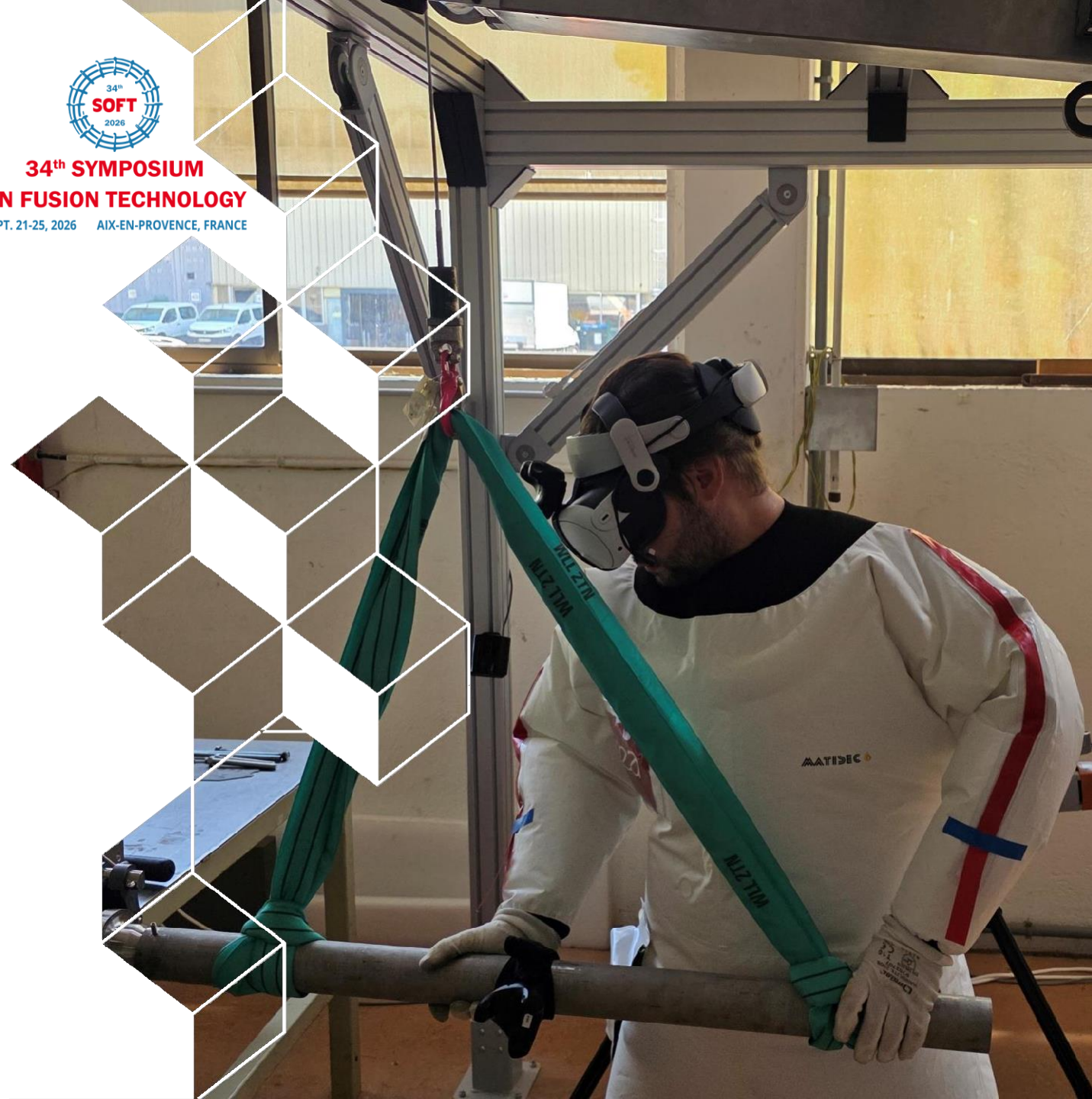
34th SYMPOSIUM ON FUSION TECHNOLOGY
SEPT. 21-25, 2026 AIX-EN-PROVENCE, FRANCE



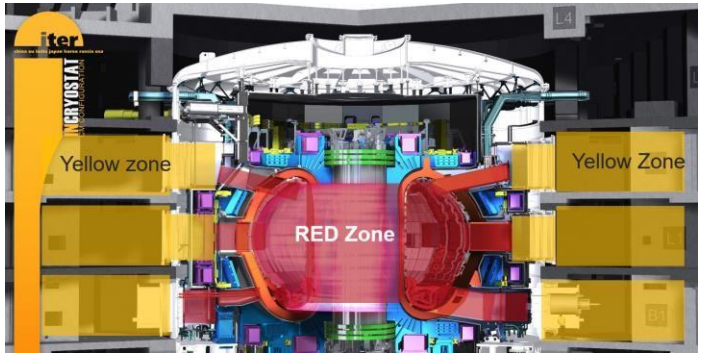
VIPER - A testbed for Fusion devices components validation under ALARA requirement

1. **ALARA and the VIPER Platform**
2. **Virtual Engineering Workflow**
3. **Experimental Verification & Validation program : ITER TBM use case**
4. **Perspectives and Conclusions**

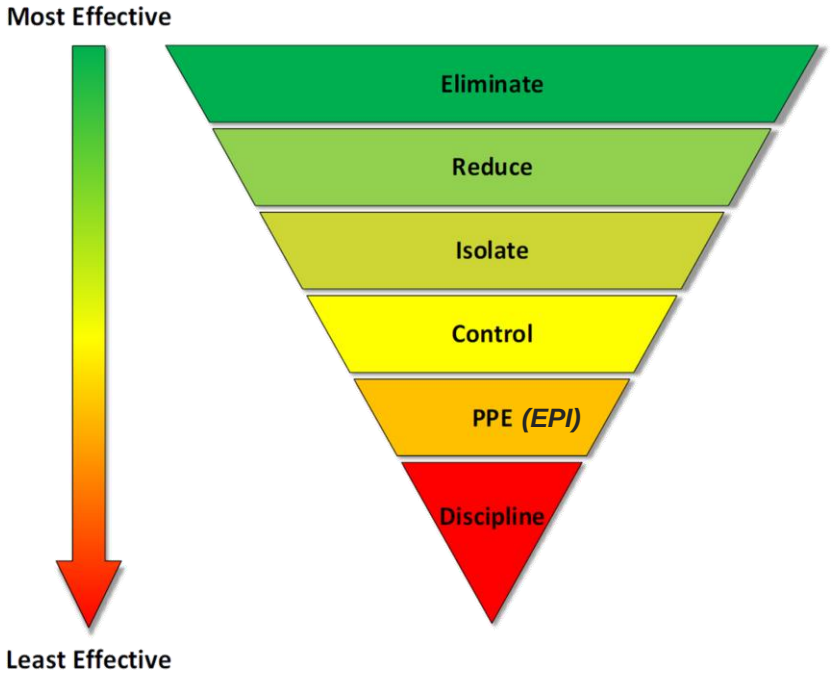
1. ALARA & the VIPER Platform

The ALARA Process: Dose Reduction Measure

- Reduce the Operator Dose **As Low As Reasonably Achievable** at early stage in the Design Process
  - Reduce the physical strain of the job
  - Streamline Operations (Avoid rework)
  - Improve workplace conditions (access, posture, assistance...)



"Robots"
+
Exposed workers





→ Poster BO-068 (23/09) FRICONNEAU J-P : System engineering approach for Tokamak component replacement under ALARA requirement: ITER TBM case

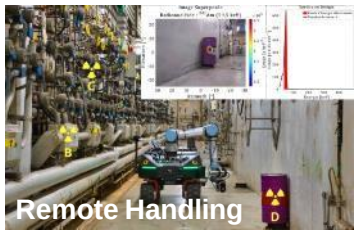
CEA Lab cluster in Fusion Technology integration



cea irfm



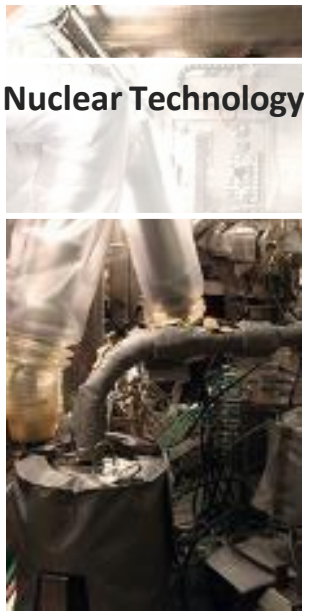
cea list





Model-Based Engineering





cea iresne

LECA STAR



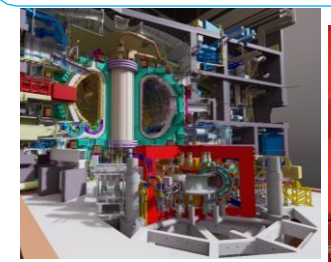
cea isec

maestral
science in sealing





VIPER – Virtual Integration Platform for Engineering & Remote Handling

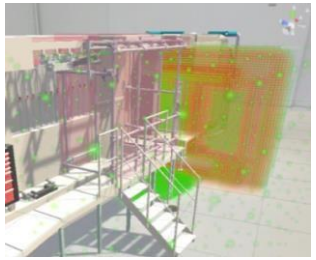




- Workflow CAD-XR-MBSE
- Digital Mock-Up validity check
- Data configuration management
- Digital Twin

- Human Factors
- Simulation of manual operations
- Sequence

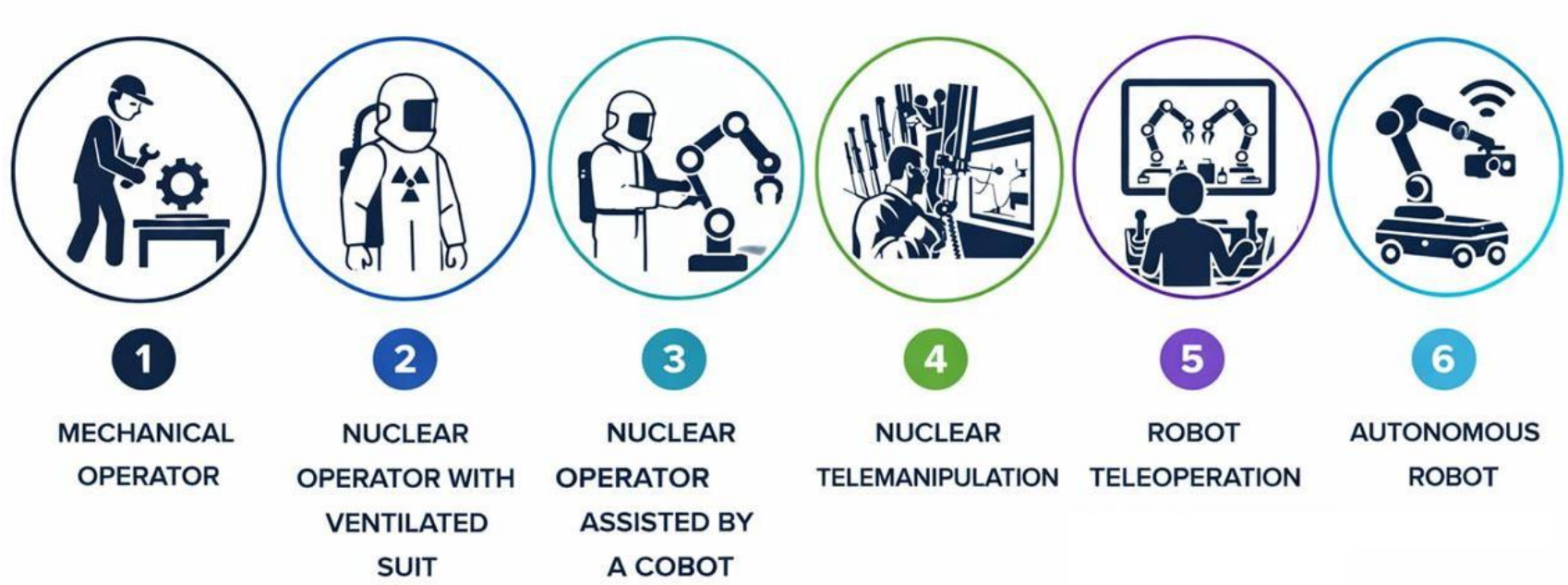




- Robotic operations
- Remote Handling
- Verification & Validation

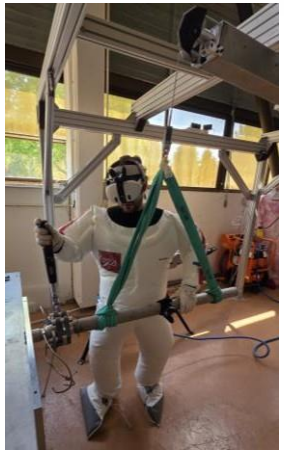
- Nuclear Engineering
- Dose calculation & visualisation
- Air Fed Suit

The ALARA Gradient: From Operator to Autonomous Robot















2. Virtual Engineering Workflow

From CAD to Operational Validation

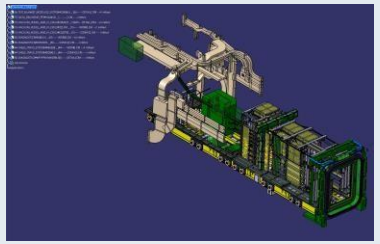
Digital Continuity

Consistent data and information flow across the engineering lifecycle

CAD Design

CAD Model
Digital mock-up & metadata

DB
metadata



Storage (SROT)

Database
Postgresql

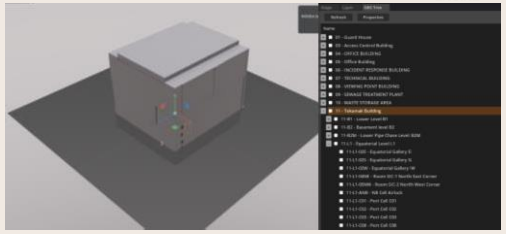
External storage
OpenUSD layers
Step files
(Sysml files)

API

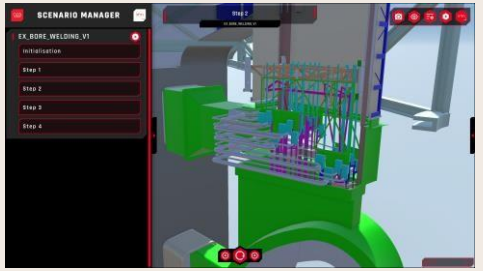
Integration

NVIDIA OMNIVERSE · unity · UNREAL ENGINE

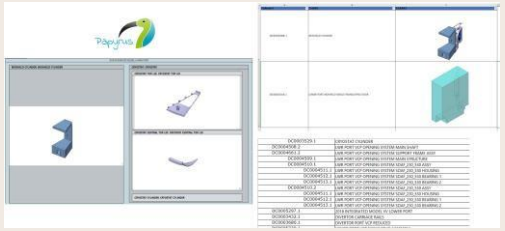
Digital twin
3D Viewer
PLM Extension
HMI Interface



4D Viewer (S4D)
Scenario Management



MBSE
SysML v2 graphical representation of operations



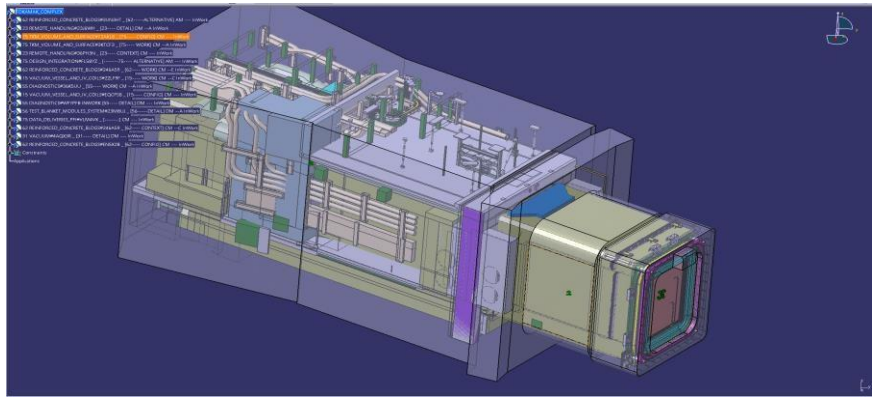
API

Application

Simulations
Clash Analysis
Accessibility
Human factors
Robotic
Dose management
…

Digital Continuity application to Sequence Analysis

- **Automated workflow** for structured data base creation, preserving **data sovereignty**
- **Metadata management** : preserves hierarchy, components, interfaces & traceability across the workflow
- Connection with digital models : links **CAD & MBSE** environments to VIPER's simulation tools
- New standards under investigation :
  - **OpenUSD** (Universal Scene Description by Pixar) : layers system
  - **SysML v2** (INCOSE) : strengthens link between system models and operational scenarios
- **S4D application**: built on the platform's 4-D viewer, dedicated tool for defining and managing sequences



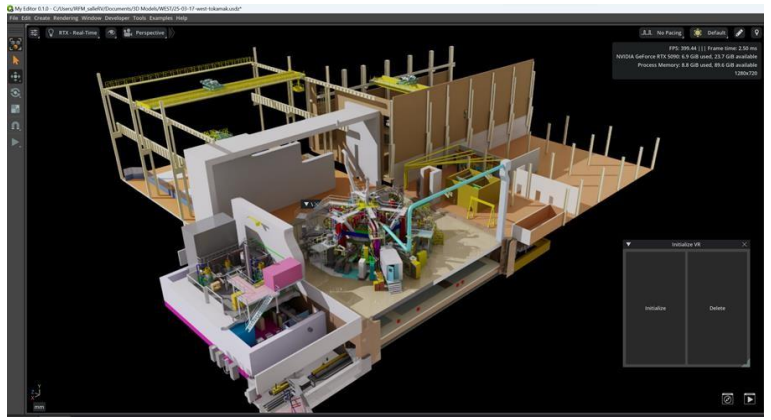


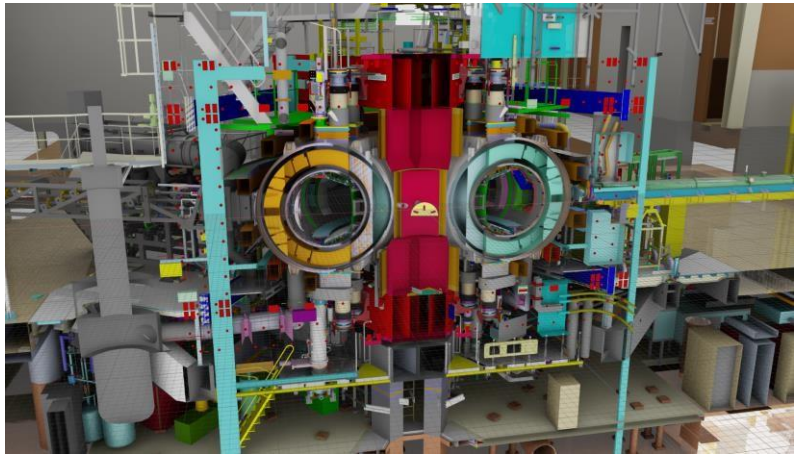
→ Poster BO-067 (23/09) HUC K. : 4D Viewer: An Interactive and Immersive Application for the Visualization of Technical Sequences in Fusion Engineering

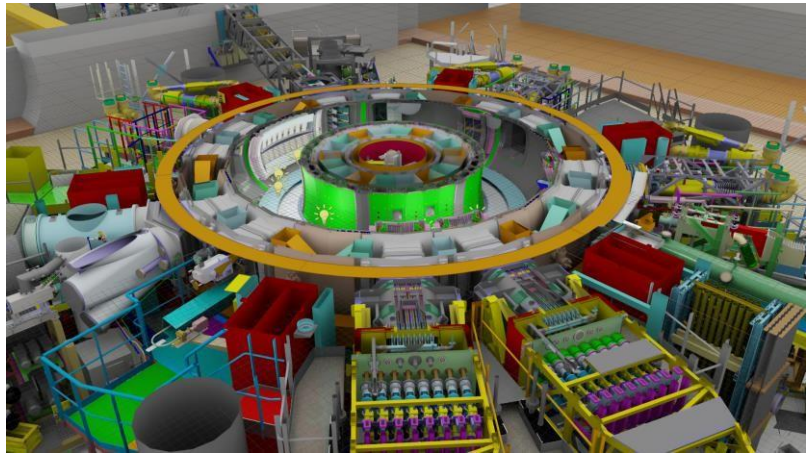
Open USD as a new standard for simulation

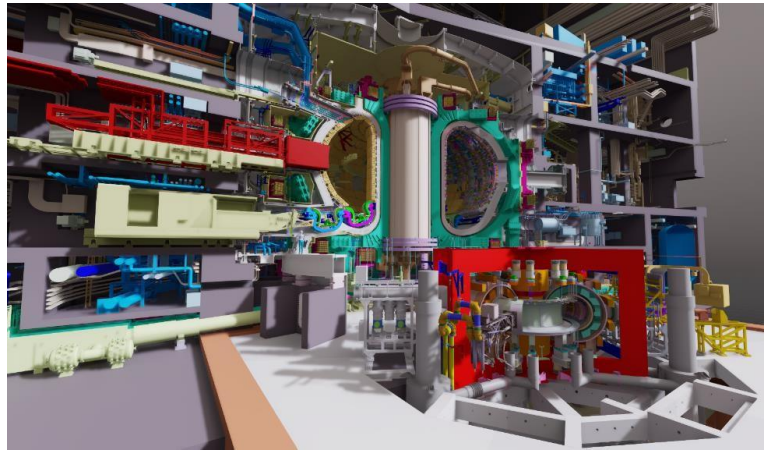
- Visualization of the **complete WEST tokamak model** :
  - Tesselated 3D model with 300M polygons & 300k parts (Creo PVZ)
  - **USD (Universal Scene Description)** conversion workflow
  - Computer with RTX 5090 & 128 Go RAM

    => 400 FPs Desktop & 50 FPS in Virtual Reality
  - Additional features : Cutting planes, measurements …





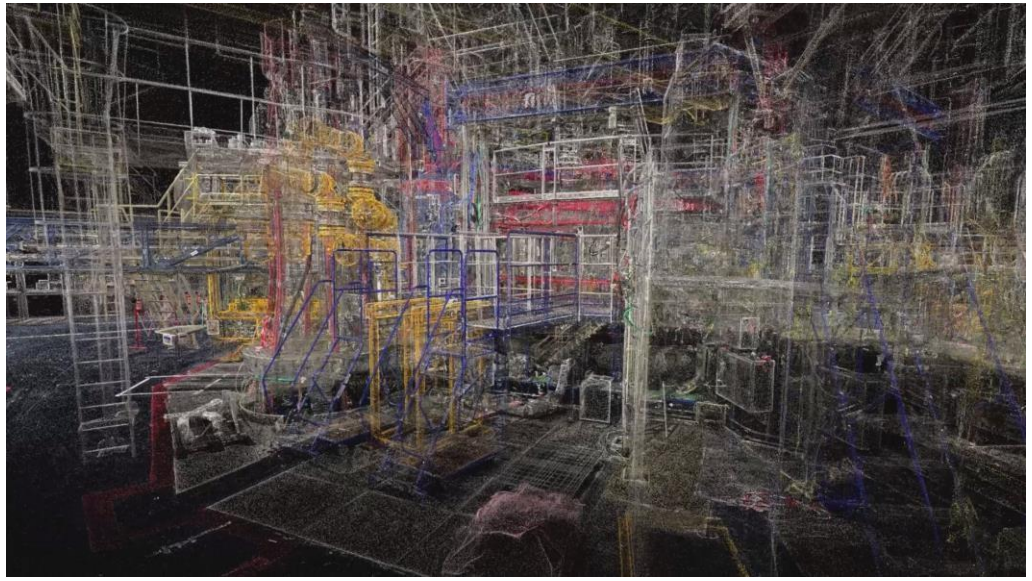


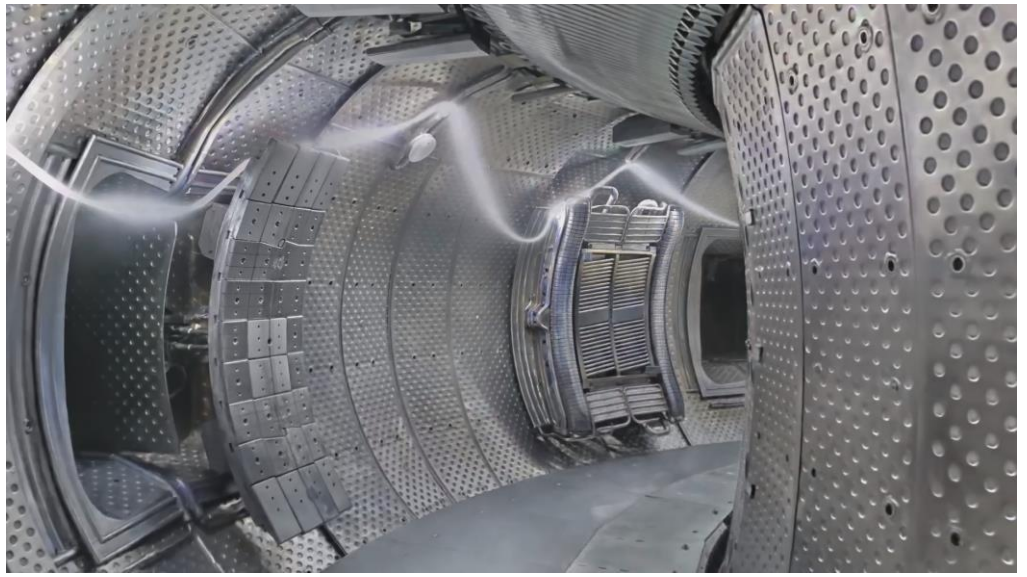


Immersive Access to the WEST Tokamak

- Virtual WalkThrough simulation of the WEST Tokamak
  - Photorealistic rendering with **Gaussian Splatting** scan https://repo-sam.inria.fr/fungraph/3d-gaussian-splatting/
  - Accuracy under 1cm
  - Speed of deployment : 1 hour to Scan the inside of the tokamak + few hours of AI post processing
  - ➢ **Accessibility of the WEST last configuration even during Plasma Campaign**
- On site Augmented Reality alternative method using Apple IPAD with LIDAR



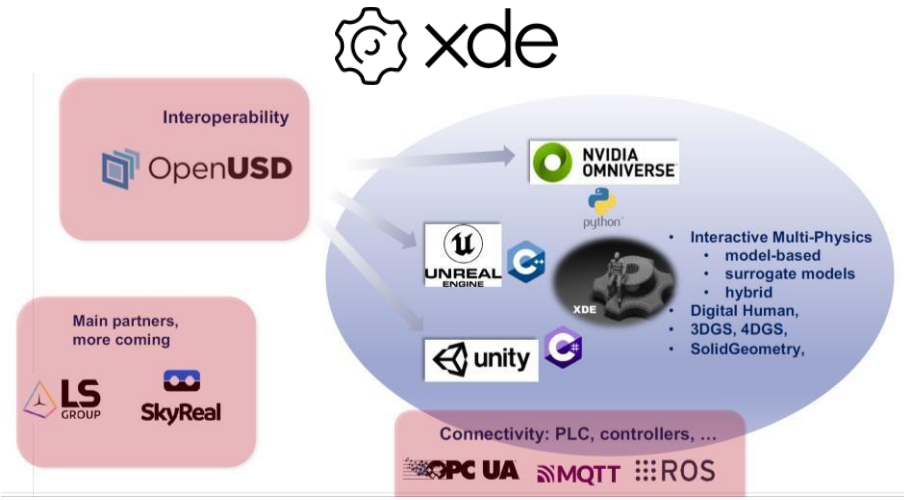




Mechanical Physics Integration into simulation

Physics-based simulation extends visualization to realistic interaction between components, tools & operators

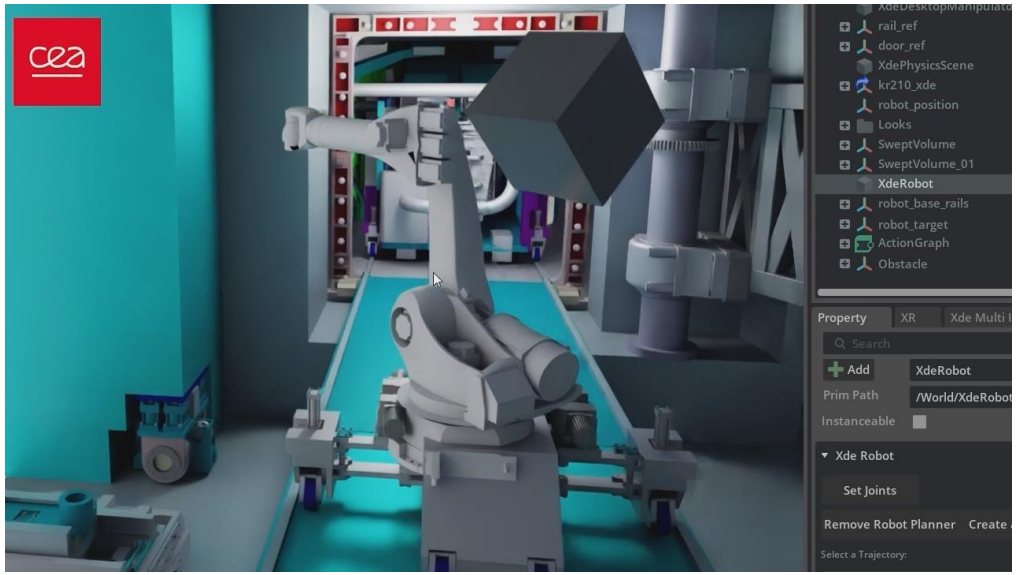
- **Integration & Feasibility** : Clash detection, trajectory definition
- **Human factors** : posture, reachability, task duration
  - ➢ workplace improvement & ALARA optimization



XDE Physics Engine developed by cea list

Core Capabilities :

- **Geometry** : Swept Volume, Boolean Operations, Minimale distance, Mesh cut, Intersection …
- **Physics** : Joints, Collision, Gravity, Velocity & damping, cable, pipes, …
- **Robot** : Motion Planning …
- **Assembly** : scenario management
- **Human** : Virtual Immersion, Puppet
- **Ergo** : Posture analysis, RULA score
- **AI integration** (MCP servers, prompt interface & skills integration …)

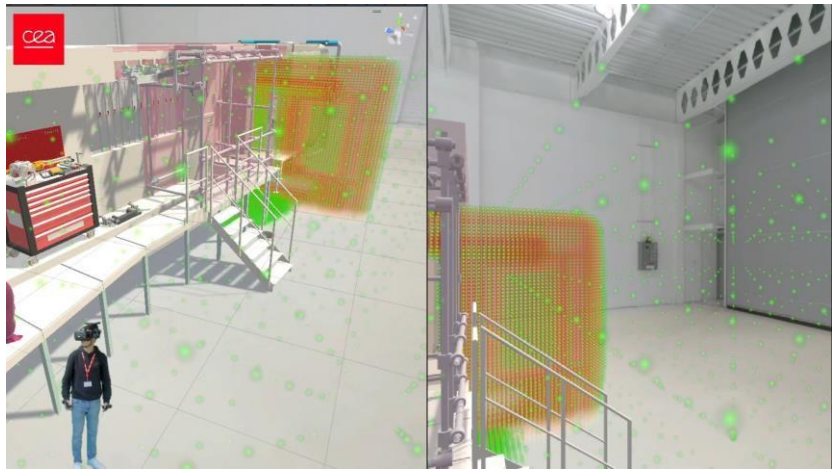


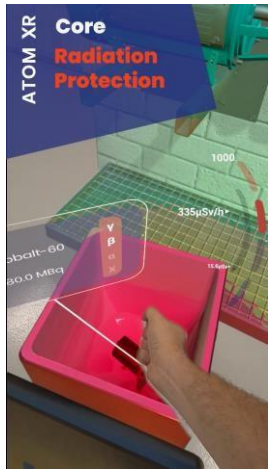
Dose integration into simulation

*Extending VIPER toward operator **dose assessment**, in support of the **ALARA** principle*

- **Visualization & integration** of previous calculated dosimetry
- **Real-time calculation** (0.1 to 1s) of the dose rate

F. ROSSI : PhD thesis "Modelling and ALARA optimization of maintenance operations in fusion nuclear power plants with Artificial Intelligence and Virtual Reality techniques"



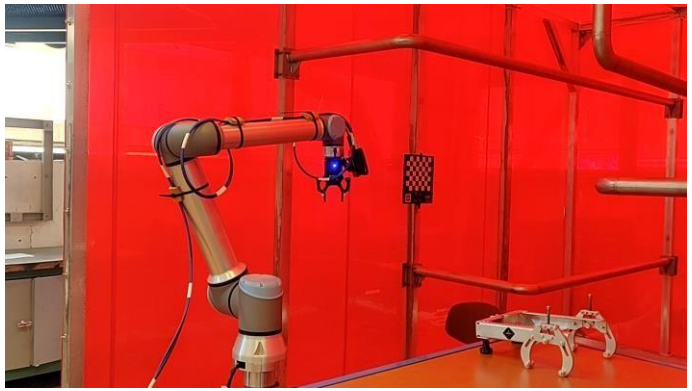


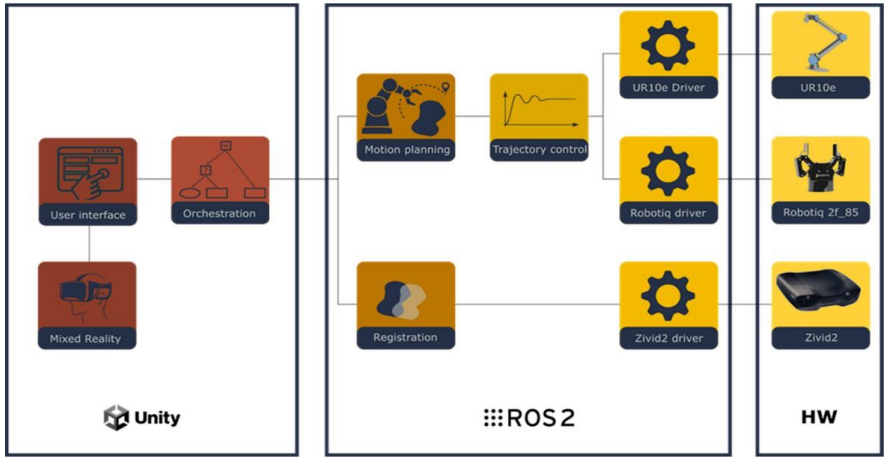
- **CEA SpinOf - AtomXR** : https://atomxr.fr/
  - New Real Time AI Radiation Protection engine
  - Radiological Digital Twin Connected with Sensors
  - XR Stand Alone application



Remote Handling Simulation tools

- **Autonomous robotic** systems equipped with vision-based perception, moving toward self-learning solutions for nuclear environments
- **Definition of a Unified ROS2-based architecture for heterogeneous robotic systems in fusion Remote Handling & inspection (Collaboration with UKAEA Race)**
- **Application to AIA (WEST remote in vessel in service inspection supervision system)**







→ Poster BO-075 (23/09) BUSSON D. : Towards a unified ROS2-based architecture for heterogeneous robotic systems in fusion remote handling and inspection applications

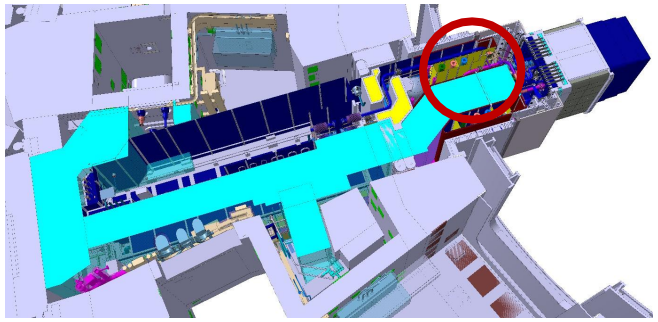
3. Experimental Verification & Validation program : ITER TBM

Experimental program applied to TBM use case

- **Verification & Validation** for installation/removal of piping in context by means of **Scale 1 Mock-Up**, tooling, ventilated suits and eXtended Reality (XR)

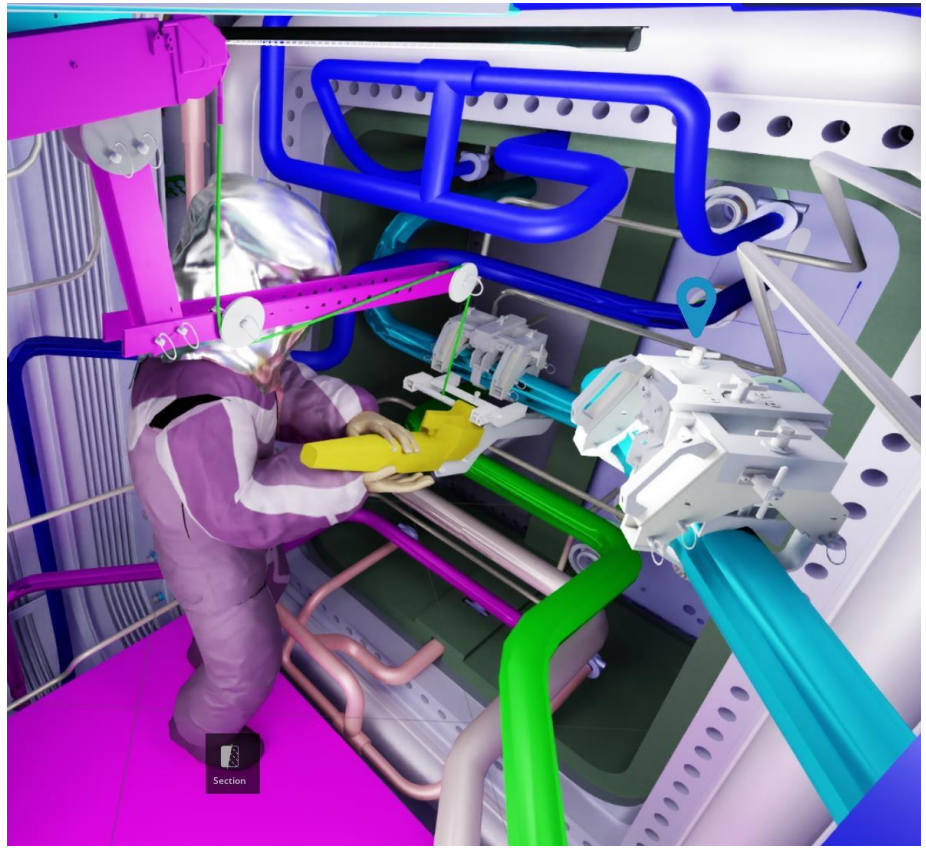
- Application to standard operations :
  - Handling
  - Cutting
  - Welding
  - Sealed connection*
  - Pipe insulation

*→ * Poster BO-067 (21/09) AYMARD Antoine : Performance assessment of a QDS sealing junction for the ITER Test Blanket Module Helium Cooling System*



PC#16 TBM

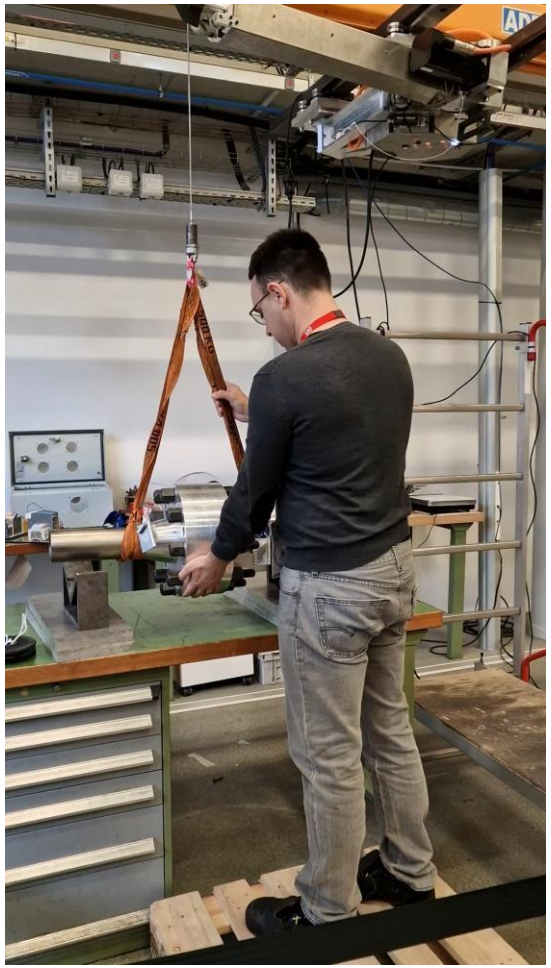
Physical mock-up of a compact lifting device with force control and automatic load weighing, designed by **CEA LIST** to enable effortless manipulation **SMARTCRANE**



Operator wearing **MRV5 T-VISION*** ventilated suits to simulate maintenance operations in confined ITER areas



Comparing Operator Configurations Under ALARA

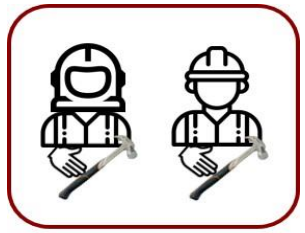








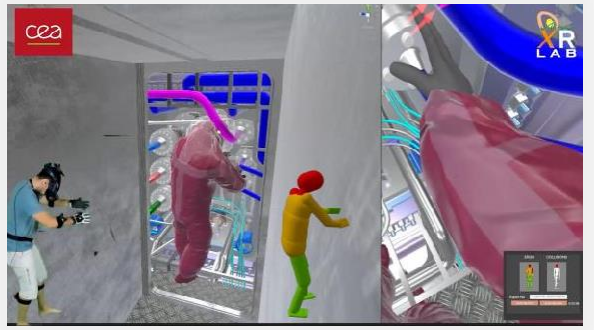
ITER use case - IO TBM PDR Meeting – July 26



Manual
(with / without diver suit)

Initial approach was ‘fully manual’

- *Ensure man access*
- *Integrate clearance to handle components and tools*





Co-manipulation

Current design approach is “Hands-on assisted”

- *Limit the operator exposure*
- *Assistance for handling*





Remote handling
with assistance

Future perspective : ‘fully remote’ ?

- *Pipe cutting and welding*
- *Flanges assembly and disassembly*





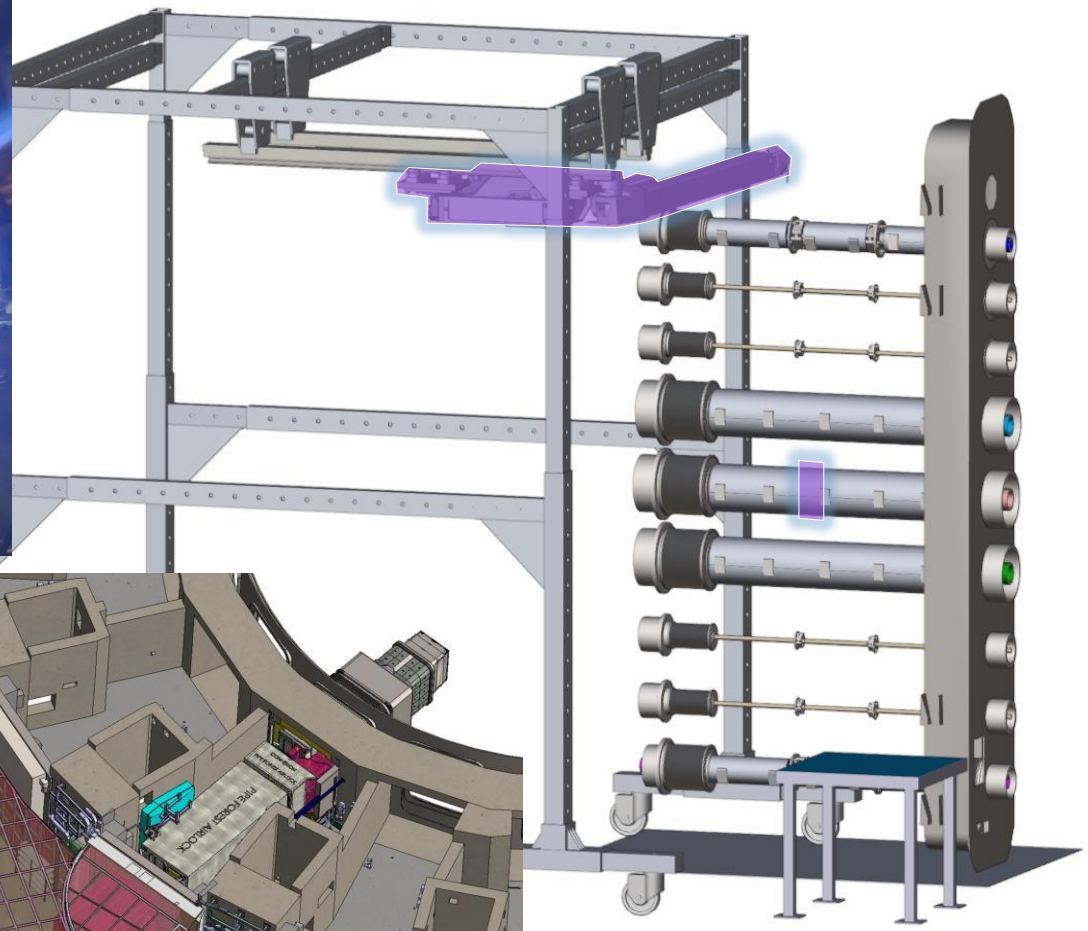
https://doi.org/10.1016/j.fusengdes.2023.113425

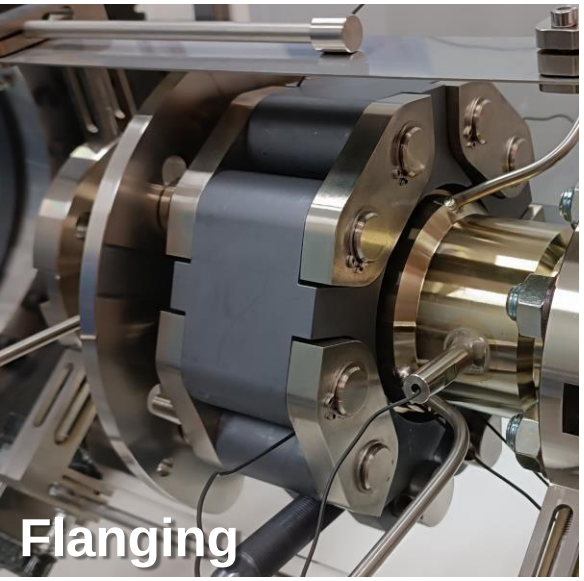
OPEN POINTS / LOOK AHEAD – Installation and Replacement

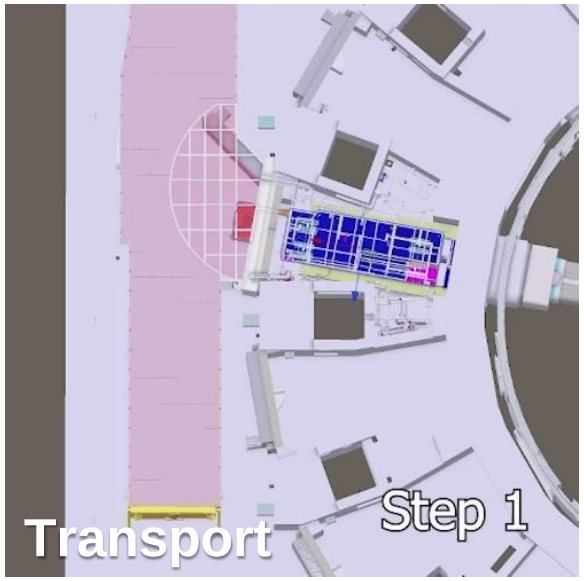




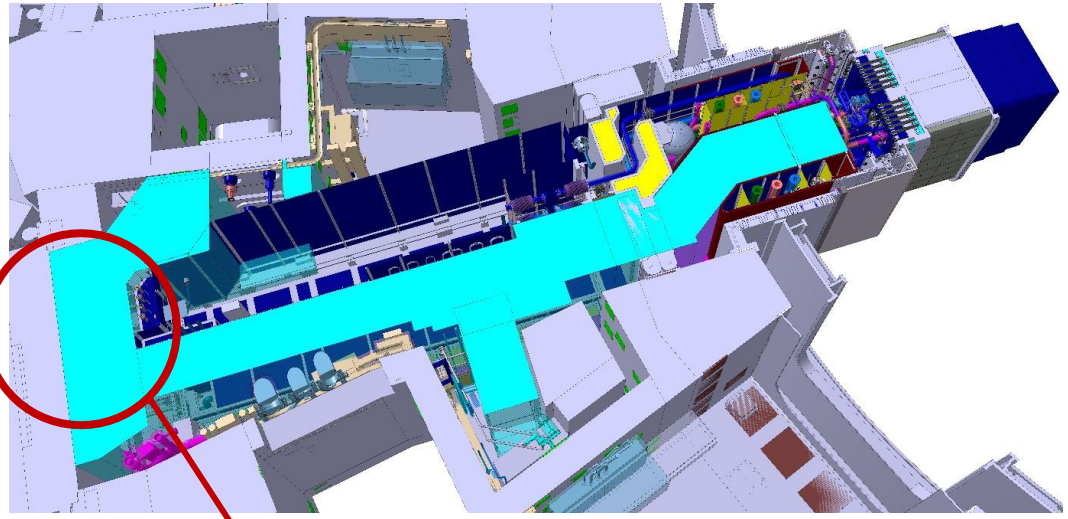








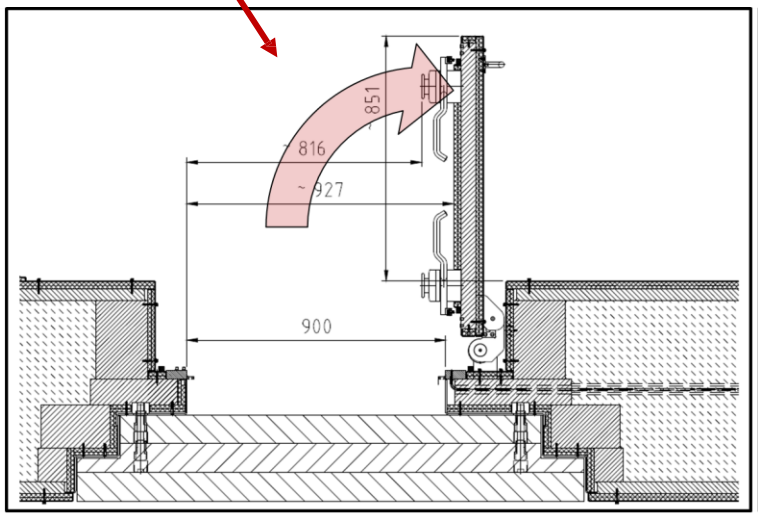




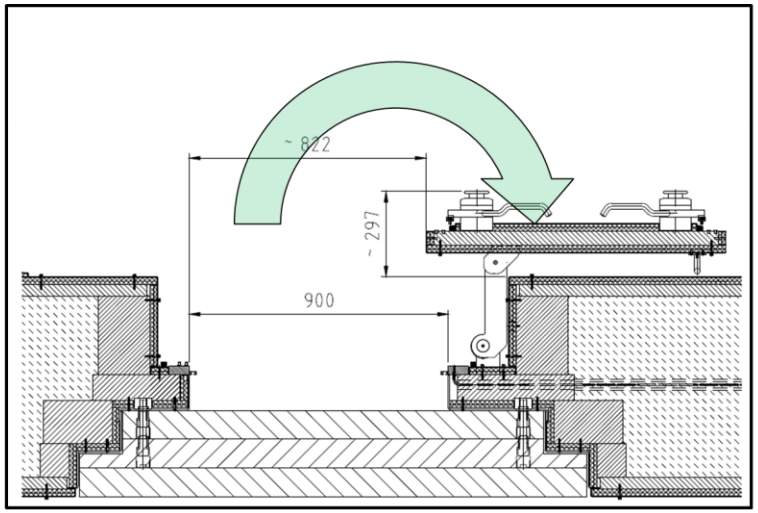
Project change request : **Increase Personnel Access Door opening angle for maintenance in Port Cells**





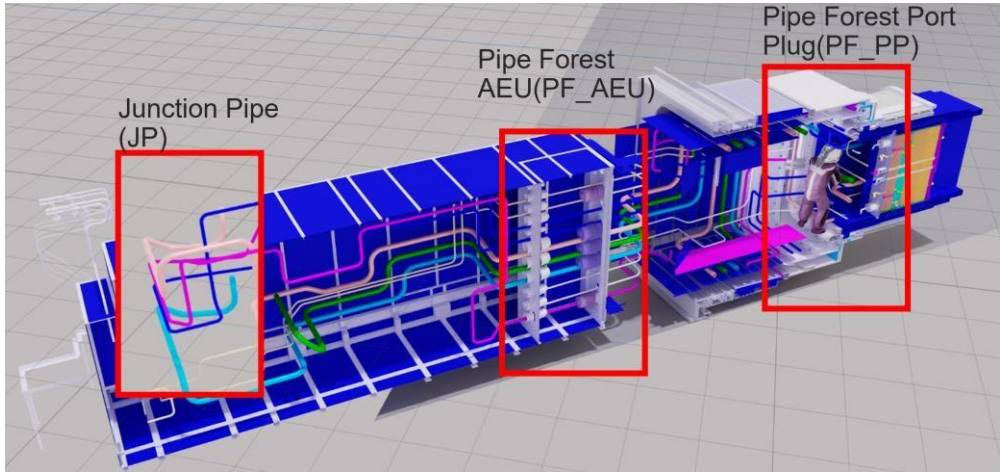


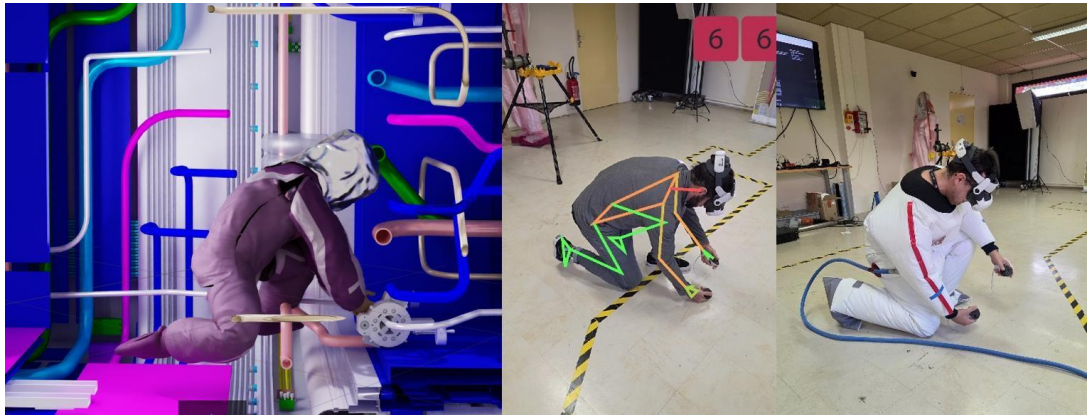
Current configuration 90°

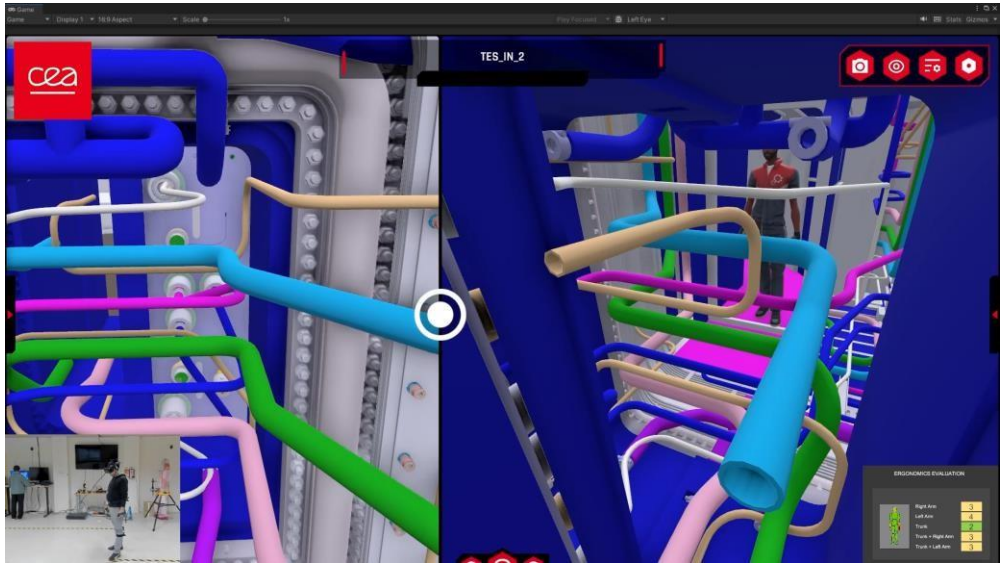


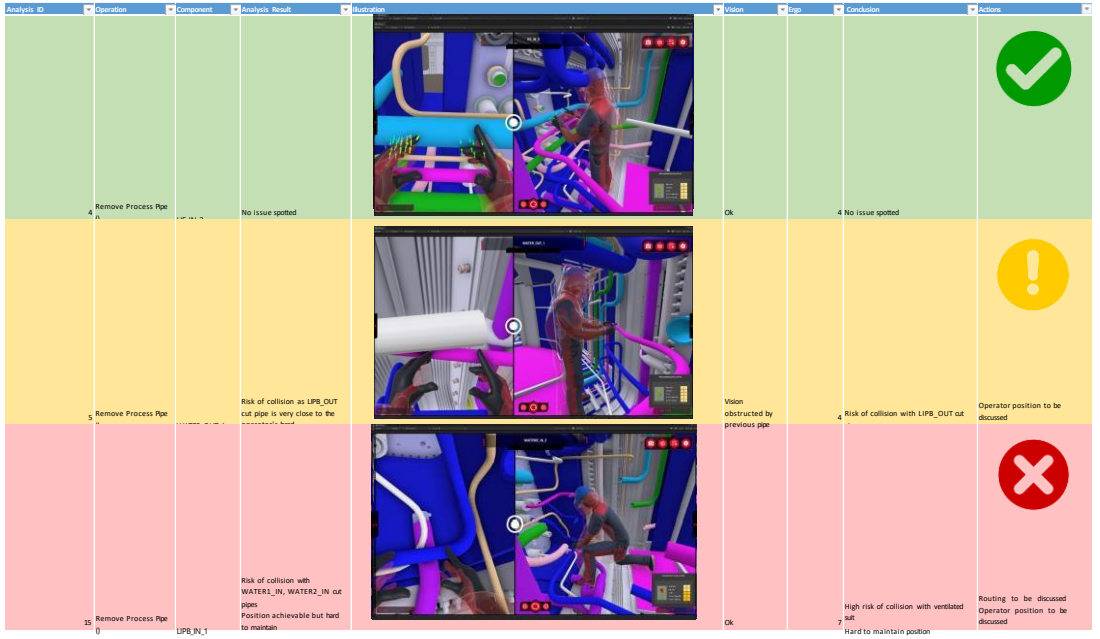
Proposed configuration 180°

ITER TBM Portcell 16
Human access and tools validation



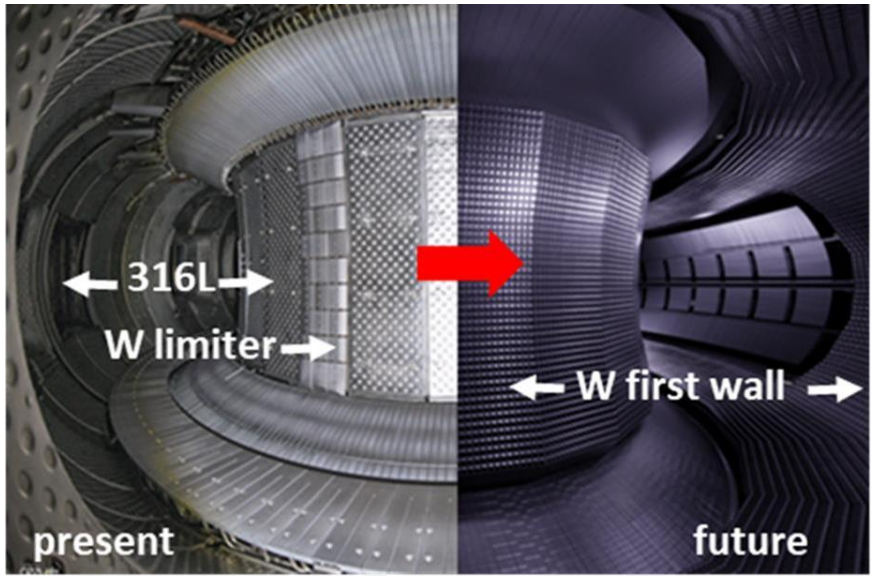






4. Perspectives & Conclusions

Next Steps



Extend tools & methodology to other applications :

- **WEST Phase III :** New Full Tungsten First Wall
- **Dismantling** operations
- **Fully remote** intervention

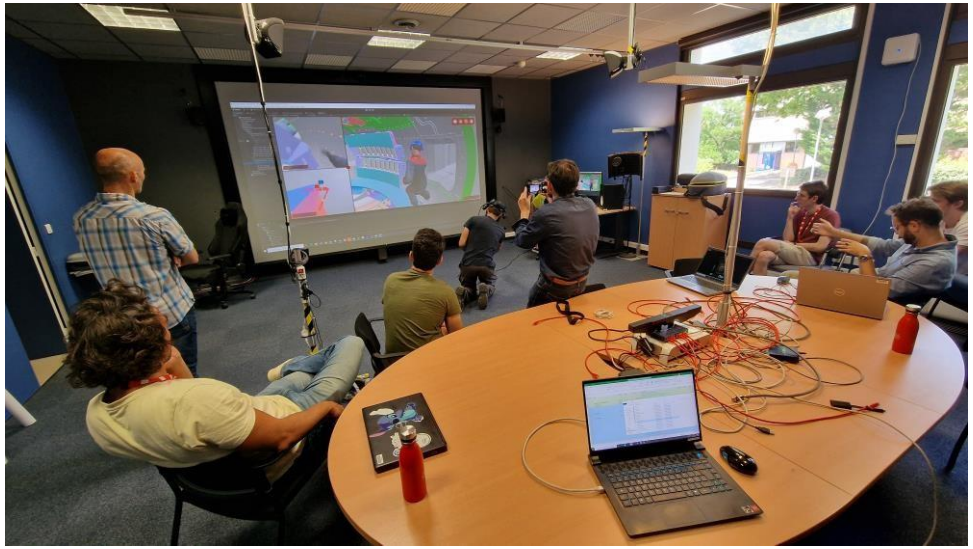
Strengthening the platform :

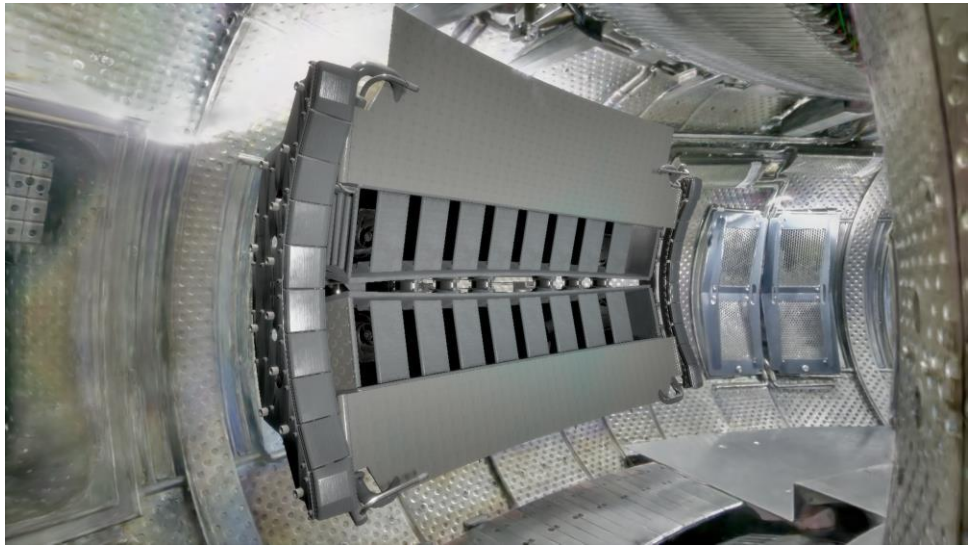
- Extend **digital interoperability** (AI-assisted engineering, autonomous workflows)
- **Integrate Dose assessment** → close the loop on ALARA compliance directly within design & validation phases

WEST TWA antenna (project) integration studies

- Full-scale, one-to-one **immersive virtual design reviews** at VIPER platform
  - **Clash detection** analysis
  - **Accessibility** tests for mechanical assembly (verification of clearance for parts and tools)
  - Testing of **assembly** and collision scenarios with the vacuum vessel
- Augmented Reality simulation inside WEST Tokamak
- Integration in the WEST virtual visit in Gaussian Splatting

→ Poster S1-021 (24/09)
HILLAIRET J. : Final design of the WEST ion cyclotron travelling wave heating system





Summary

- **VIPER** is an integrated digital engineering platform that supports the entire lifecycle of Fusion component including **design validation**, **integration**, **maintenance** & **remote handling**.

- **Real-time, high-fidelity simulation :** combines physics, ergonomics, and immersive rendering to reproduce accurately operator conditions
- **Experimental validation program :** Early validation of design choices (human factors, accessibility, and task feasibility) can be assessed before physical implementation
- **Remote handling & robotics :** Unified ROS2-based architecture applied to AIA robot in WEST with progressive path toward autonomous & intelligent systems for nuclear environments
- **Dose assessment integration** directly supports **ALARA compliance** from the earliest design stage

A foundation for future development : *the platform's extensibility positions it as a strong basis for further Fusion technology studies, from WEST to ITER and beyond*

To go further

- Virtual Visit of WEST Gaussian Splatting



- Android App WEST Facility with System vision



- Gazzotti & al. Ventilated immersive suit for interactive & operative nuclear operations (VISION) applied to ITER test blanket modules, Fusion Engineering and Design, 2025, https://doi.org/10.1016/j.fusengdes.2025.114889
- Gazzotti & al. Virtual Integration Platform for Engineering and Remote Handling (VIPER), *IEEE Transactions on Plasma Science*, 2026, https://doi.org/10.1109/TPS.2026.3700733
- C. D. Paolo et al., "Methodology for Applying Extended Reality Simulations for ITER Design and Hands-On Interventions Verification," in IEEE Transactions on Plasma Science, doi: http://dx.doi.org/10.1109/TPS.2024.3435355

- Poster at SOFT 2026 :
  - *AYMARD Antoine : Performance assessment of a QDS sealing junction for the ITER Test Blanket Module Helium Cooling System (BO-067 21/09)*
  - *HUC Killian : 4D Viewer: An Interactive and Immersive Application for the Visualization of Technical Sequences in Fusion Engineering (BO-067 – 23/09)*
  - *BUSSON David : Towards a unified ROS2-based architecture for heterogeneous robotic systems in fusion remote handling and inspection applications (BO-075 – 23/09)*
  - *FRICONNEAU Jean-Pierre : System engineering approach for Tokamak component replacement under ALARA requirement: ITER TBM case (BO-068 – 23/09)*
  - *MIRAILLES Florian : Engineering based model for ECRH heating system integration (S1-033 24/09)*
  - *HILLAIRET J. : Final design of the WEST ion cyclotron travelling wave heating system (S1-021 – 24/09)*

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Thanks



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