

PSD Project Board 30 October 2024

## **WPPrIO: Preparation of ITER Operation**

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**João FIGUEIREDO** (Coordinator Officer @ Programme Management Unit)



**CEA lead lab. for WP-PrIO**

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# Introduction

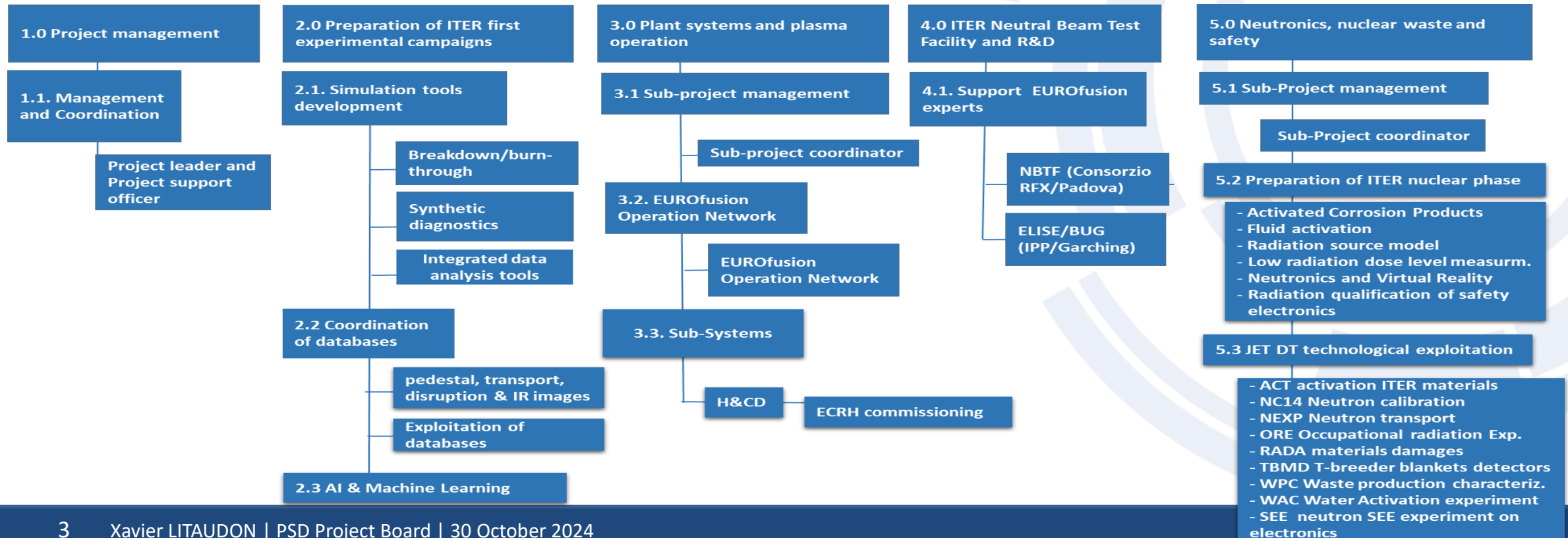
- **WP created in 2021** to implement some of the recommendations from 2020 General Assembly<sup>1</sup> on “**EUROfusion role in ITER operation and scientific exploitation**”
- “Operation” to be understood in the global sense encompassing integrated commissioning, plasma & machine/sub-systems operation including scientific exploitation to be carried out in advance of the start of ITER plasma operation
- In the context of the ITER revised baseline with the aim of **achieving Q=10 as soon as possible**, EUROfusion should ensure that **operational tools**, broadly defined to include methods, codes and procedures are **ready before ITER application (tested, validated and reliable)**
- **Overview PrIO activity (2021-2023) published in 2024: EUROfusion activity commended by the external referees [2024 Nucl. Fusion 64 112006 <https://iopscience.iop.org/article/10.1088/1741-4326/ad346e>]**

<sup>1</sup>EUROFUSION GA (20) 32 - 4.7 - ITER White Paper Report WG1 Issue 1 10-Dec-2020 (Decision).docx and EUROFUSION GA (20) 32 - 4.7 - ITER White Paper Report WG2 Issue 3 7-Dec-2020 (Decision).docx



# PrIO Main structure (WBS)

- 5 Sub-Projects with delegation and gender equality
  - SP-1 Project management (G. Falchetto)
  - SP-2 Preparation of ITER first experimental campaigns (X. Litaudon)
  - SP-3 Plant systems and plasma operation (E. Belohony)
  - SP-4 ITER Neutral Beam Test Facility and R&D (U. Fantz, D. Marcuzzi)
  - SP-5 Neutronics, Nuclear waste and Safety (S. Villari)





# Major changes

SP-1 Project Leader X. LITAUDON  
Project Support Officer G. FALCHETTO

[October 2024]

## SP-2 Preparation of ITER first experimental campaigns

SP coordinator:  
X. LITAUDON

Tools development and  
synthetic diagnostics

Breakdown/burn-through

H.T. KIM

Synthetic Diagnostics:  
Infra-Red, FILD, FOCS,  
Bolometer, Magnetics,  
Radial Neutron Camera,  
Gamma Ray Spectrometer

M.H. AUMEUNIER, M. GARCIA MUNOZ  
A. GOUSSAROV, ...

Integrated data analysis tools  
for ITER exploitation

R. FISCHER

Multi-machine  
Databases

Disruption, pedestal,  
Infra-red image databases

A. PAU, L. FRASSINETTI,  
R. MITTEAU

AI and Machine  
Learning

AI & ML projects

F. ALMUHISEN, A. JARVINEN,  
A. PAU, A. SNICKER,  
G. VERDOOLAEGE, S. WIESEN

2024 AI call

## SP-3 Plant Systems and Plasma Operations

SP coordinator:  
E. BELONOHY

EUROfusion Operation Network

E. BELONOHY

2024 call

ECRH: ITER Gyrotron  
commissioning procedure

L. DELPECH

## SP-4 NBTF & R&D

SP coordinator:  
X. LITAUDON

EUROfusion delegates to  
NBTF Advisory Committee (NAC)

G. FEDERICI

NBTF (Consorzio RFX/Padova)

D. MARCUZZI

ELISE/BUG facilities  
(IPP/Garching)

U. FANTZ

2024 call (5 positions)

ITER tools development

Activated corrosion products tools  
development & exp.

N. FONNESU

Fluid activation tools dev. & exp.

L. SNOJ

Radiation source models for ITER

Z STANCAR, P. SAUVAN,  
A. J. LOPEZ-REVELLES

Low radiation dose measurements

N. FONNESU

Neutronics and virtual reality

Y. PENELIAU

Radiation qualification of safety  
electronics

M. DENTAN

## SP-5 Neutronics Nuclear waste & safety

SP coordinator:  
R. VILLARI

JET DT technological exploitation

ACT Activation ITER materials

L. PACKER

NC14 14MeV Neutron calibration

Z. GHANI

NEXP Neutron transport

R. VILLARI

ORE Occupational radiation  
exposure (safety)

N. TERRANOVA

RADA materials damages

R. VILA

SEE experiment on electronics

M. DENTAN

TBMD T-breeder blankets  
detectors

N. FONNESU

WAC Water Activation Project

R. VILLARI

WPC Waste production charac.

S. REYNOLDS

- Completion of the JET neutronics activity in 2025
- Participation in the JET decommissioning ?



## 2025 Highlights : new activities initiated in 2024 (calls with extra resources following July 2024 GA decision)

- **SP-2: Synthetic diagnostics (in support to ITER EU procured diagnostics)**
  - Bolometer diagnostics for ITER and tomographic reconstruction software
  - Analysis Tools & Calibration Techniques for the ITER magnetic measurements
  - Radial Neutron Camera and Gamma Ray Spectrometer
- **SP-2: multi-machine Infra-Red image database** (experimental & simulation data)
- **SP-2: Integrated multi-diagnostics data analysis tool (IDAV) in view of ITER** (density & temperature)
- **SP-2: Artificial Intelligence projects related to operation and/or use of multi-machine databases**
  - Tokamak operation Conversational AI Interface Using Multimodal Large Language Models
  - AI-assisted Plasma State Monitoring for Control and Disruption-free Operations
  - Identification and confinement scaling of hybrid scenarios across multiple devices
  - Applying AI/ML for NBI ionization and slowing-down simulations using ASCOT/BBNBI
  - Machine learning accelerated pedestal MHD stability simulations
  - Machine learning accelerated SOL simulations: SOLPS-NN
- **SP-3: ECRH commissioning procedures transferable to ITER-plant**
- **SP-5: Special issue in Plasma Physics & Controlled Fusion on JET D-T neutronics**





## Other 2025 highlights

- **SP-2 databases**

- The transport database coordinator (ENEA) has resigned in 2024 and this activity is on hold
- Resources allocated to database exploitation (pedestal, disruption) but **lack of local support from MAST-U & AUG**
- Availability to EUROfusion users via web interface & authentication procedure - **ongoing**
- **Strong interests from ITPA and Private sectors : prepare an agreement for users to sign before accessing the DB ?**

- **SP-3 :**

- Face to Face meeting of the EU facilities heads of operation: **to be organised in 2025**
- Develop the EON foundation course on Session Leading : task initiated within the EON (**under TRED in 2025**)
- **Request for SL training could not be accomodated within the 2025 budget (under TRED)**

- **SP-4:**

- **Visibility beyond 2025 for the long term NBTF secondments: NBTF agreement with IO to be extended beyond 2025 ?**
- Long pulses on ELISE limited by the RF generator to be replaced by solid state RF generator

- **SP-5 :**

- New tasks implemented within the existing PRIO team using part of the extra resources allocated by GA in support to ITER new baseline and safety issues
- Strong collaboration with F4E and IO but recent departure from IO of Y LE TONQUEZE
- **Neutronics activities during the JET decommissioning phase: strong scientific interest - pending agreement with UKAEA ?**



## SP-2 Multi-machine databases 2025 Activity (with WPTE and WPAC)

- **Pedestal multi-machine database**

- Deployment of the database on the new EUROfusion Gateway (pending ACH support)
- Extend including the recent TCV and MAST-U data
- Update with new parameters (in particular for JET)
- Exploit for pedestal prediction (using Artificial Intelligence techniques )

- **Disruption multi-machine database**

- Extend validation and pipelines to access/include WEST, MAST-U
- Make available the DEFUSE framework on the new EUROfusion Gateway (with ACH) for large scale analysis and scientific exploitation, in connection with AI & ML EUROfusion projects.
- Update the mapping to IMAS as far as the IDS for disruptions
- Adapt the web catalogue and interface (with ACH)

- **Infra-Red (IR) images database (new activity following 2024 call)**

- set-up a multi-machine IR database (WEST and W-7X) to support the development of the IR synthetic diagnostic and to further develop wall thermal events and hot spot monitoring system in view of ITER applications.
- Develop common definitions and data format for IR images database

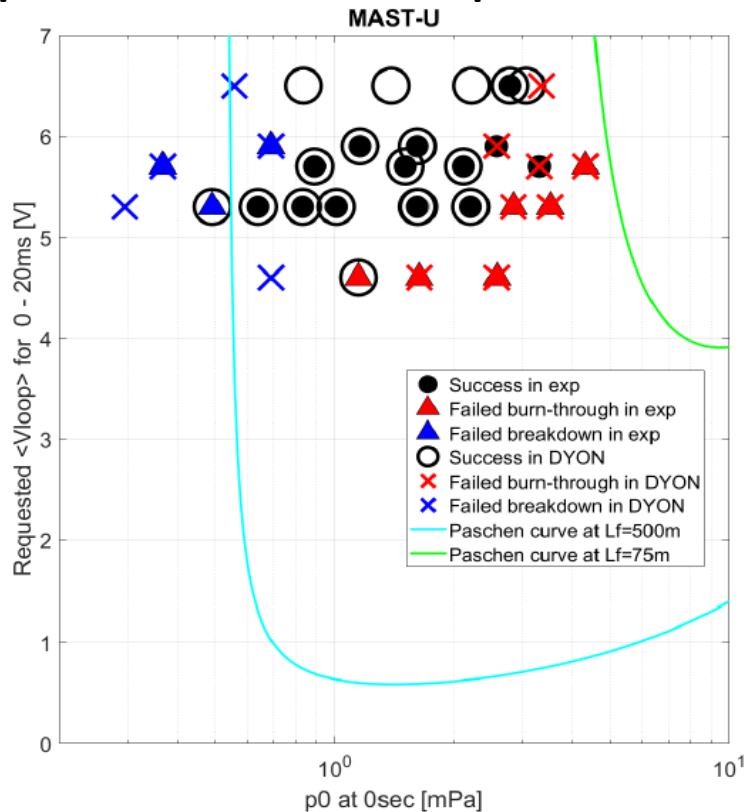


# SP-2 Breakdown/burn-through simulation tools and apply to ITER

with WP TE & SA

✓ Grant Del. "Validated models for plasma burn-through and breakdown adapted to ITER conditions"

## Operating space for plasma initiation in MAST-U experiments and in DYON prediction



[ Kim et al to appear in Nuc Fus 2024]

- ITER predictive simulations using CREATE-BD/BKDO/GRAY scheme fully integrated within the IMAS with W Wall
- Validation of plasma initiation operation space prediction capability against multi-devices data in the frame of ITPA international collaboration (e.g. EAST, DIII-D and KSTAR)
- Development in DYON of the radial force balance solver for the plasma initiation phase and the early plasma current ramp-up phase.
- Improvement and validation of the early plasma current ramp-up modelling with the free boundary equilibrium
- Development and maintenance of GUI and user interface of the DYON-IMAS interface scripts

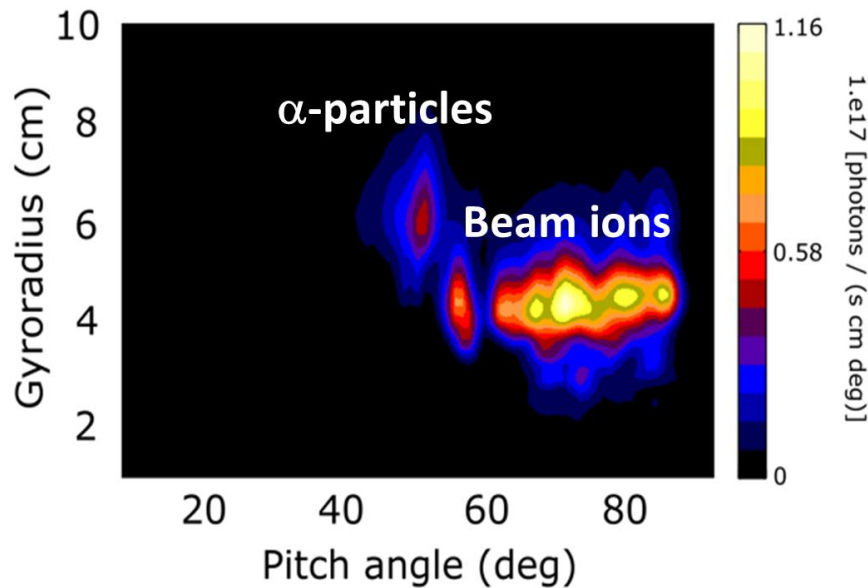




# SP-2 ITER fast ion loss detector support to design and synthetic diagnostics

with WP SA - TE

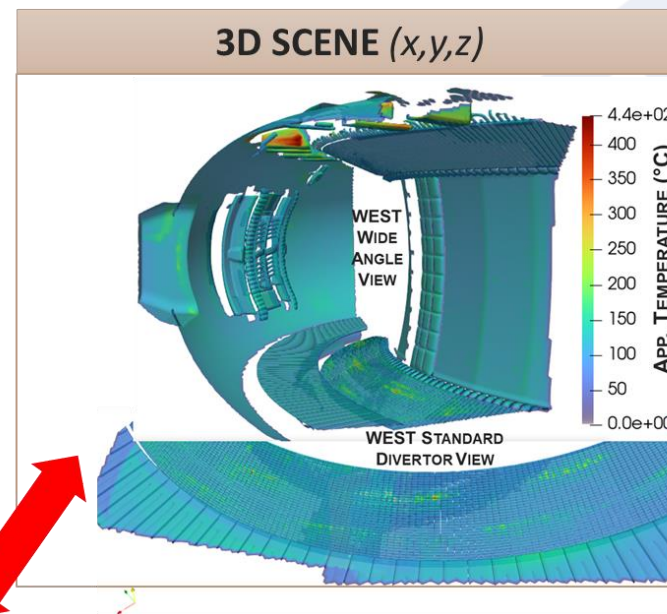
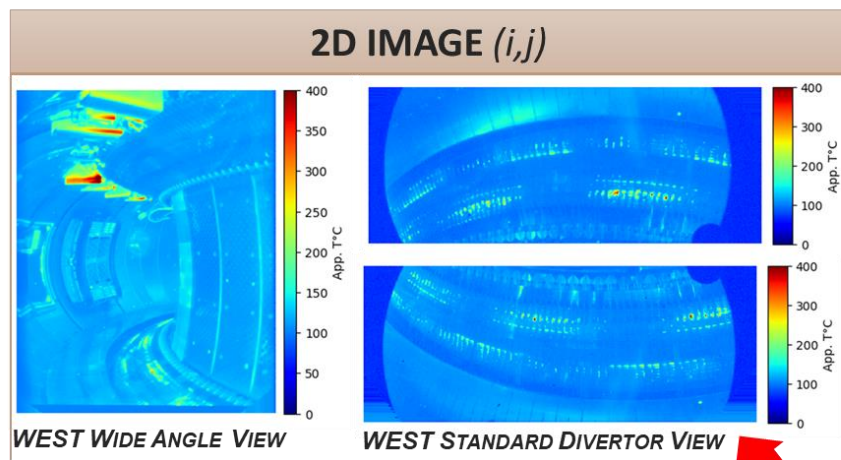
- ✓ Simulated FILD measurements of the velocity-space distribution (as a function of gyroradius and pitch angle) of the escaping ions for ITER baseline scenario
  - **synthetic diagnostic FILDSIM + ASCOT simulation for calculating the fast ion losses at diagnostic location.**



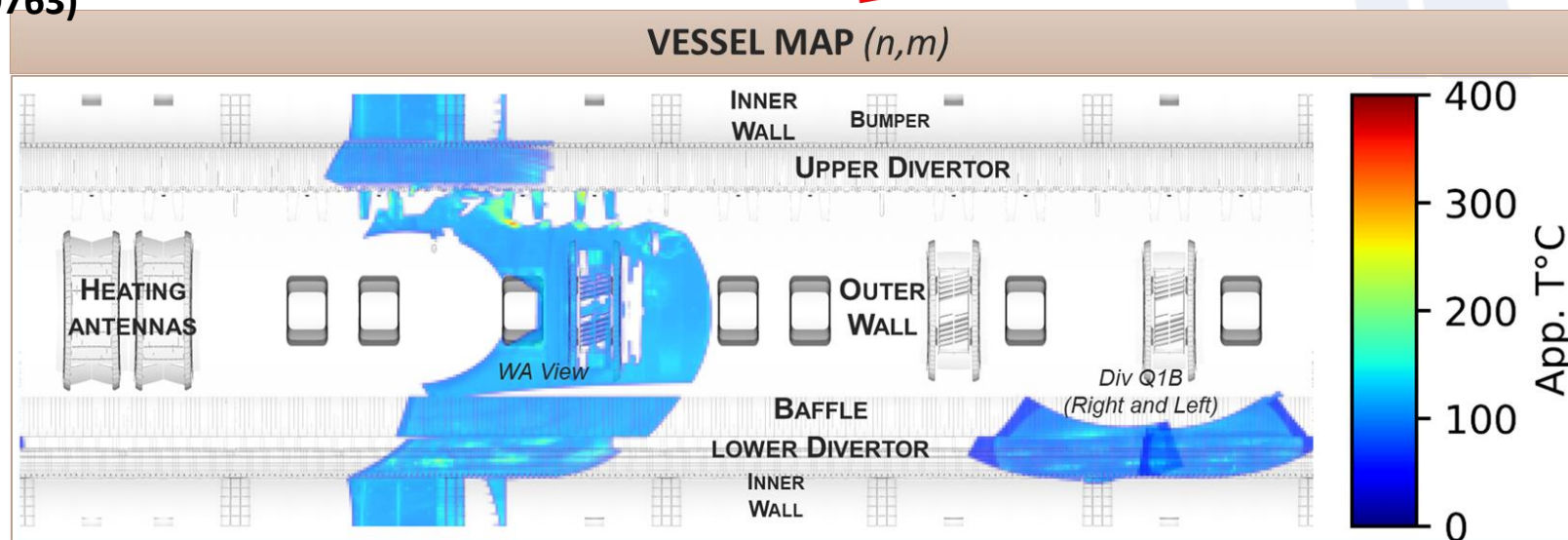
- Hybrid kinetic-MHD MEGA simulations to self consistently obtain the Alfvénic mode structures, to estimate the Alfvénic instabilities induced fast-ion flux on the FILD head.
- FILDSIM to estimate the signals induced on camera and photo-multipliers by combination of MHD instabilities and magnetic perturbations;
- Impact of the new magnetic configuration (W wall) on the radial profile of fast ion losses (pending IO to provide reference scenarios).
- **Validate the FILDSIM workflow on JET DT experiments**



# SP-2 A new tool for evaluating and mapping (simulated and experimental) data of optical diagnostics for ITER, validated on WEST



1<sup>st</sup> demonstration on WEST  
(pulse #59763)



- check the compliance with the scientific requirements
- identify the operating limits (uncovered area or poorly resolved camera)
- Support operation for the interpretation and localisation of thermal events or surface change between pulse

Linked EEG proposal shortlisted for interview



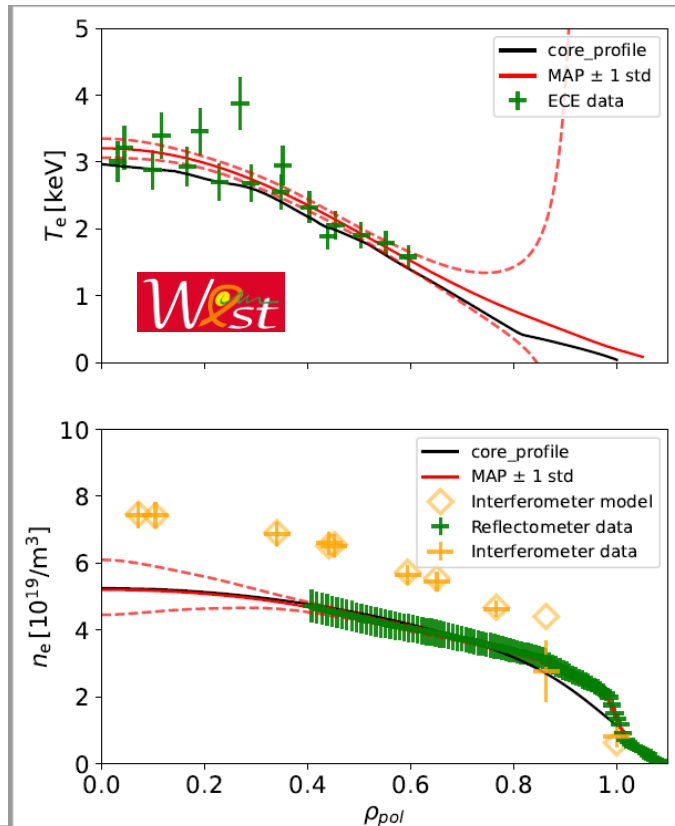
## SP-2 Develop IR temperature synthetic diagnostic for off-line analysis and ITER real-time application – 2025 activity

- Develop mapping tool to assess spatial coverage and spatial resolution of ITER optical diagnostics:
  - upgrade the prototype code and add new optical diagnostics
- Simulation of ITER IR synthetic images in presence of plasma emission in IR range
  - Modelling Bremsstrahlung radiations for inclusion in IR ray tracing code (new module)
  - Simulate IR synthetic images while including Bremsstrahlung radiation
- Integration of IR synthetic diagnostics in IMAS
  - test the whole chain of simulation using WEST IMAS data for a standard plasma scenario
- Validation of temperature inversion model on calibrated test bed (MAGRYT at CEA)
  - tests the temperature inversion model on MAGRYT test-bed
  - theoretical and experimental characterization of metallic materials properties
- Development of temperature inversion tools
  - demonstrate algorithm of temperature inversion using Machine Learning method exploiting a large training database of simulated IR images in various plasmas scenarios



## SP-2 Integrated multi-diagnostic Data Analysis (IDA) tools for ITER

- methods and tools for a coherent combination of measurements from various diagnostics validated on AUG & WEST before ITER applications
  - Extension from AUG to WEST: fully based on IMAS



- Develop integrated multi-diagnostic data to full maturity with a workflow for routine density and temperature profile estimation.
- Extend Integrated Data analysis Equilibrium code to be IMAS compatible for use in ITER and to be applied to WEST for studying equilibrium uncertainties.
- Implement the ECrad (optically thin plasmas, etc.) forward model for ECE data interpretation within IMAS and validation
- Coupling of IDA actors with MUSCLE3 for ITER applications





## SP-3 Heating & Current, ECRH (new activity following 2024 call)

- 2024 increase ECRH EUROfusion effort in support to ITER revised baseline
  - ITER Significant transition from 24 Gyrotron procurements to 80 in the revised baseline
  - commissioning on test beds will be on the critical path of the timeline



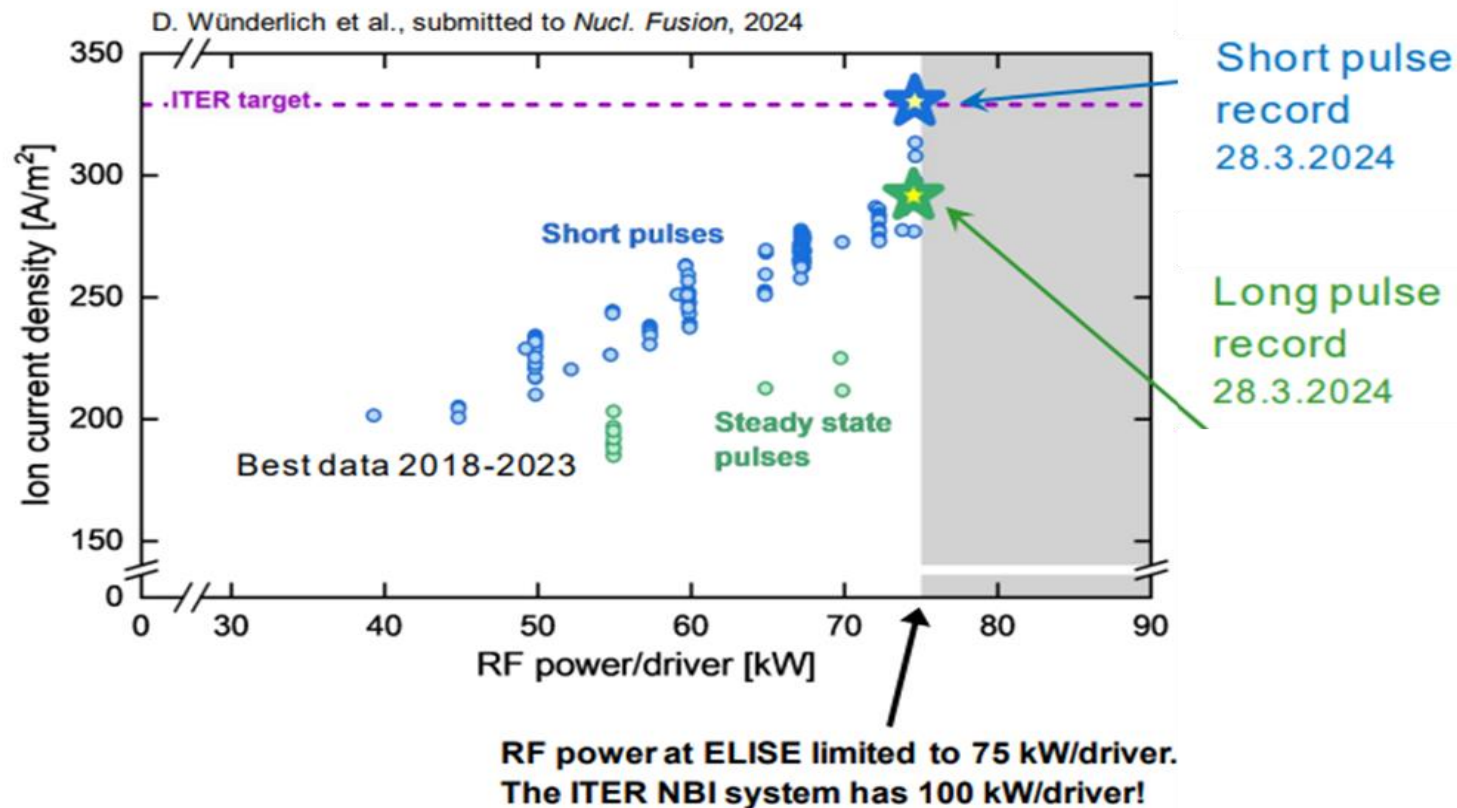
- Develop EON subnetwork on Electron Cyclotron Resonance Heating (ECRH) together with F4E
- Provide a validated (on existing facilities) commissioning procedure of the CW ECRH system or one of its major parts that is directly transferable to ITER applications and the ECRH plant
  - with IO and F4E experts participation





# SP-4 ELISE breakthrough but **significant concerns** for 2025 without solid-state RF generators

- ITER target extracted ion current density in hydrogen in short pulses (10 s)
- For long pulses (600 s): 90 % of the target values were achieved.
- solid-state RF generators (from AUG during shutdown) operated at that time only provided 75 kW/driver (150 kW/generator), i.e. 75 % of the RF in the ITER NBI systems



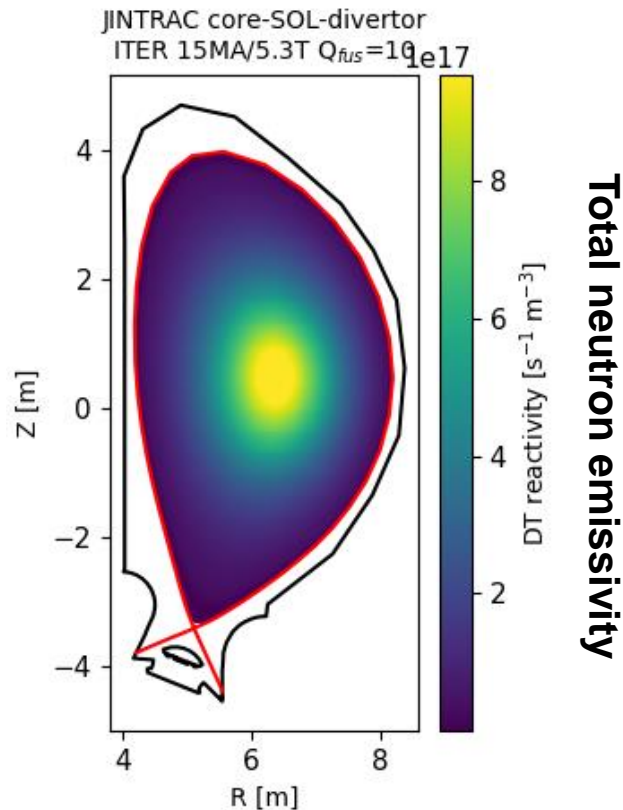
- ELISE is now using the RF generators (180 kW each) based on amplifier tubes
- Serious limitation for long pulse operation
  - frequency jumps leading to the loss in matching conditions
- Replace the two 180 kW amplifier tube RF generators by 200kW solid-state RF generators for reliable high power long pulse operation ?



## SP-5 Bridging plasma Physics and Neutronics

- Advanced computational workflow comprises plasma transport (JINTRAC), Fast ion transport (ASCOT), neutron spectrum calculations (DRESS), and MCNP neutron transport code : **Validation on JET and application to ITER in 2025**

ITER 15MA baseline  $Q_{fus}=10$  scenario



[Ž. Štancar *et al* 2021 *Nucl. Fusion* **61** 126030]

- Adaptation of the neutronics calculations for ITER in the context of the revised ITER research plan**
  - demonstration of JINTRAC-DRESS-MCNP workflow compatibility with IMAS and application to neutron synthetic diagnostics studies
- Studies of runaway electrons in W: analysis of W activation due to runaway electrons and dose rate assessment; model validation in WEST
- Optimisation of decomposition algorithm and application to ITER of GEOUNED open-source tool for geometry conversion from CAD-based models to neutronics calculations using Monte Carlo (MC) particle transport codes.



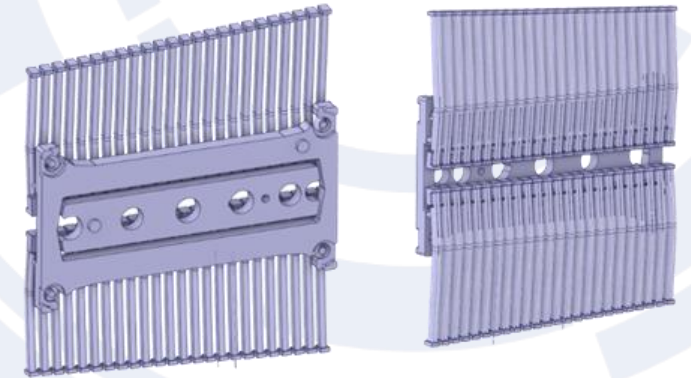
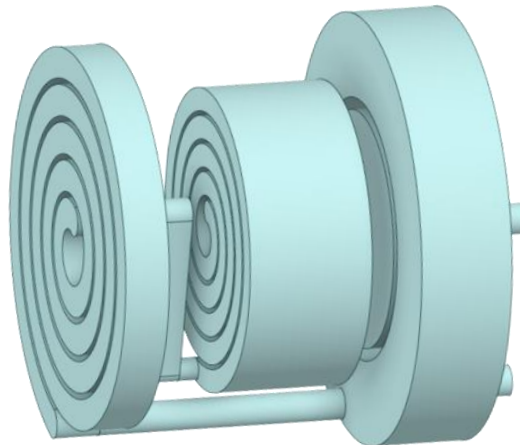
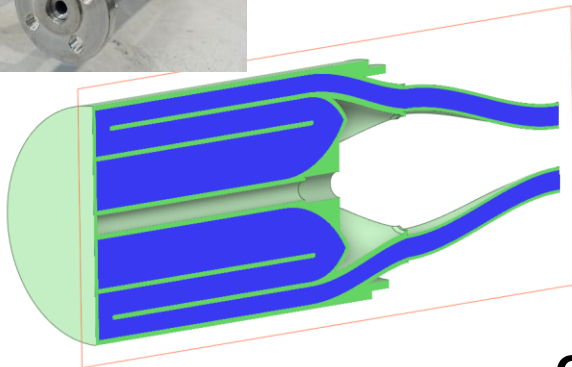
# SP-5 KATANA, new closed-water activation loop at JSI TRIGA fission reactor to validate water activation codes for ITER:

## Expands activity with different cooling loop

- Replacing Snail head with ITER relevant FW head (2025)
- neutronic & hydraulic simulations in 2024
- Conceptual design is to preserve:
  - **Hydraulic features:** pipework, water boxes, fingers
  - **Residence time:** adjusted flow rate (same regime, i.e. Reynolds #)
  - **Orientation of neutron flux gradients**

Snail head to be replaced by **ITER-relevant head**

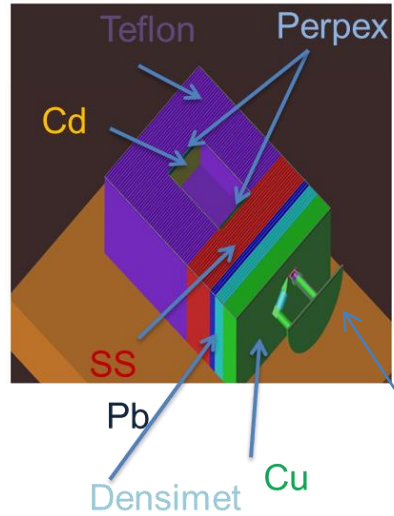
ITER FW cooling channel



Challenging Computational Fluid Dynamics effects: vortexes, stagnation points, etc.



# SP-5 Replicate ITER neutron energy spectra shape at FNG



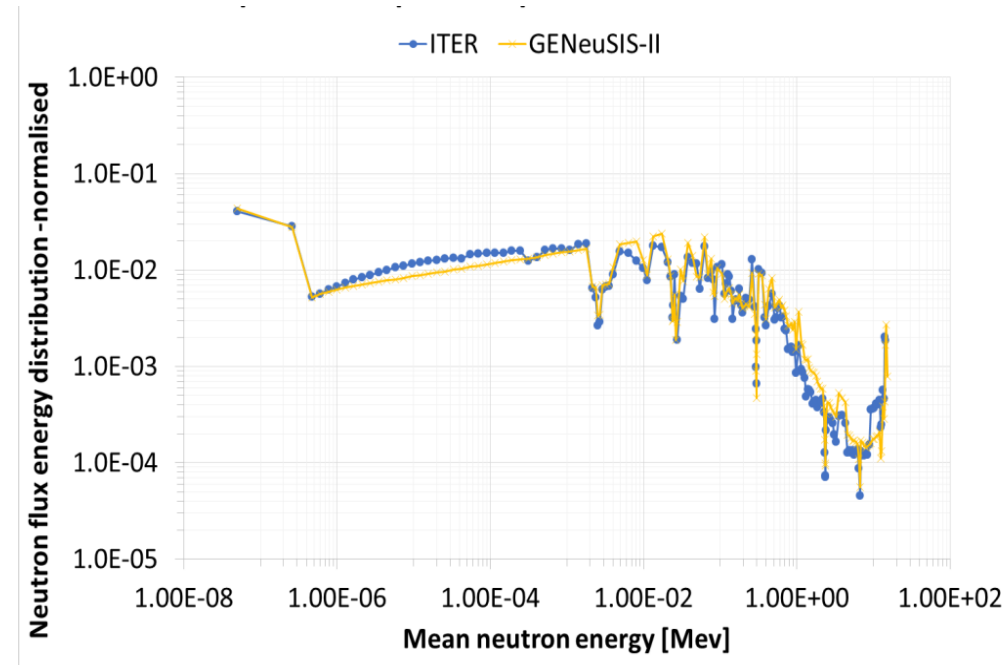
**GENeuSIS General Experimental Neutron Systems Irradiation Station:** Novel neutron test bed facility for testing diagnostics, electronics and critical ITER components

**Support from ITPA, IO**

**Materials assembly as moderator in front of 14MeV neutron flux to replicate the required neutron energy spectra distribution.**

**Neutron energy spectra as in ITER Port Cell: unique facility for testing Single Event Effects (SEE) on electronics with ITER-like neutron spectrum**

**FNG target**



- Procurement, installation and characterization of GENeuSIS
- Database for AI training to reproduce any neutron and development of advanced algorithms for testing electronics under neutron irradiation
- Experiment and analyses on neutron induced Single Events Effects (SEE) on electronics for ITER and DTT at FNG with GENeuSIS and at WEST from long DD plasma





## Conclusion

- PrIO project set-up in 2021 is on track with significant contributions
- Special journal issue on neutronics under preparation in 2025 related to JET DTE2 & 3
- **New activities in physics, diagnostic, operation and technology initiated in support to ITER revised baseline**
- PrIO key contribution: ensure that operational tools and procedures, broadly defined to include methods, codes, and sub-systems, are fully tested, validated, and reliable before being transferred to ITER for future application





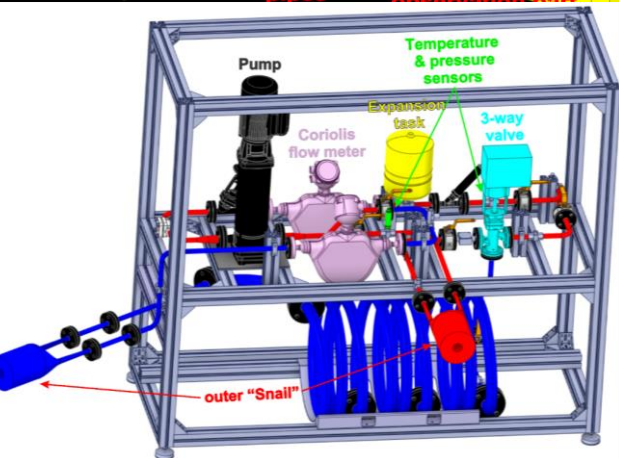
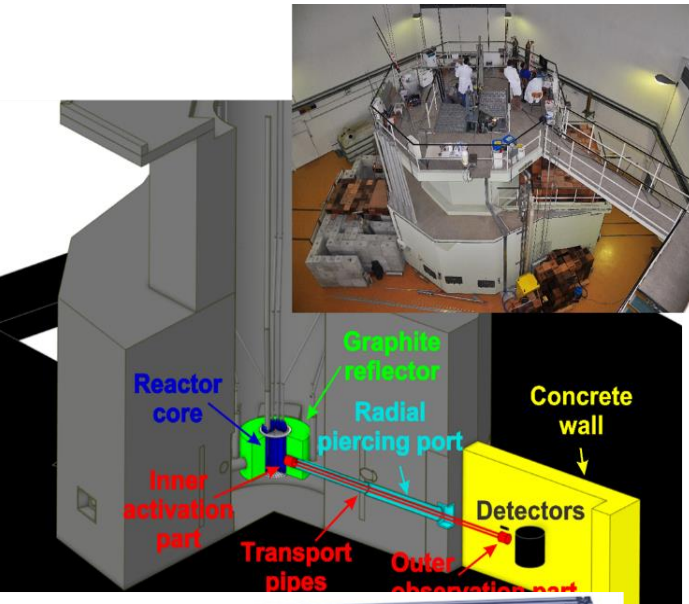
# Back-up





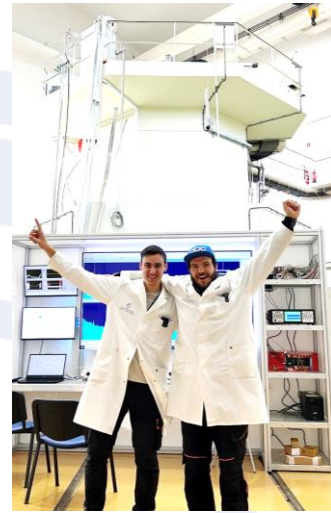
# SP-5.2.3 KATANA, new closed-water activation loop at JSI TRIGA fission reactor to validate water activation codes for ITER

- Design, construction and first experiments 20<sup>th</sup> Dec. 2023

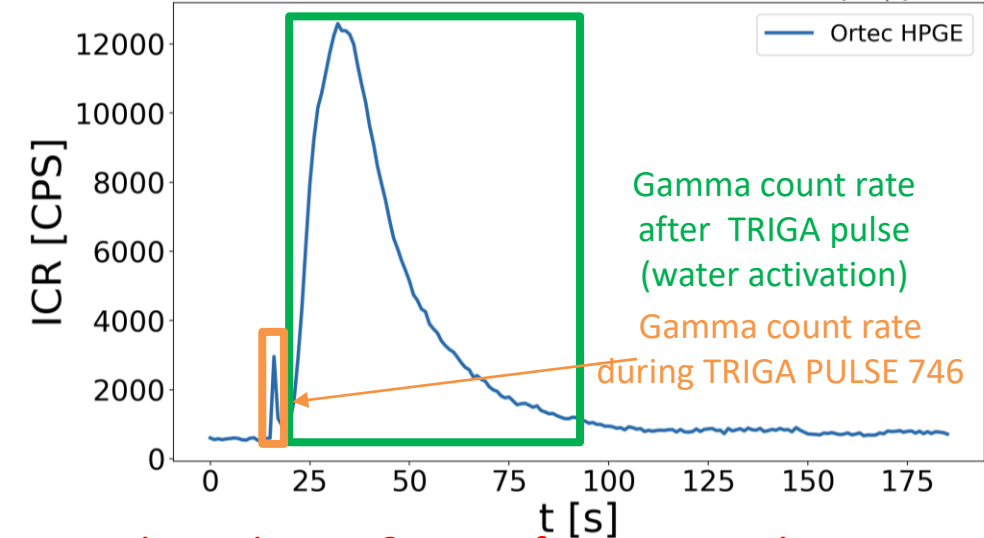


## Katana

Connecting fusion with fission



KATANA 0.13l/s, Pulse ID:746 (2\$)

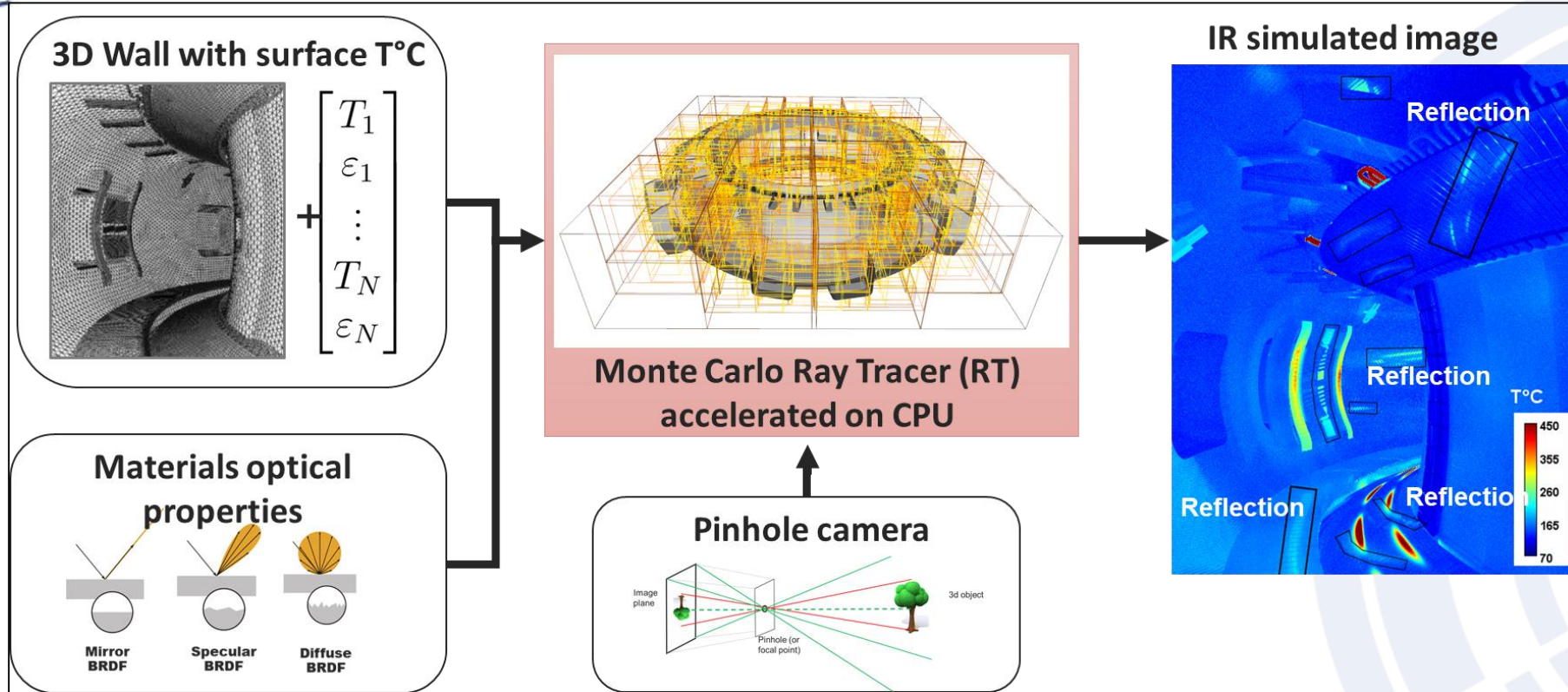


2025: KATANA loop design & manufacturing with new ITER relevant head 20 k€ (extra resource)

[Snoj, Kotnik, Peric, Lengar, Radulović et al.]



# SP-2 Progress of IR synthetic diagnostics in IMAS



- **Accelerated CPU of IR RT code done, ready to connect to IMAS**
- **New IDS required for IR synthetic diagnostics**
  - ✓ Modification of camera\_ir IDs to add **pinhole camera** model in progress
  - ✓ Adding a new structure to wall IDs to define the **materials optical properties** (reflectivity/BRDF) in progress
  - ✓ **Saving synthetic data and associated**





## Status on PrIO calls (FSD-AWP24-PrIO-25 and 26) issued in July 2024 with deadline end of September

- **SP-2:** EUROfusion support to ITER diagnostics procured by the EU, focusing on the development of synthetic diagnostics, analysis tools and calibration techniques  
**Allocated resources** ~75k€ CC **26 PM**
  - **5 proposals** from EK-CER, ENEA, JSI; joint with MPG, EPFL, IPPLM, VR for a **total of 51PM**
  - Review of the proposals with IO experts to develop collaborative activity
  - Two proposals (ENEA, JSI) will be combined on the neutron camera (link with SP-5)
  - Action to reduce down to ~42.5 PM and get resources within PrIO (cf PCR)
- **SP-3:** EUROfusion support to ECRH system commissioning for ITER  
**Allocated resources** ~360k€ CC for 2024 /2025: 60 PM, 50k€ of Hardware and 30k€ of mission costs
  - Joint coherent proposal from CEA, IPP, EPFL/SPC, KIT **within the budget. Strong support letter from IO.**
  - IO and F4E experts participation in the proposed project
  - Selection meeting organised with IO, results to be communicated to the proponent
- **SP-4 :** Call for Experts to be seconded to IPP-Garching and NBTF in Padova in the frame of the Support Activities by EUROfusion
  - Call for 3 positions at IPP and 2 at NBTF
  - Only 2 replies for one job description at IPP.
  - Interviews to be organised but **call to be re-opened for the other 3 positions**



# SP-2 Pedestal multi-machine Database – status

L Frassinetti

- JET
  - database available on JDC since 2021\*
  - stored in IMAS on the EUROfusion Gateway contains all the data till DTE2. to be updated by the end of 2024 to include all the JET pulses till the end of 2023.
- TCV database is stored in IMAS on the EUROfusion Gateway, being extended, by the end of 2024 it should be significantly larger.
- MAST-U & AUG dataset (no 2024 Task): lack local contact person.
- The plan is to have a web interface to download from the Gateway a simplified version of the DDB in text format (easy to transfer to excel)- **when the new Gateway is ready.**
- Concerning the availability, two options:
  1. At end 2024 when the JET version will reach its final state (or almost final) and the TCV version is extended, provide scripts to download it from the present Gateway.
  2. Wait for the new Gateway, provide all the tools to download the database (both scripts to download the full database and the web-interface to download a simple text/csv file)

**! Action on PMU pending since Sept 2023 : prepare an Agreement for users to sign before being allowed to download the database.**

[\\*https://wiki.jetdata.eu/tf/index.php?title=EUROfusion\\_JET\\_Pedestal\\_database\\_GUI](https://wiki.jetdata.eu/tf/index.php?title=EUROfusion_JET_Pedestal_database_GUI)





## SP-2 Disruption multi-machine database – status

A Pau

- **DEFUSE framework released as open source by the end of the year**
- Codes and data in the process of being migrated from SPC cluster to the new EUROfusion Gateway
  - The interfaces for mapping data to IMAS have been developed and are currently under test before the migration to the EUROfusion Gateway by the end of October.
  - Urgent to discuss the update of the IDS for disruptions to accommodate the various related quantities.
  - authentication and the availability of the data for a given machine needs to be carefully discussed
- JET: the validation of the entire JET-ILW completed and a an SQL/noSQL currently hosted for tests in a dedicated server at SPC with IMAS tools available
- TCV: large database validated and available locally to EUROfusion users with access to TCV data. Ready to be mapped to IMAS after the update of the disruption IDS.
- MAST(-U): successful extension to MAST data. data-mapping for MAST-U is currently being finalized, and while MAST data are already publicly available, MAST-U access / availability needs to be discussed.
- AUG: good progress with recover/update of the various data-processing pipelines and DEFUSE installed and working also on IPP TOK clusters
- WEST: first contacts with local experts to identify data sources and key diagnostics.
- JT60-SA: proposal to include also JT60-SA disruptions in the EUROfusion database as well as for implementing the mapping to IMAS.



## SP-2 Pedestal multi-machine Database – status

L Frassinetti

JET version already available on JDC since 2021 to all EUROfusion users with a JET account ([https://wiki.jetdata.eu/tf/index.php?title=EUROfusion\\_JET\\_Pedestal\\_database\\_GUI](https://wiki.jetdata.eu/tf/index.php?title=EUROfusion_JET_Pedestal_database_GUI)). This version contains only the data before DTE2.

- JET version stored in IMAS on the Gateway contains all the data till DTE2. It will be updated by the end of this year to include all the JET pulses till the end of 2023.
- TCV database is stored in IMAS on the gateway, being extended, by the end of 2024 it should be significantly larger.
- MAST-U dataset (no 2024 Task): lack local resources. There is a chance to extend by end of 2024.
- AUG dataset (no 2024 Task): lack local resources.

The plan is to have a web interface to download from the Gateway a simplified version of the DDB in text format (easy to transfer to excel)- **when the new Gateway is ready**.

Concerning the availability, two options:

- At end 2024 when the JET version will reach its final state (or almost final) and the TCV version is extended, provide scripts to download it from the present Gateway.
- Wait for the new Gateway, provide all the tools to download the database (both scripts to download the full database and the web-interface to download a simple text/csv file)

**! Action on PMU pending since Sept 2023 : prepare an Agreement for users to sign before being allowed to download the database.**



# SP-2 Disruption multi-machine database – status

A Pau

- **DEFUSE framework being released open source by end 2024** (various requests also in the context of international collaborations).

Agreement for a "code camp" at the very beginning of 2025.

Codes and DDB in the process of being migrated from SPC clusters to the EUROfusion Gateway by the end of October (GUB request for resources accepted).

**Interfaces for mapping data to IMAS developed and currently under test** in the aforementioned server.

**Urgent to discuss the update of the IDS for disruptions to accommodate the various related quantities.**

- JET: validation of the entire JET-ILW (identified as the main priority) completed and SQL/noSQL (MongoDB) currently hosted for tests in a dedicated server at SPC with IMAS tools available
- TCV: large database validated and available locally to EUROfusion users with access to TCV data. **Ready to be mapped to IMAS after the update of the disruption IDS.**
- MAST(-U): successful extension to MAST data, with fully functional processing pipeline, UKAEA first run for 3k shots (vast majority ending up with a disruption). Data-mapping for MAST-U being finalized. **While MAST data are already publicly available, MAST-U access / availability needs to be discussed.**
- AUG: good progress with recover/update of the various data-processing pipelines and DEFUSE installed and working also on IPP TOK clusters. Collaboration with Gabriella Pautasso to advance in the validation (data and corresponding DDB should also be available in the EUROfusion Gateway at least for people with access to AUG data).
- WEST: first contacts to identify data sources and key diagnostics for the construction of the DDB.
- JT-60SA: proposal accepted to include also JT-60SA disruptions in the EUROfusion database as well as implement mapping to IMAS (as far as plasma states events and disruptions are concerned).

**“Availability”** according to the recent discussions with WPTE TFLs and JET people:

migrate to the new Gateway, providing tools and documentations to download and query the DDB, both for data-sources and metadata (disruption derived characteristic quantities) from a MongoDB versioned multimachine DDB (already tested locally). It is essential to have this additional layer, because not all the events and plasma state descriptions relevant for disruption analysis are mapped in IMAS .

**A server-client installation on the Gateway would allow to handle user access with authentication (tested already locally).**

Proposal : local MongoDB instances (and DEFUSE tools) in the computational nodes of the various machines to make data access and validation as efficient as possible, and then move the validated DDB to the Gateway for final checks and IMAS mapping. This scheme allows the needed flexibility for the various applications. **The authentication and the availability of the data for a given machine needs to be carefully discussed.**