THEMATIC WORKSHOP

Plant systems program ▪ Fuel Cycle Systems Status & future business opportunities

Christopher GRANT-WILSON
ITER Detritiation System Coordinator

He leads a team of engineers to design, procure and follow up the ongoing installation of the Atmosphere Detritiation System.

Biswanath SARKAR
ITER Technical Advisor

He is expert in superconducting magnets, cryogenics, fusion materials and other fusion related technologies, namely, Divertor and Blanket as well as fusion fuel cycle.

Josep BENET
F4E Head of Cryoplant & Fuel Cycle Program

He is skilled in managing large-scale projects, driving operational improvements.

Hadrien MONET
Amentum Chief Operating Officer

He has a strong project delivery experience both in the European Nuclear and Oil & Gas industries.

Chairperson:

Olivier Gastaldi
Tritiated Waste & Dismantling Program Manager
Deputy Director of CEA-AIF

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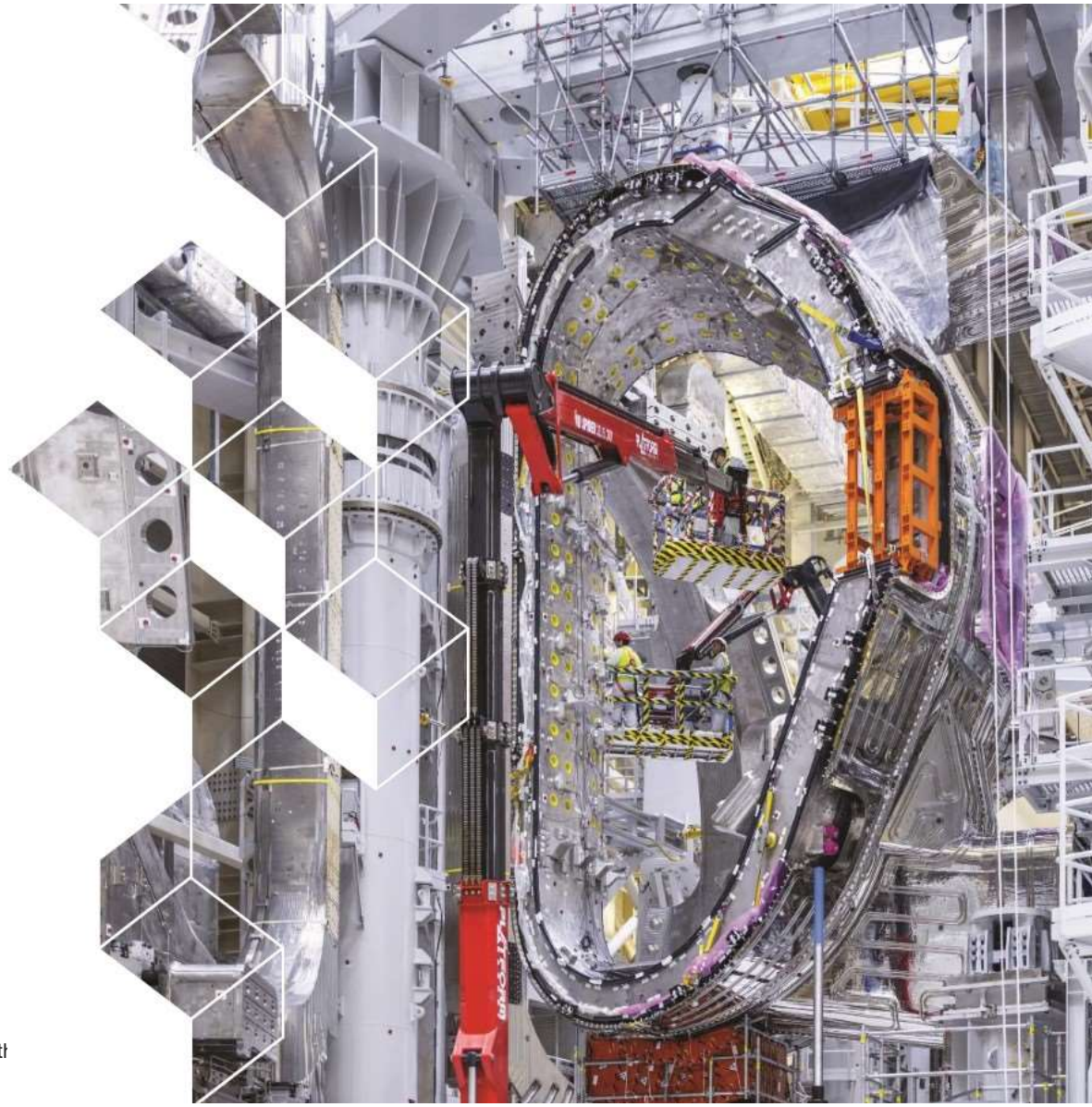
Plant System Program: Fuel Cycle

Biswanath Sarkar

Technical Advisor

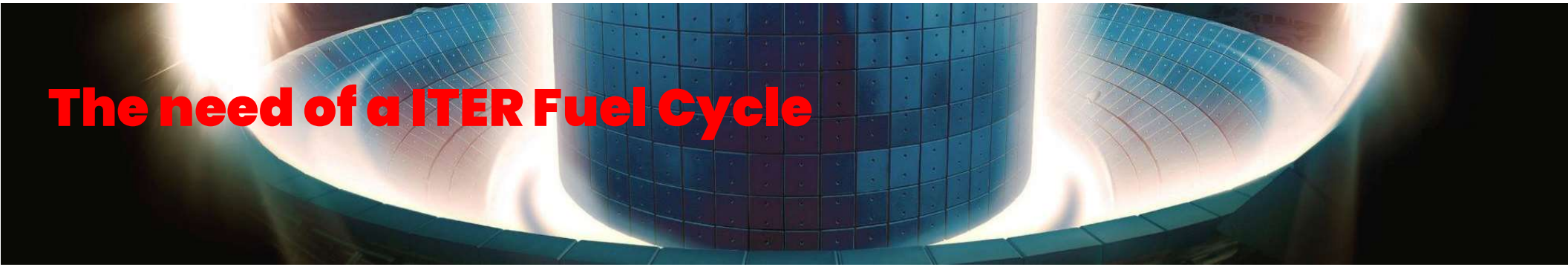


FRIDAY APRIL 25th

Outline of Session

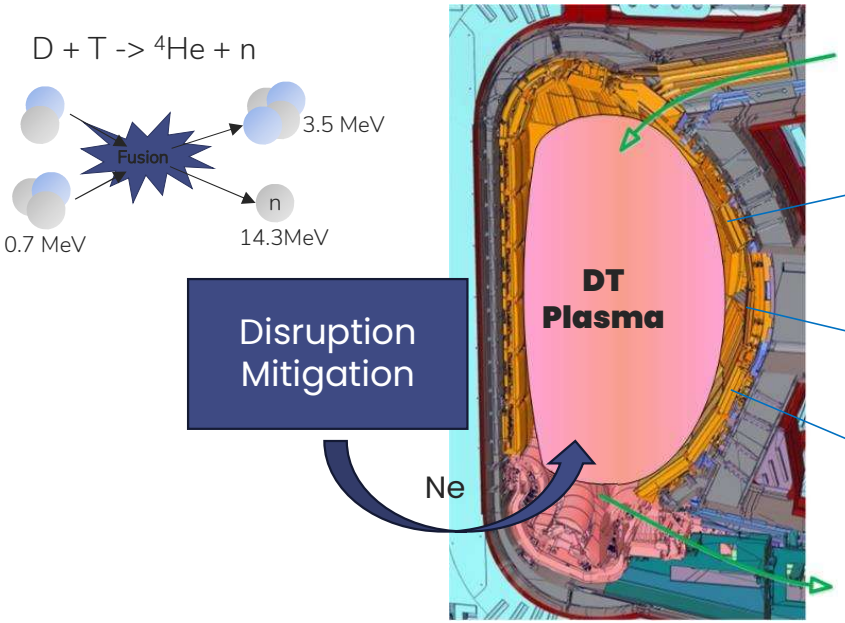
Session Chair: Olivier Gastaldi, CEA

1. **Introduction to the Fuel Cycle systems at ITER**
   Biswanath Sarkar, ITER Organization
2. **IO Project Status and Opportunities**
   Christopher Grant-Wilson and Jun Park, ITER Organization
3. **Working with ITER**
   Hadrien Monet, Amentum International
4. **F4E Project Status and Opportunities**
   Josep Benet, Fusion for Energy



The need of a ITER Fuel Cycle

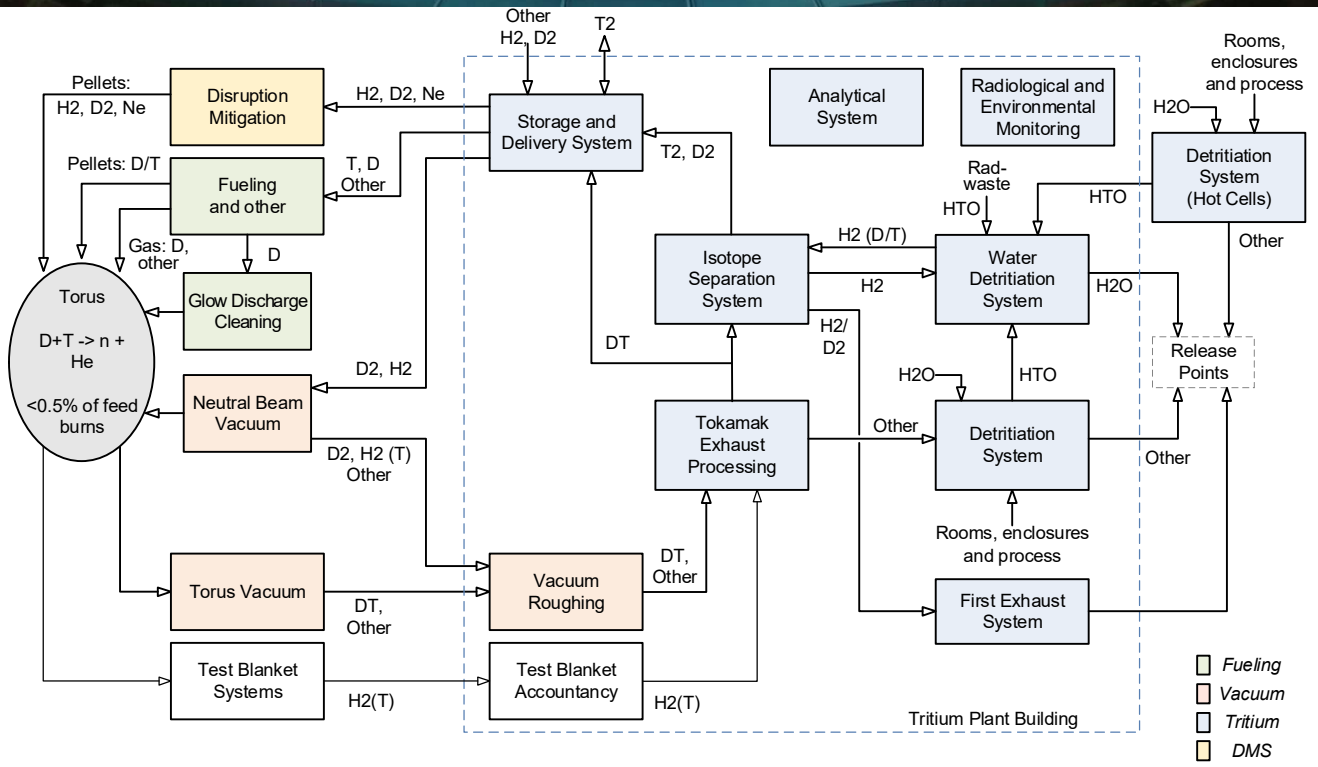
Characteristics of magnetic fusion



Technology needs

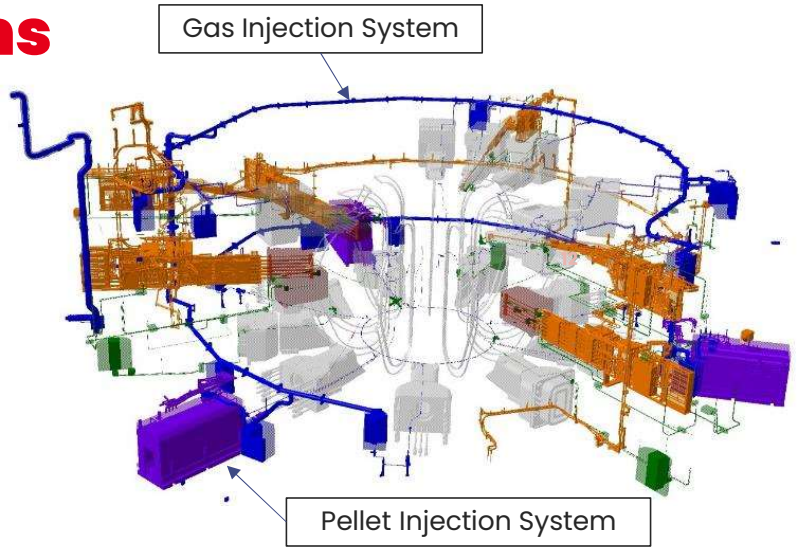
- **Magnetic plasma resists injection of replacement fuel** — ***Fuelling***
- **He "ash" and impurity build-up quenches fusion reaction** — ***Tritium Processing***
- **Tritium is radioactive and expensive**
- **Only a fraction (< 1%) of the fuel burns per pass** — **Means we need to *Cycle the fuel***
- **Vacuum must be maintained around plasma** — ***Vacuum***

Fuel Cycle Block Diagram



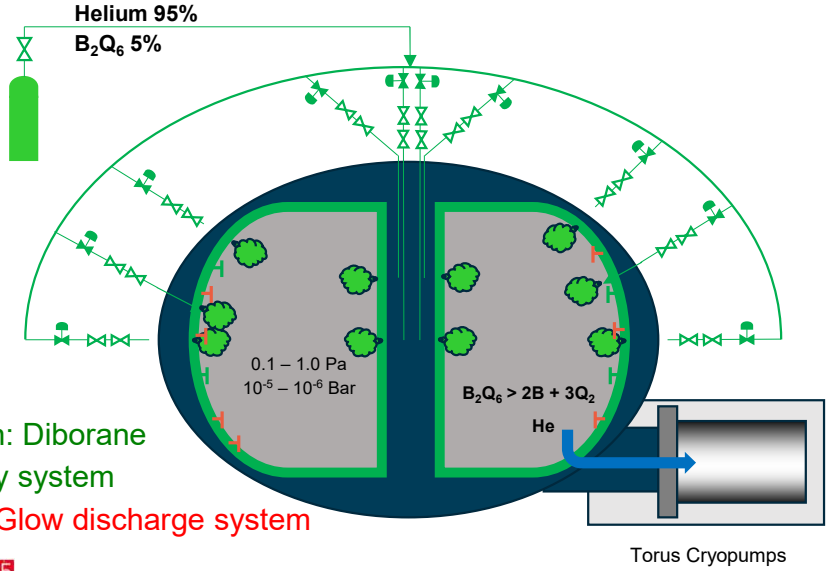
Fuelling and Wall Conditioning Systems

FWC System consists mainly of Gas Injection System and Pellet Injection System to provide fuel particles in the form of gas or cryogenic pellets for stable plasma operation. Boronization System is newly introduced system to deposit boron layer on the tungsten plasma facing wall, with glow discharge assist.



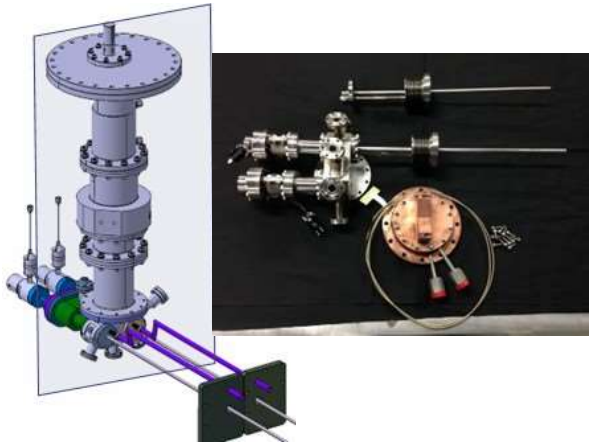
Boronization operation

Mixture of diborane and He gas is injected to the vacuum vessel through 21 injection points and crack to boron and Q_2 to deposit boron layer. He and remaining gas are exhausted through the Torus Cryopump and processed by the Tritium Plant.



Green: Diborane supply system

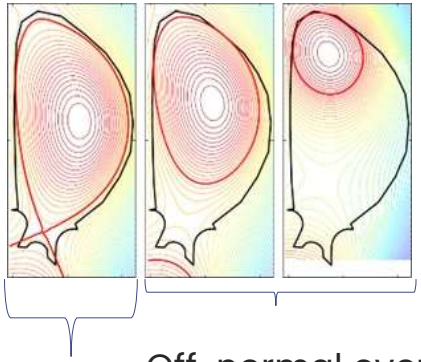
Red: Glow discharge system



Pellet Injector

Pellet Injectors continuously inject cryogenic pellets (H_2/D_2/T_2) into the vacuum vessel for plasma density and ELM frequency control, which are formed by the extruder and pneumatic gun system shown on left.

Disruption Mitigation System (DMS)

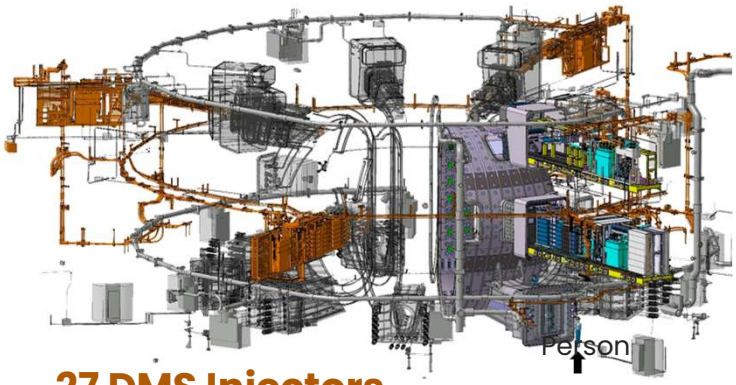


Normal Operation

Off-normal event on millisecond time scale

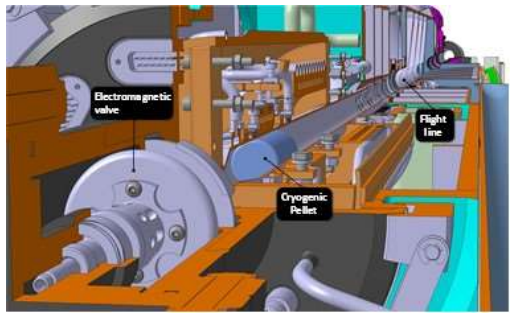
Disruptions, the fast accidental loss of plasma confinement and rapid release of plasma current and stored energy can reach around 1 GJ *combined and be release on a milliseconds time scale.*
This is a significant risk to the mechanical structures and the plasma facing components (PFC) of a reactor scale facility like ITER.

JET PFC
G.F. Matthews, Phys.Scr. 2016



27 DMS Injectors at ITER

- A set of 27 cryogenic pellet injectors equipped with fast electromagnetic valves are integrated around the ITER machine.
- Their purpose is to inject hydrogen and neon ice at 1800 km/h through a narrow flight line.
- This mitigate the detrimental effects of the disruption by “cooling” down and re-distributing the plasma energy milliseconds before an impact to the wall has occurred.
- From start to finish the mitigation system operates within 15 milliseconds
- This time includes disruption detection, processing, triggering and pellet delivery



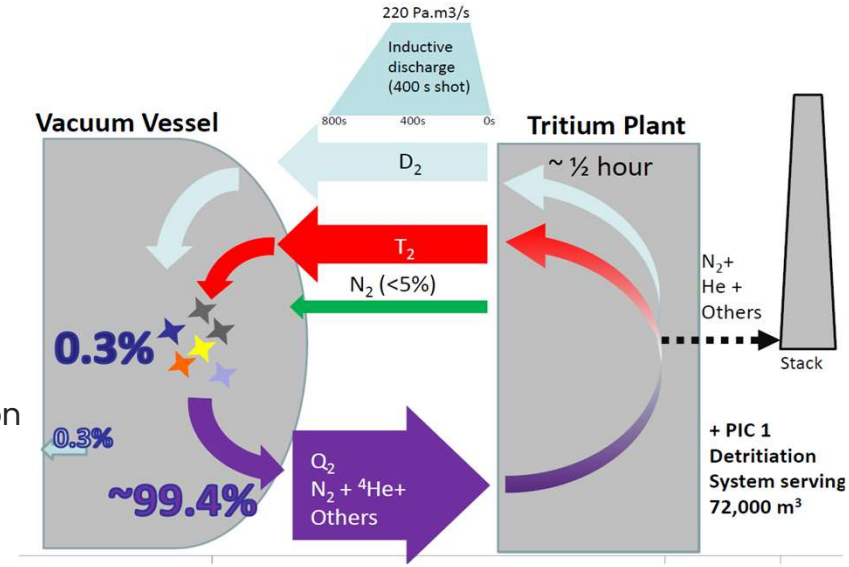
Tritium Plant Systems

For the first time in history, the ITER Tritium Plant will demonstrate:

- A complete fusion fuel cycle that is able to be run in a continuous steady state,
- Receive tritium bred in blanket modules and;
- Recycle tritium from water arising from fugitive emissions and incidents/accidents.

The ITER Tritium Plant will be one of the largest facilities for processing and handling tritium in the world.

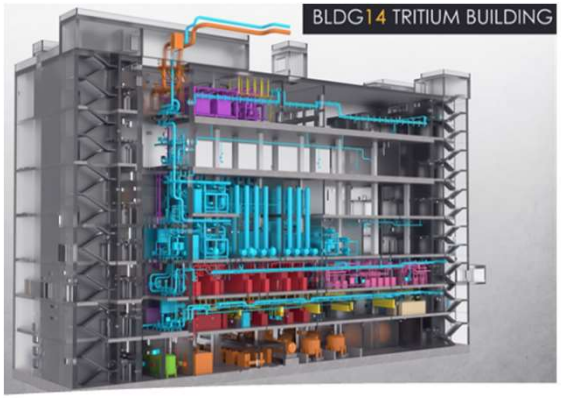
A state-of-the-art modern day nuclear safety qualified atmospheric detritiation system will also be demonstrated serving the Tokamak Complex and Hot Cell.



A typical Fuel Cycle scenario requiring recycling by the Tritium Plant in 30 minutes

Additional functions include:

- Serving Neutral Beams (D2/H2)
- Post processing of unused Diborane from Boronization
- Tritium receipt, storage and inventory management
- Non-active gas supplies
- Radiological and Environmental Monitoring systems



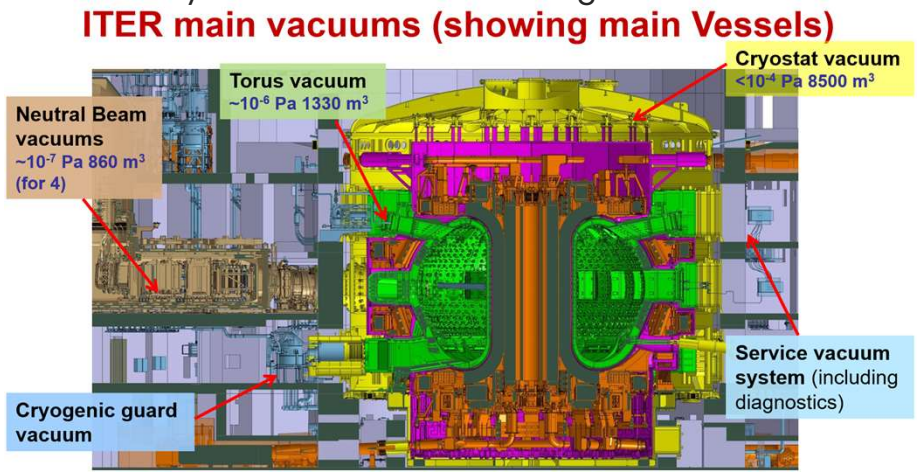
ITER Talks (11): The Tritium Plant

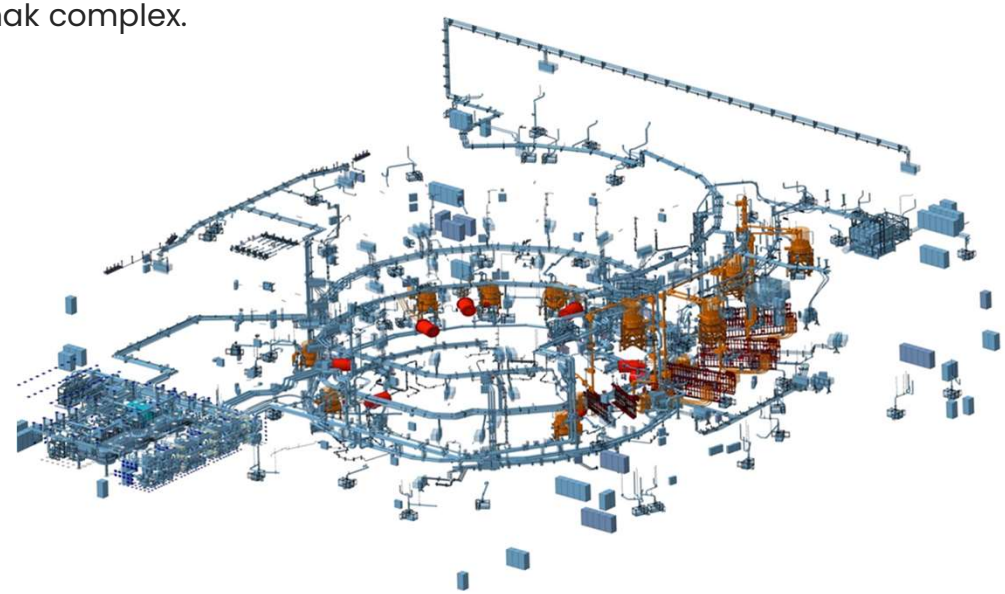
YouTube · iterorganization
Mar 13, 2023

More depth overview available online

Vacuum Systems

- Vacuum is at the heart of fusion with over 10 Km of vacuum pipework, over 100 pumps covering 10 different pumping technologies
- The Vacuum system is distributed throughout the entire tokamak complex.





- The main purposes of the Vacuum Systems are to provide;
  - Conditions for a clean plasma
  - Insulation vacuum for the ITER cryostat and cryogenic distribution systems
  - Vacuum required for the operation of heating devices (neutral beam, electron/ion cyclotron etc.)
  - Service vacuum for the maintenance for the confinement boundary and producing vacuum for diagnostic systems
  - Leak Detection/localisation systems (permanent and temporary)

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THANKS

TO BE PART OF THE WORLDWIDE **FUSION** NETWORK

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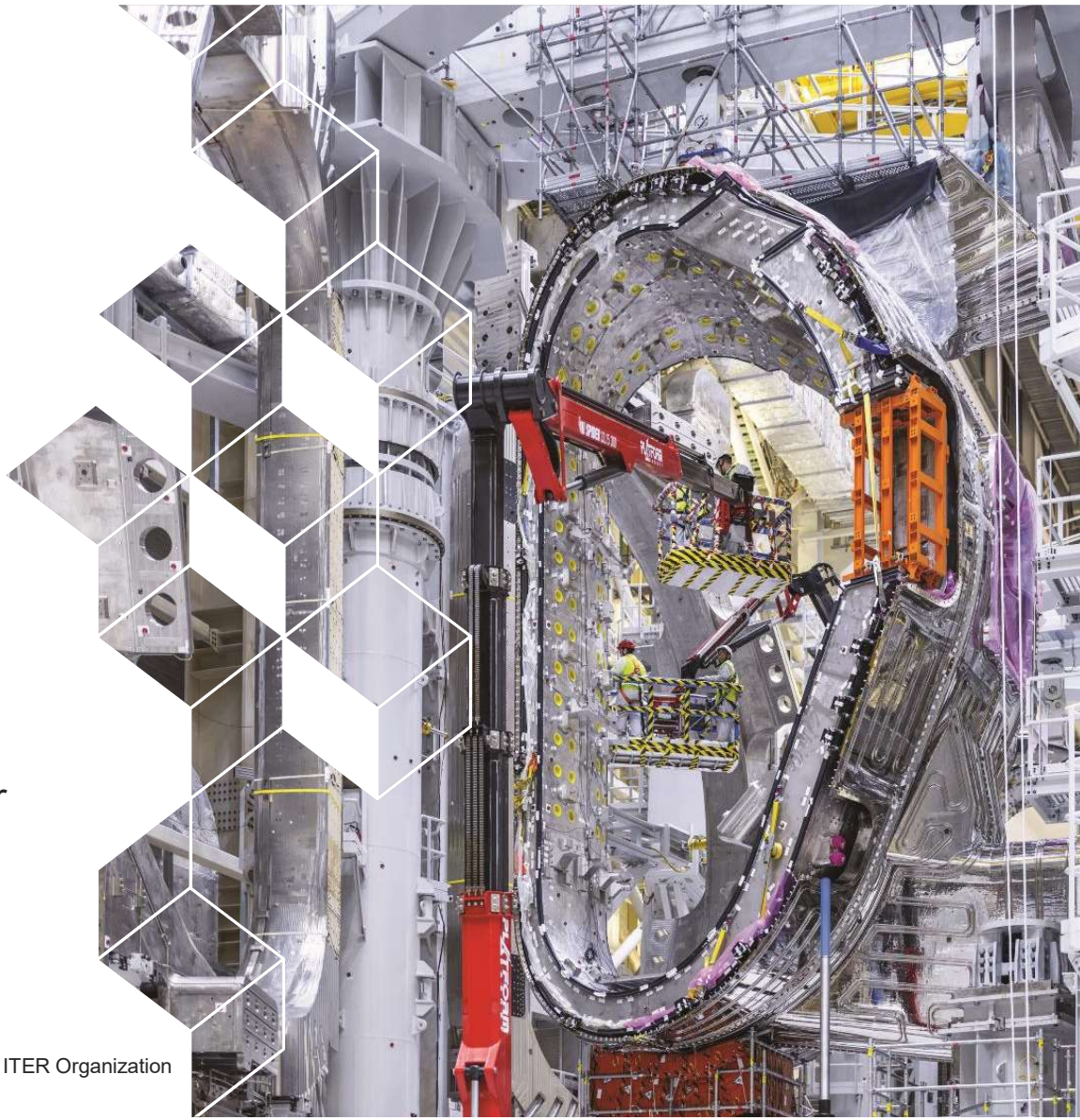
PSP Fuel Cycle – Project Status and Opportunities

Christopher Grant-Wilson
Detritiation System Coordinator

&

Jun Park
Procurement Officer

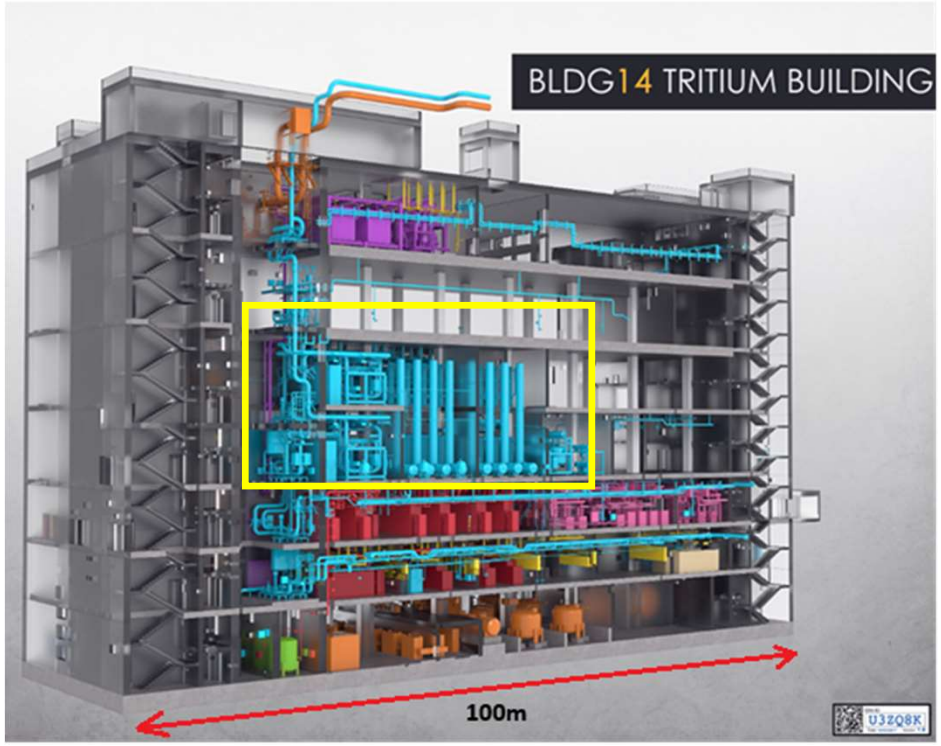
FRIDAY APRIL 25th



1. Tritium Plant Systems

Tritium Plant Systems

Project Status



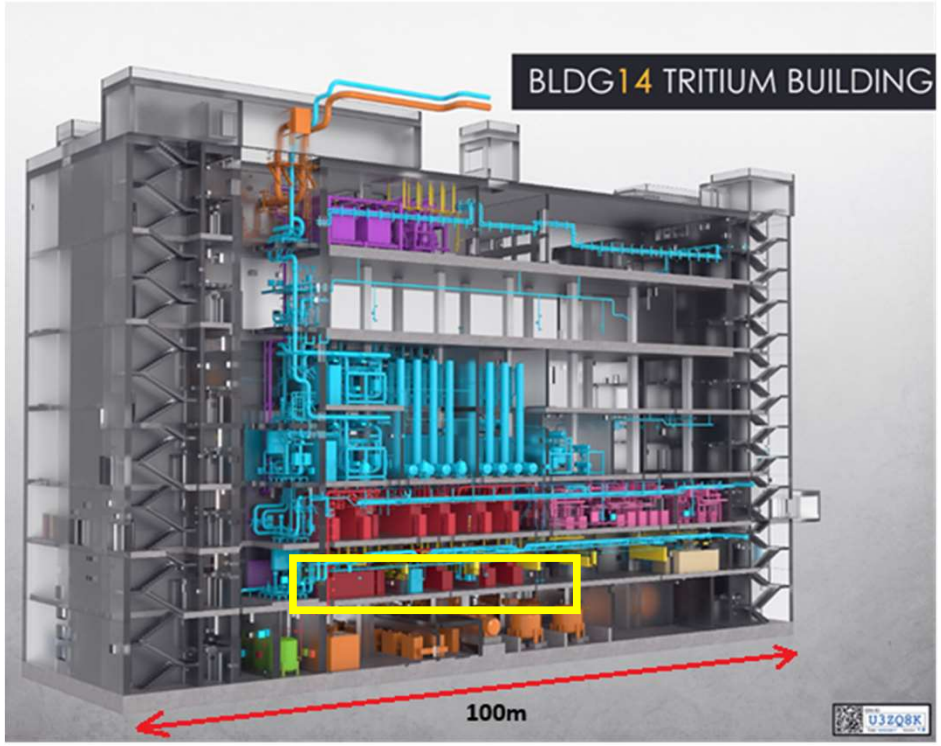
Tritium Plant main sub-systems:

Atmosphere Detritiation System (ADS)

- IO & JADA Final Design & Build
- Central Processing Plant (B14) in Detailed Design, next milestone MRR
- Parts of the piping network in B11 already installed

Tritium Plant Systems

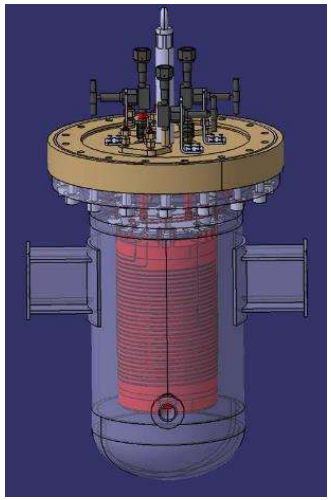
Project Status



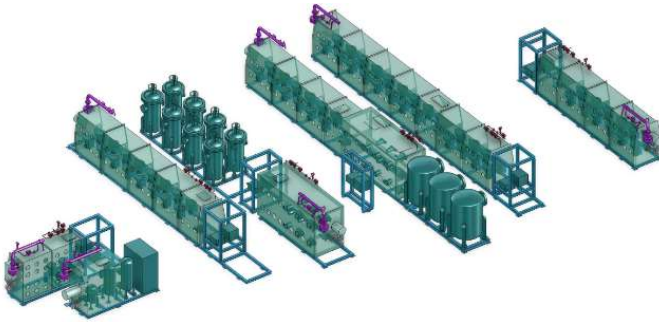
Tritium Plant main sub-systems:

Storage & Delivery System (SDS)

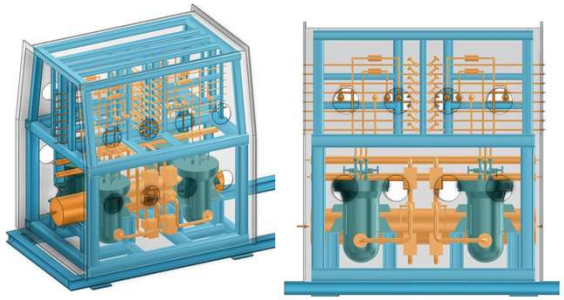
- KO-DA Final Design & Build
- In Final Design, next milestone FDR planned for 2027



Hydride bed for passive storage of hydrogen isotopes



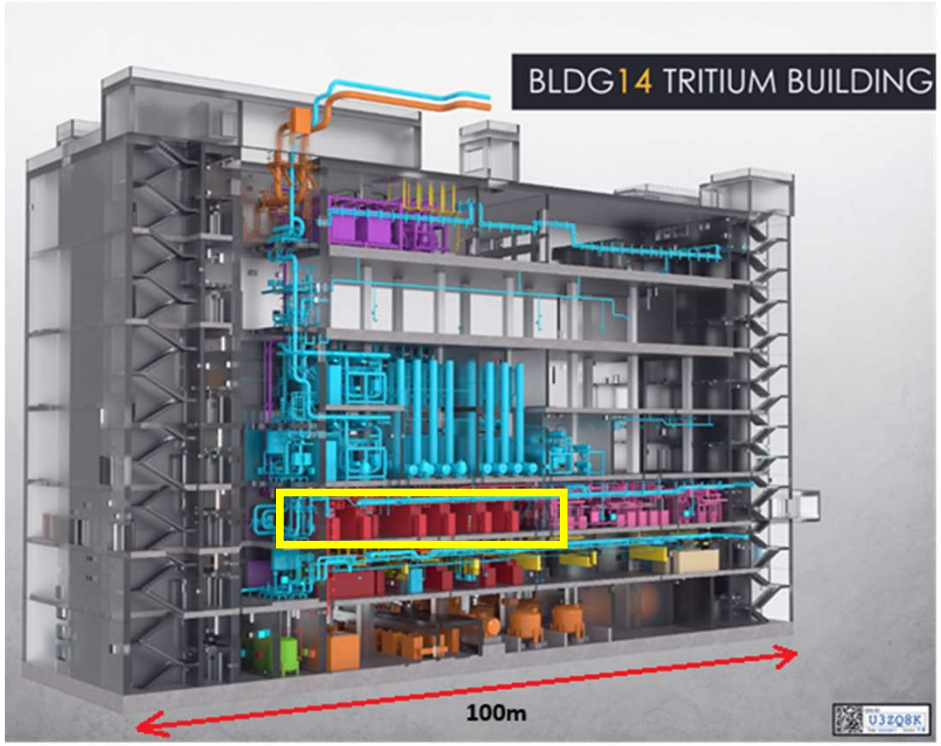
Glovebox layout in B14



Glovebox with hydride beds

Tritium Plant Systems

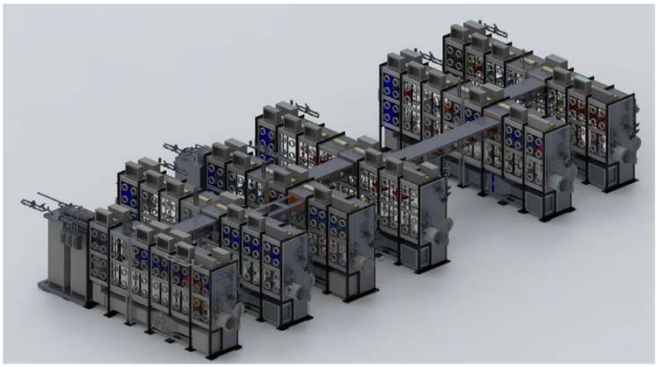
Project Status

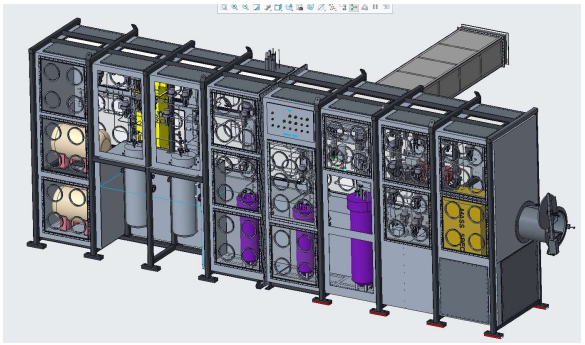


Tritium Plant main sub-systems:

Tokamak Exhaust Processing (TEP)

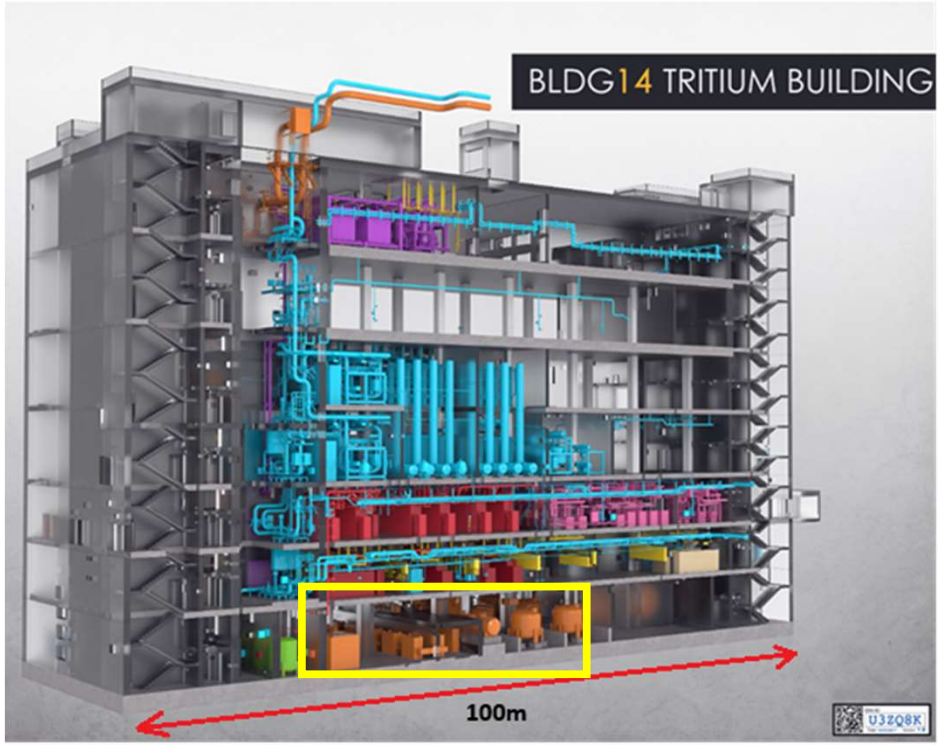
- US-DA Final Design & Build
- In Final Design, next milestone FDR in June 2025 (by US-DA)





Tritium Plant Systems

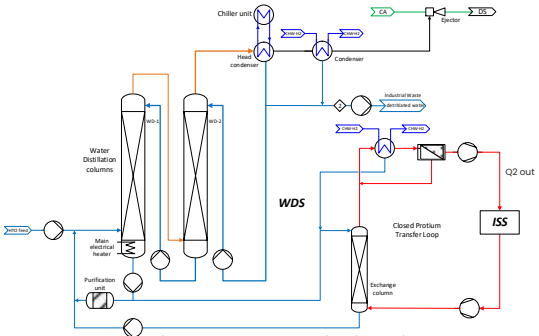
Project Status



Tritium Plant main sub-systems:

Water Detritiation System (WDS)

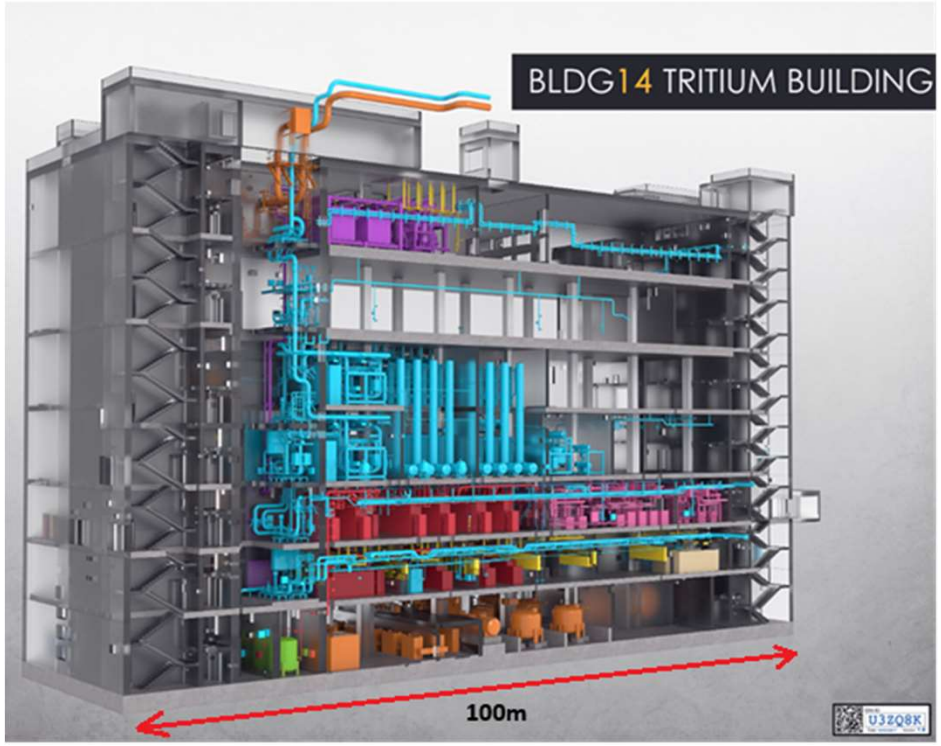
- IO Concept & Preliminary Design, EU-DA Final Design & Build
- WDS Main in Preliminary Design, next milestone PDR in 2026
- WDS Tanks – already installed in B14



WDS Main – Water Distillation PFD

Tritium Plant Systems

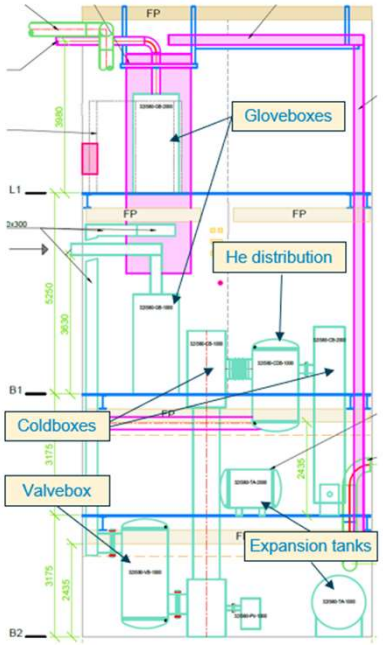
Project Status



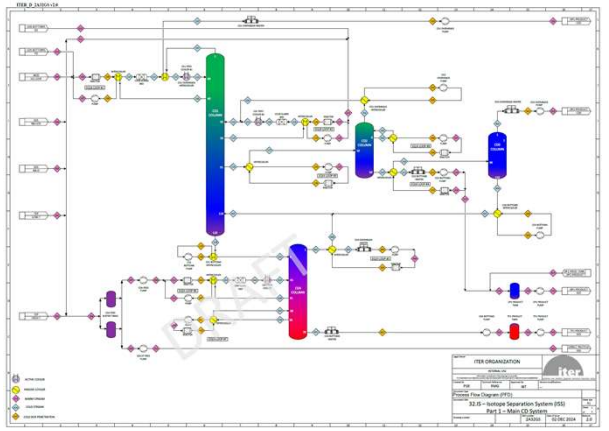
Tritium Plant main sub-systems:

Isotope Separation System (ISS)

- IO Concept & Preliminary Design, EU-DA Final Design & Build
- Preliminary Design Phase completed in 2025
- Next milestone is FDR in 2027



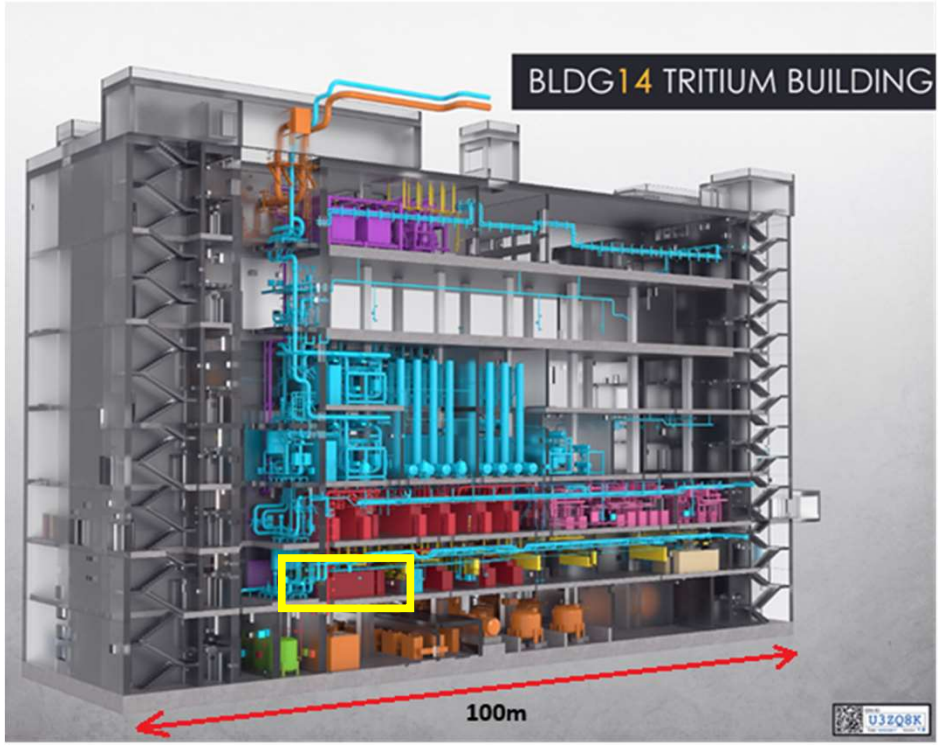
ISS arrangement in B14



ISS Process Flow Diagram

Tritium Plant Systems

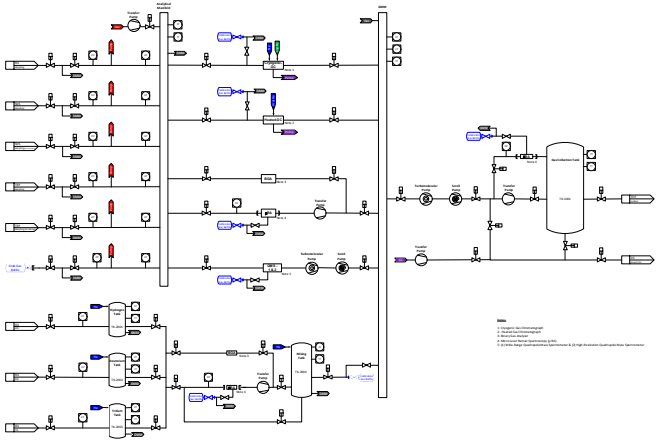
Project Status



Tritium Plant main sub-systems:

Analytical System (ANS)

- IO Concept, Preliminary & Final Design
- In Preliminary Design
- Next milestone is PDR in 2025



ANS Process Flow Diagram

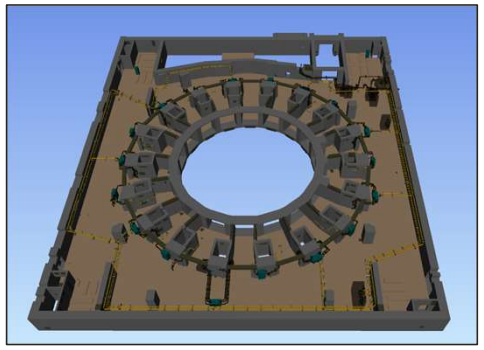
Tritium Plant Systems

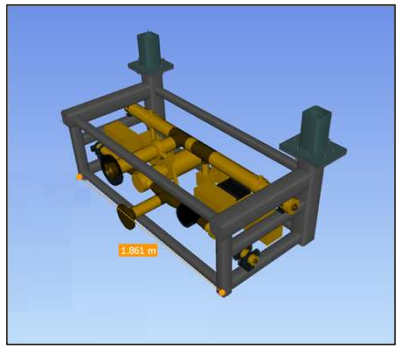
Upcoming Opportunities

Atmosphere Detritation System

1. Port Cell Skids Qualification & Supply

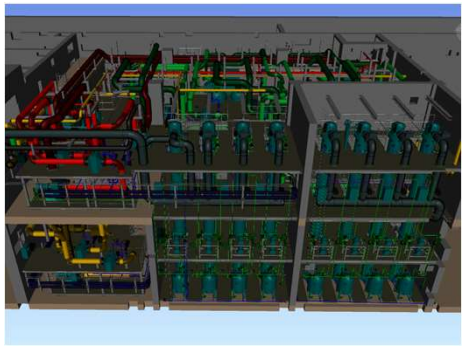
- The Detritiation System extracts air from the Port Cell rooms
- 23 x prefabricated and tested Valve Skids will control the flow from each Port Cell
- Valves and instruments need to be qualified for process and environmental conditions in normal operation and accident scenarios
- Fluid is air, normally at room temperature but also operates in fire conditions

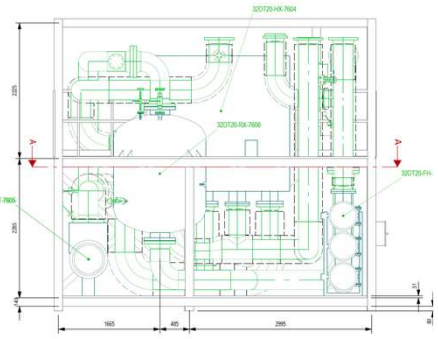




2. TC-DS Design & Fabrication Inspection Services

- The detailed design and equipment selection for the TC-DS Central Processing Plant will begin in 2025
- The contractor will support the IO to ensure compliance with the design, quality and nuclear safety:
  - During detailed design: review of engineering deliverables (structural analysis reports, detailed drawings, cable diagrams etc.)
  - During procurement, fabrication & testing: inspection and witnessing of fabrication steps, FATs, receiving inspections





Tritium Plant Systems

Upcoming Opportunities

Simplified Q_2 Recycling System (SQRS)

3. Equipped Process Glovebox & Supply

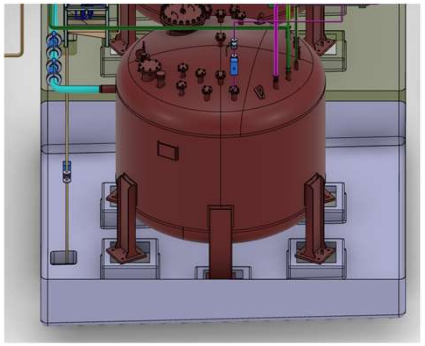
- Final design of purification units for fusion exhaust gases (Q_2 separation) and recycle, and for diborane destruction unit
- Full second barrier (glovebox) design
- Installation of tanks, separation/process units, pumps and instrumentation inside glovebox
- Main process equipment: permeator, cryogenic mole sieve bed, tube furnace

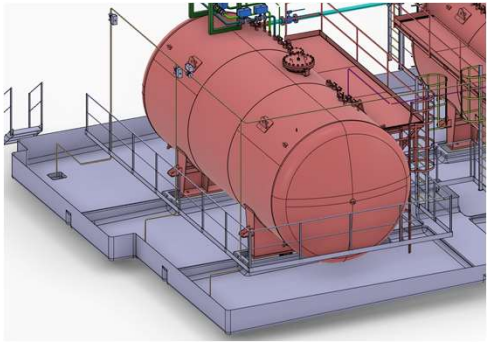
Example of process glovebox with tritium process equipment

WDS water tank liners

4. Liner design & installation

- Final design of tank liners for tritiated water storage tanks
- Up to 10 individual liner designs for complete WDS Receipt and Purification system
- Supply & installation of liners in existing concrete bunds





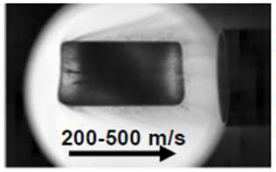
Stainless steel liners for tritiated water tanks

2. Disruption Mitigation System

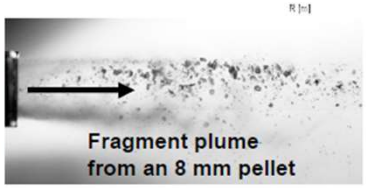
Disruption Mitigation System (DMS)

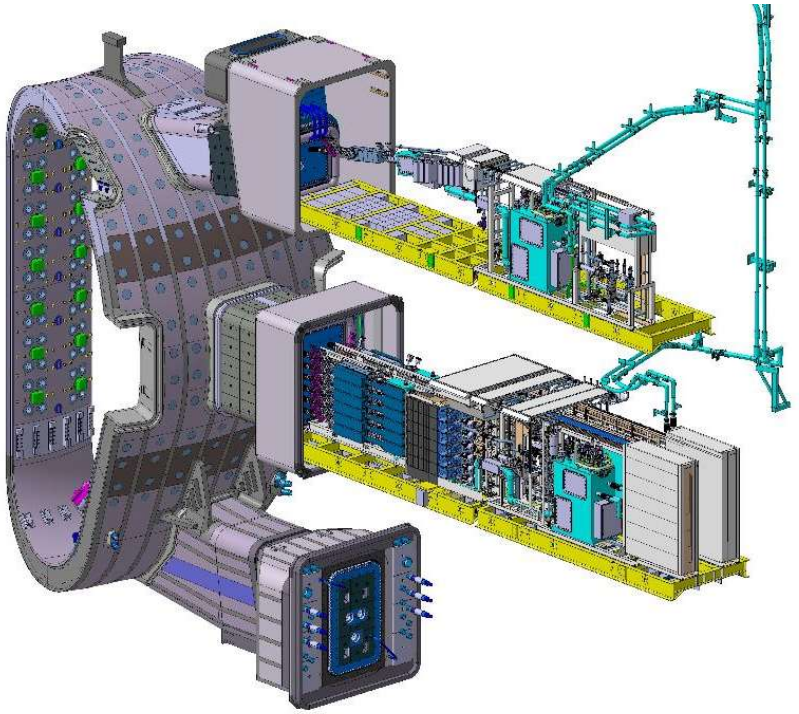
Purpose, scope and status

- Purpose: the DMS is a machine protection system, essential to avoid damages to the in-vessel components upon plasma disruptions or displacement events.
- DMS will be based on the injection into the plasma of shattered pellets made of protium, neon or their mixtures, to convert the electromagnetic and thermal energy into radiation and mitigating the impact of runaway electrons.
- Scope: 27 injectors, distributed in 3 equatorial ports (6 injectors each, 12 injector in one port) and 3 upper ports (1 injector each).
- Subsystems: gas, cryogenics, vacuum, I&C, optical diagnostics, frames and shielding
- Status: Final Design Review closed for the full integrated system.
- Challenges: First-of-a-kind Cold Cell and injector design requires prototyping and laboratory test in parallel to manufacturing preparation, ongoing for risk mitigation:
  - R&D still ongoing at CEA Grenoble, CER Budapest, ITER-US Oak Ridge, until end-2027.



SPI technology:
D=28.5 mm, L=57 mm pellets formed at ~5.5 K, get accelerated and shattered against a tilted target, to enter the plasma as mm-size fragments, within ≤50 ms from trigger signal.

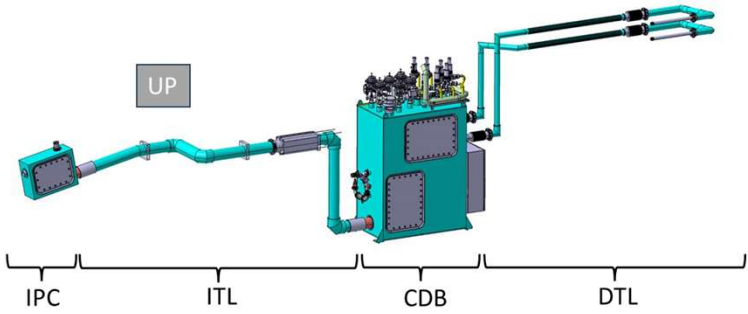




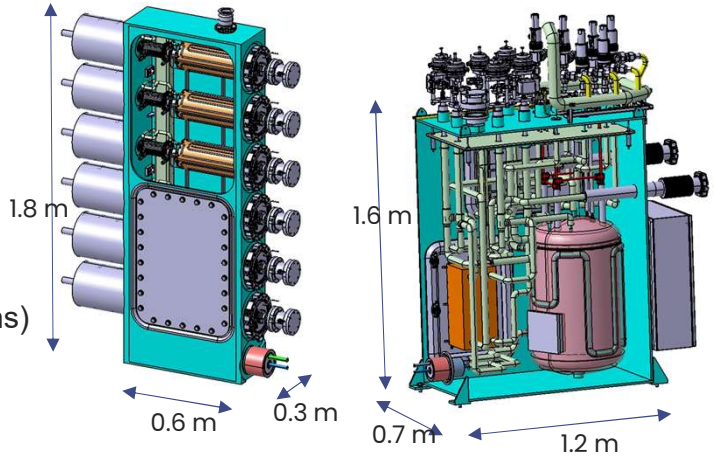
Disruption Mitigation System (DMS)

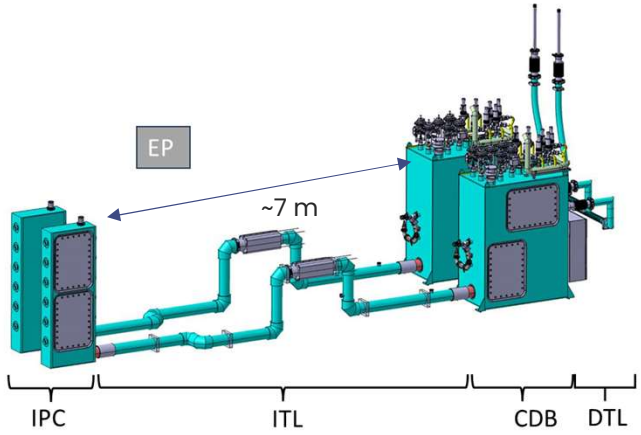
Upcoming opportunities

- Scope of supply: Manufacturing preparation (up to MRR), procurement, manufacturing/assembly and factory test of:
  - LOT 1: Qty 7 Cold Distribution Boxes (CDB: 6 valves, 120L LHe vessel, JT heat exchanger)
  - LOT 2: Qty 7 Injectors prismatic cryostat (IPC: 3 large, 3 single)
  - LOT 3: Qty 7 Intermediate transfer lines (ITL: vacuum insulated, 2 pipes, rigid, shielded) and Qty 14 Disconnection transfer lines (DTL: vacuum insulated, 1 pipe, flexible, Johnston couplings)



- Main requirements:
  - Built-to-Print specification, with few exception at lower detail.
  - Mainly austenitic steel pipe fitting, welding, assembling technology.
  - Instrumentation specified and pre-qualified (Velan, Lake Shore, Opsens)





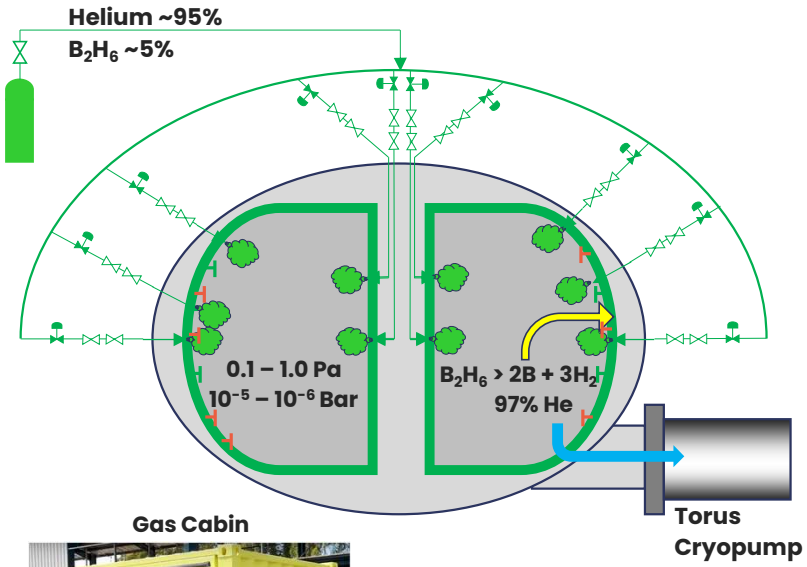
3. The ITER Boronization Gas Supply System

ITER FWC Project

Boronization Gas Supply System (BGS)

Purpose, scope and status

- Purpose: ITER, as all tungsten first wall machine, the boronization of the plasma facing wall required to have a layer of boron, which is a good oxygen getter in place of Be first wall.
- BGS provides the boronization gas, mixture of diborane and He (5%-B_2H_6/95%-He), to the vacuum vessel through double wall tubing at 21 locations.
- Scope:
  - Gas cabin stores the bottles of boronization gas
  - Double wall gas distribution network from gas cabin to the injection points, including in-vessel gas lines
  - Mass flow controller and VV safety isolation valves
  - Instrumentation and control system
- Status: Conceptual Design Review completed in 2024.
- Challenges: Handling of extremely explosive and toxitic gas of diborane
  - R&D to study glow discharge assist boronization process at SWIP in China will be launched in Q2 2025.



4. Summary of Opportunities

Summary of Fuel Cycle opportunities

ITEM	Project	Description	Solicitation Type	Expected Publication Date	Expected Signature Date
1	DMS	Disruption Mitigation System (DMS) Cryogenic System Manufacturing: Lot 1 Cold Distribution Box (CDB)	CFT: Call for Tender	Q1-2026	Q4-2026
2	DMS	Disruption Mitigation System (DMS) Cryogenic System Manufacturing: Lot 3 - Injector Prismatic Cryostat (IPC)	CFT: Call for Tender	Q1-2026	Q4-2026
3	DMS	Disruption Mitigation System (DMS) Cryogenic System Manufacturing: Lot 2 - Intermediate Transfer Lines (ITL) & Disconnection Transfer Line (DTL)	CFT: Call for Tender	Q2-2026	Q1-2027
4	TPP	Qualification & Supply - Tokamak Complex Detritiation System(TC-DS) Distribution Network Port Cells to First Exhaust System (JPK)	CFT: Call for Tender	Q3-2025	Q2-2026
5	TPP	Tokamak Complex Detritiation System (TC-DS) Design & Fabrication Inspection Services Phase 1 (JPK)	OT: Open Tender	Q2-2025	Q3-2025
6	TPP	Manufacture Test and Deliver - Simplified Q2 Recycling Systems (JPK)	CFT: Call for Tender	Q3-2026	Q3-2027
7	TPP	Water Detritiation System (WDS) Liners	CFT: Call for Tender	Q1-2026	Q4-2026
8	TPP	Tokamak Complex Detritiation System (TC-DS) Fabrication Inspection Services Phase 2 and 3: Tokamak Complex Detritiation System(TC-DS) Core (JPK)	CFT: Call for Tender	Q3-2027	Q4-2027

DMS: Disruption Mitigation System Project
TPP: Tritium Plant Project

2025: 1 CFT and 1 OT; **2026**: 5 CFTs; **2027**: 1 CFT

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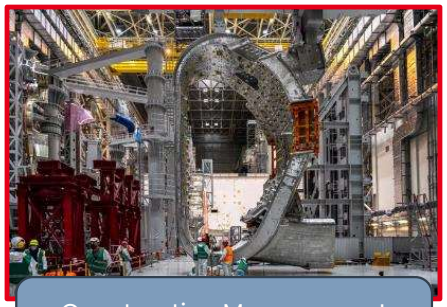
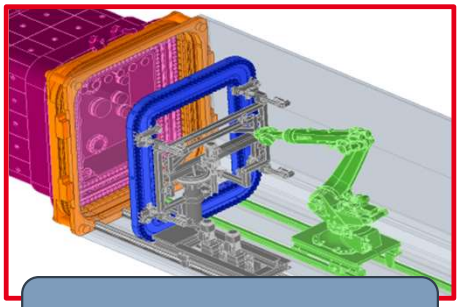
Thematic workshop
Plant system program n°1

Hadrien Monet

Our current projects with IO



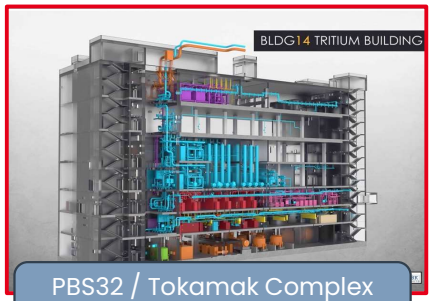
Construction Management Agent



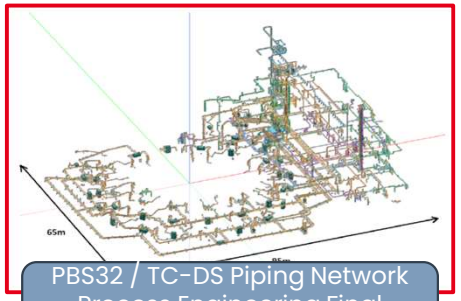
Remote Handling Operations

ITER wide contracts (RPrS, OHS, PCO,…)

Vacuum Vessel In-Service Inspection Corrosion Monitoring Chamber

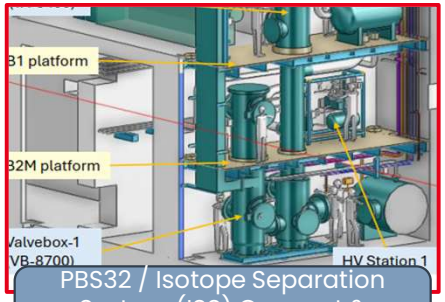


PBS32 / Tokamak Complex Detritiation System (TC-DS)



PBS32 / TC-DS Piping Network Process Engineering Final Design

PBS32 / Equipment Qualification



PBS32 / Isotope Separation System (ISS) Concept & Preliminary Design

What are the main challenges for Amentum?

ITER Project Environment
- PBS Structure
- Data Access (IDM, Multi stakeholders, …)
- ITER Terminology
- Multi-cultural environment

ITER Technology – First of a Kind

Constant evolution of the design – Configuration management

What are the Amentum added values?

Good communication between our project teams across ITER

Capitalise on the wider Amentum involvement and knowledge to bring continuous improvement and focus on delivery

Proximity with our direct client and stakeholders
Local office and regular presence on site

Provide wider expertise to meet the requirements
Amentum France, Wider Amentum and beyond by partnering with the supply chain

Focus on coming up with the optimised solutions bringing best value to ITER
Consider project constraints and wider objectives as much as possible

Thank you.

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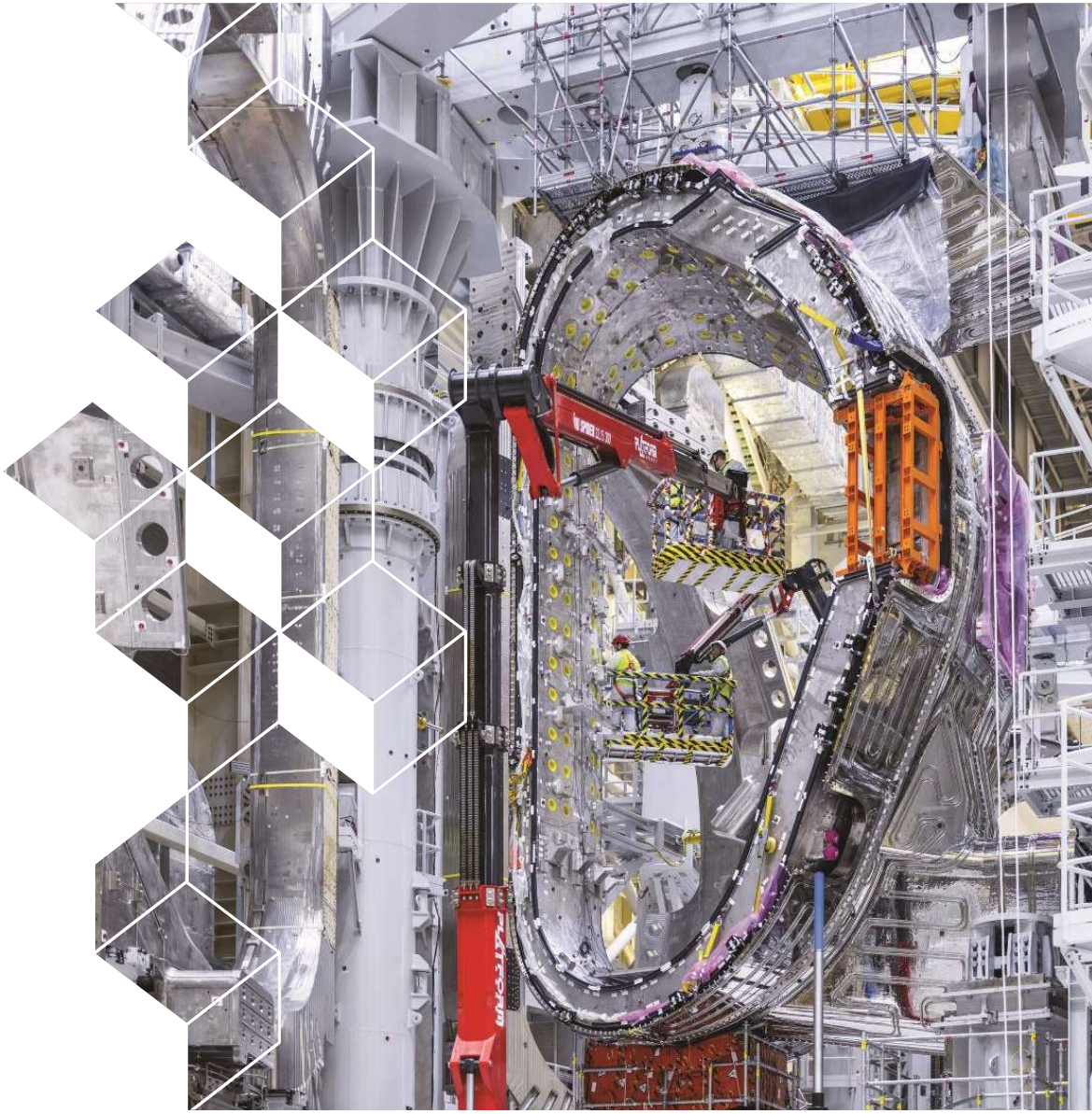
F4E Cryoplant & Fuel Cycle Status and description of upcoming opportunities

Josep Benet

Fusion For Energy – Cryoplant and Fuel Cycle Programme Manager

FRIDAY APRIL 25th



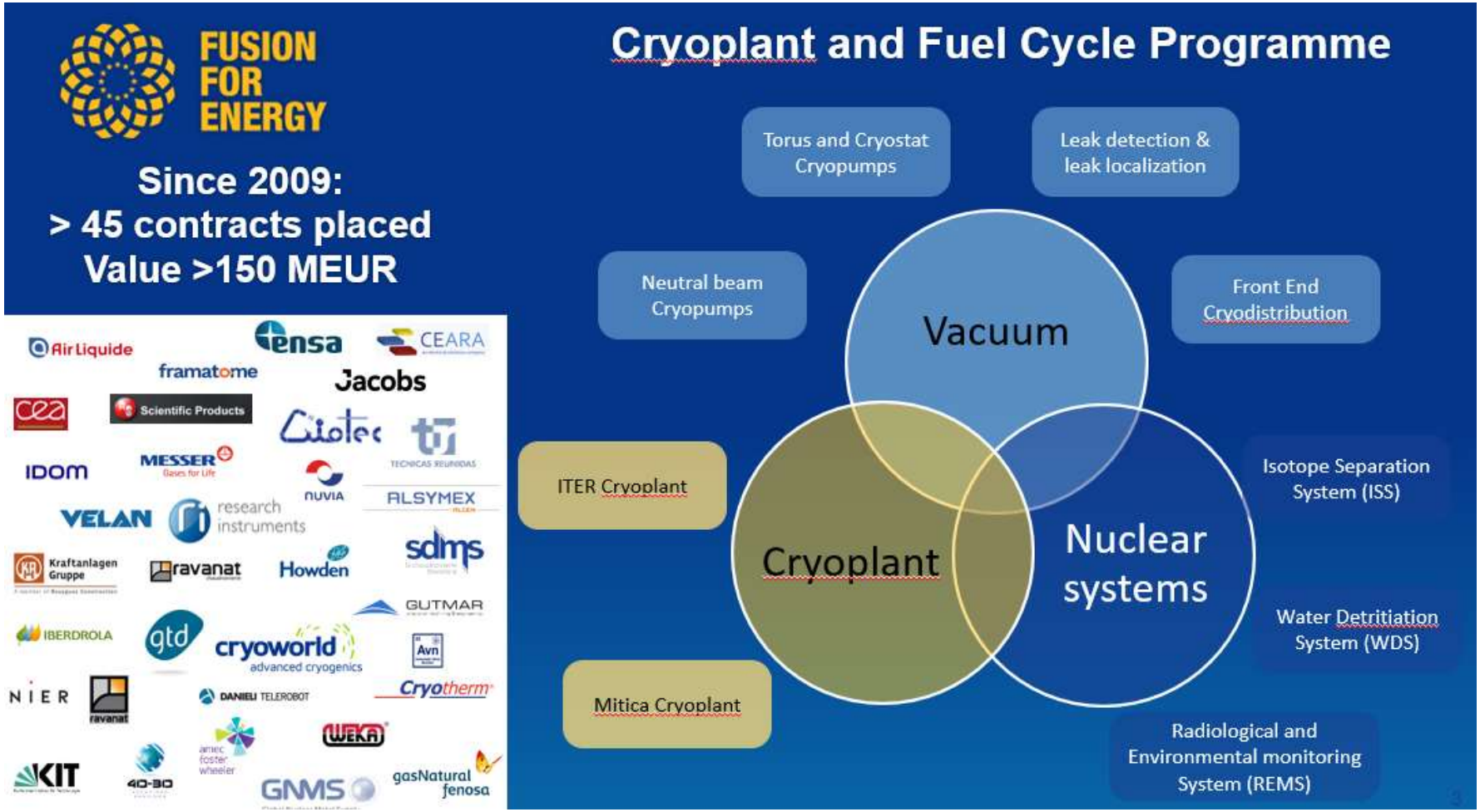
Outline

Cryoplant and Fuel Cycle Programme scope

Opportunities in:

1. **Isotope Separation System**
2. **Water Detritiation System**
3. **Neutral Beam Cryopumps**
4. **Leak Detection System**
5. **Radiological and Environmental Systems**
6. **Vacuum and Cryogenic services**
7. **Conclusions**
8. **Key notes**

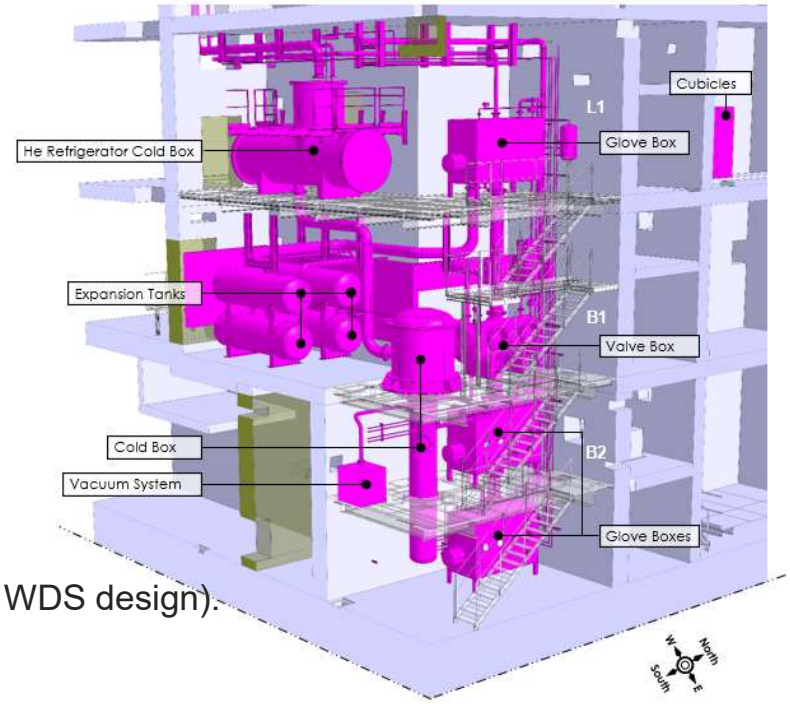
Cryoplant and Fuel Cycle Programme



Cryoplant and Fuel Cycle Programme

1. Isotope Separation System

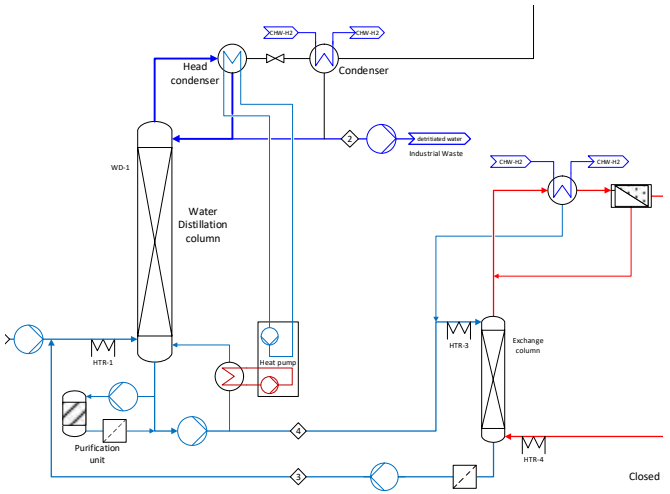
- **Scope**: Final design, Procurement and manufacturing (columns, piping, skids, vessels, glove boxes…), Control system, support to installation
- **Key function**: Nuclear system, Cryogenic distillation of H/D/T
- **Nuclear Safety**: Primary confinement. Protection Important Component (PIC)
- **Key technologies**:
  - Cryogenics, process plants, SS piping assemblies
  - Cryogenic refrigeration
  - Cold valve boxes and glove boxes
  - 6 cryogenic distillation columns 3 - 7 m high
  - Column height: ≈ 7.5 m, cooling power: ≈ 1kW @ 16K
- **Status and Procurement activities:**
  - ✓ Front End Engineering Design
  - ✓ Tender preparation for design activities (Framework contract for ISS and WDS design).
  - ✓ **Market survey will be published**
  - ✓ Est. contract 2026 (Tender)
  - ✓ Value > 10 MEUR

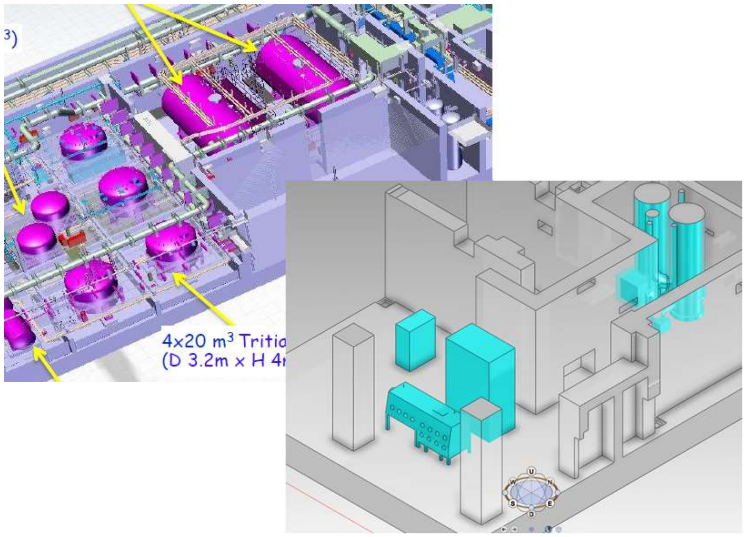


2. Water Detritiation System

- **Scope**: Final design, Procurement and manufacturing (columns, piping, skids, vessels, glove boxes…), Control system, Support to installation
- **Key function**: 60kg/h water treatment, Water Distillation technology, Catalytic exchange, Hydrogen permeators
- **Nuclear Safety**: Primary confinement, Protection Important Component (PIC)
- **Key technologies**: SS component manufacturing, Water Distillation technology, Catalytic exchange, Hydrogen permeators, process piping and instrumentation

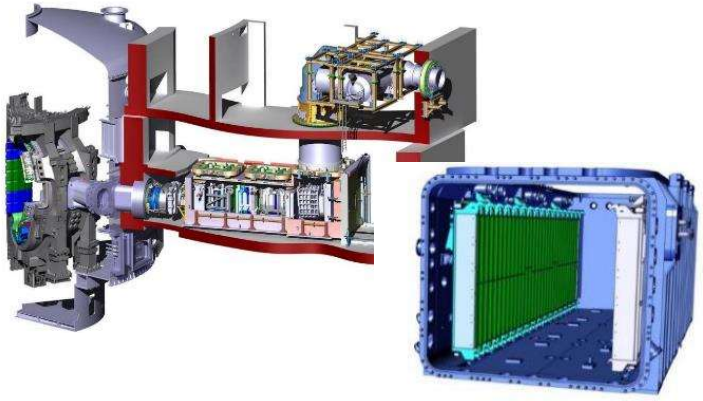
- **Status and Procurement activities:**
  - ✓ Front End Engineering Design
  - ✓ Definition of procurement strategy
  - ✓ Tender preparation for design activities (FwC for WDS and ISS).
  - ✓ **Market survey will be published**
  - ✓ Est. contract 2026 (Tender)
  - ✓ Value: > 10 MEUR





3. Neutral Beam Cryopumps

- **Scope**: 2 HNB Cryopumps + 1 DNB Cryopump, manufacturing, testing and delivery to IO site.
- **Key function**: Vacuum pumping inside the BLV-BSV by cryo-absorption
- **Nuclear Safety**: Primary confinement, Protection Important Component (PIC)
- **Key technologies**: tight tolerances, charcoal coating, SS tubes expansion, aluminum profiles extrusion, cold shock, welding, leak test:
  - > 100m2 pumping surface
  - > 1000 panels
  - > 9000 welds including Rx
  - > 500 leak tests
- **Status and Procurement activities:**
  - ✓ Prototype testing (MITICA)
  - ✓ Manufacturing documentation in preparation
  - ✓ **Market survey opened**
  - ✓ Est. contract 2026 (Tender)
  - ✓ Value > 10 MEUR



4. Leak Detection System

- **Scope**: 7 skids with leak detection equipment. Build-to-print design:
  - Procurement
  - Manufacture
  - Testing

❖ **Key function**: continuous monitoring of the gas coming from various vacuum systems during machine operation for any abnormal functioning detection

❖ **Nuclear Safety**: Protection Important Component (PIC)

❖ **Key technologies**:

High leak tightness
>300 vacuum flanges
>1000 welds including Rx
Vacuum assembly and clean area availability (ISO 8/ ISO 9)

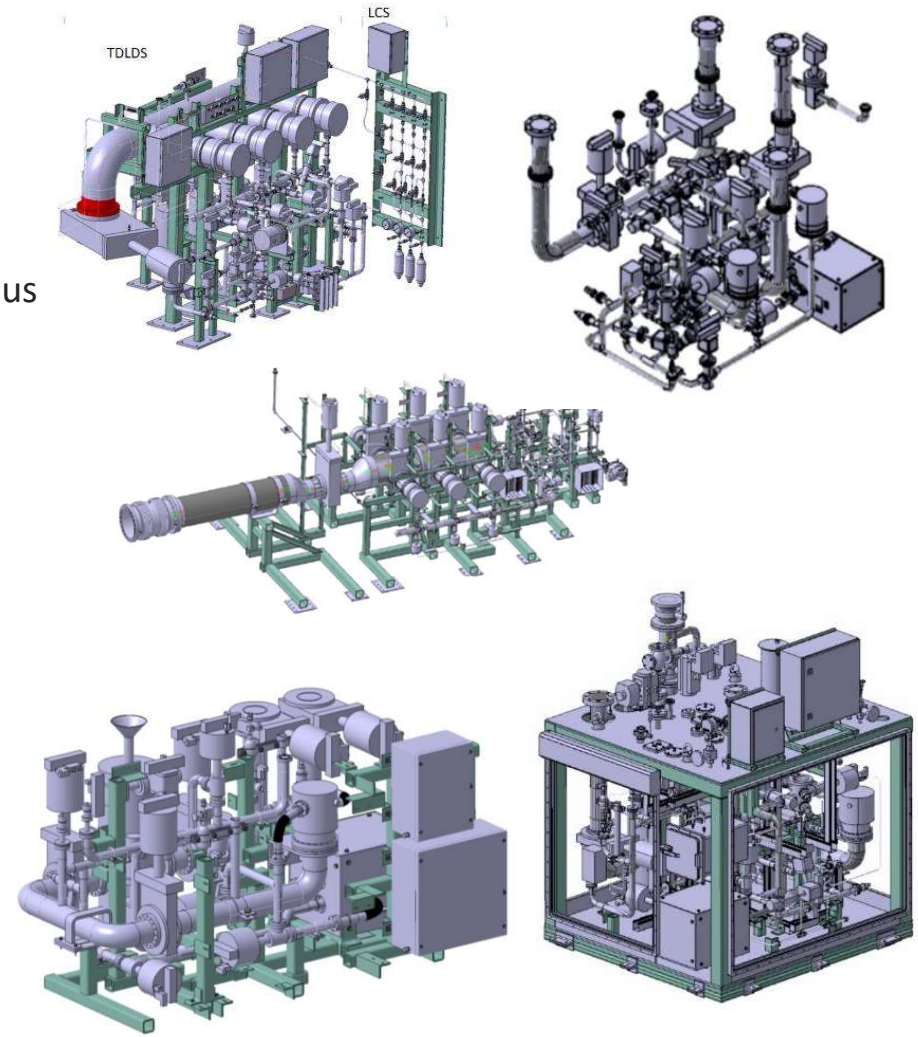
❖ **Status and Procurement activities:**

✓ Qualification of components + Final Design finalization

✓ **Market survey opened**

✓ Next contract 2025

✓ Value 2-5 MEUR



5. Radiological and Environmental systems (REMS)

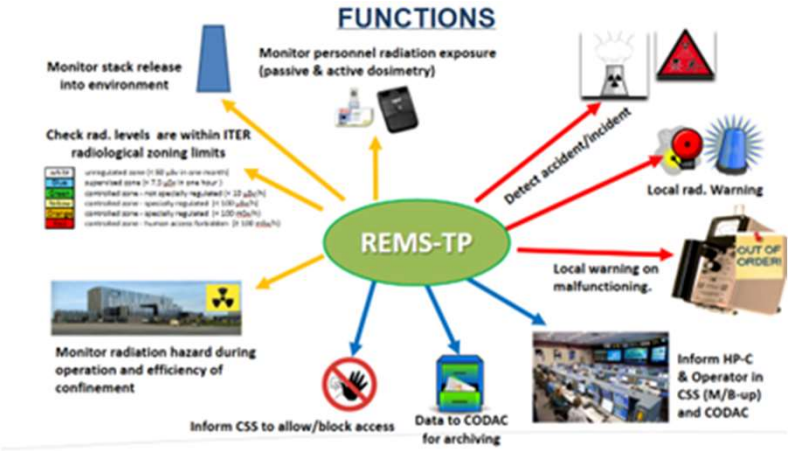
- **Tender Scope:** Qualification and procurement of REMS for ITER.
- **Nuclear Safety**: Protection Important components for protection of workers and public.
- **Key technologies**:

Manufacturing of radiological systems for:

- Measurement **a**, **b**, **g**, x-rays and neutrons.
- Contamination detection from Tritium and radioactive particulate

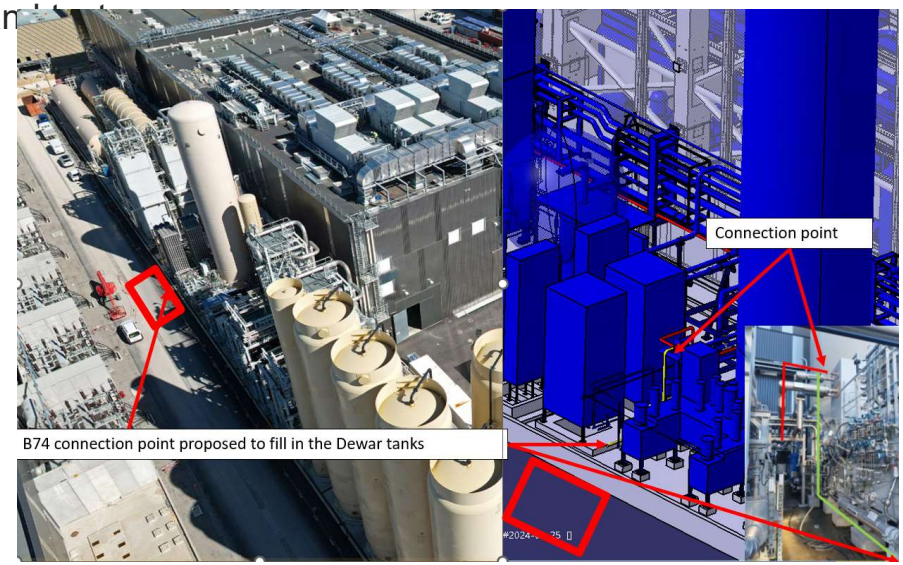
- **Qualification for ITER loads during e.g.**
  - Seismic events
  - Static magnetic field
  - Contamination detection from Tritium and radioactive particulate

- **Status and Procurement activities:**
  - ✓ Optimization baseline preliminary design.
  - ✓ Pre-qualification testing of instrumentation at ITER SMF test Facility
  - ✓ Tender Framework with re-opening of competition for qualification and procurement.
  - ✓ Tender publication 2026
  - ✓ Value: 30M€ (2026-2030)



6. Vacuum and Cryogenic services

- **Tender Scope: Services and small mechanical part Framework contract**
  - Small mechanical components. Provide small subsystems and components.
  - Site services. Provide support to F4E and IO during installation an
- **Nuclear Safety**: Protection Important Activities may be required
- **Key technologies**:
  - **Small mechanical components, Procurement, Manufacture, Testing**
    - Simple cryogenic lines
    - Dewars
    - Filling stations
    - Flanges…
  - **Site services.**
    - Maintenance
    - Small modifications
    - Installation
    - Test
    - Supervision
    - Training.



- **Status and Procurement activities:**
  - ✓ On-going activities Framework contract tender preparation
  - ✓ Tender publication Q3 2025
  - ✓ Value up to 4 M€ (4 years)

7. Conclusions on Business Opportunities

- Previous slides shows a significant number of tenders: for final design and/or manufacturing, to be launched between 2025-2029

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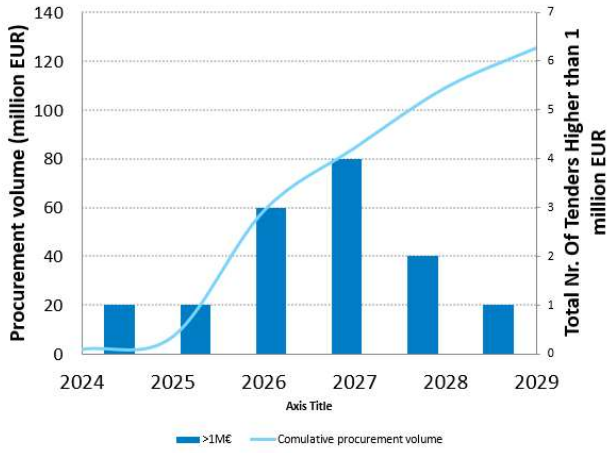
Key notes

- 2025-2029
- > 12 contracts*
- > 120M€**

*Number of contracts to be confirmed.
**Estimated values for procurement volume.

We will tender **several multi-M€ contracts** in the next years.



8. Key notes

Fusion for Energy
Industry and Fusion Laboratories Portal

https://industryportal.f4e.europa.eu/categories/market-surveys/

Stay tuned on our call for tenders!

- Neutral Beam Cryopumps Market Survey (on-going)
- Isotope Separation System (**published soon**)
- Water Detritiation System (**published soon**)
- Leak Detection Market Survey (**on-going**)
- REMS Presentation Update (attention of the Industry **available**)

Contact our Business Intelligence team: mehdi.daval@f4e.Europa.eu

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