

# Preparation of ITER Operation, WPPrIO

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DE LA RECHERCHE À L'INDUSTRIE

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.



## **2022 programme goals & strategy (AWP 2022):**

**WP activities, TSVV links, resource allocations, risks, synergies,  
international collaborations, 2022 GA milestones/deliverables...**



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# Recommendations\* on “EUROfusion role in ITER op. & scientific exploitation” and PrIO contributions



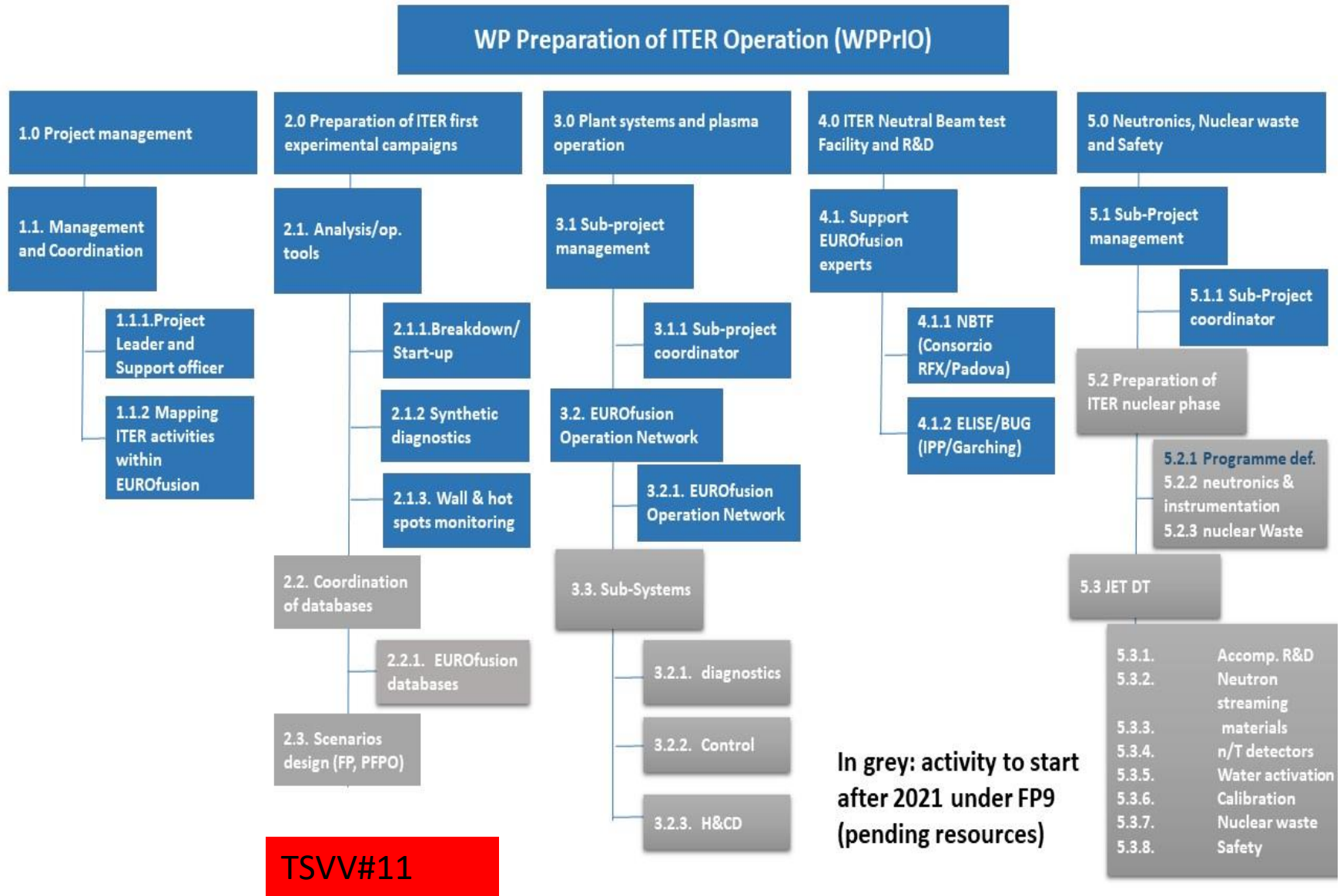
\*) EUROFUSION GA (20) 32 - 4.7

	Sub-systems	Required involvement for EU implication in ITER operation	Impact level on the EU DEMO design
2022 ?	TF & PF Magnets and Cryo-plant	*** in commissioning phase (* during full operation)	++ (for DEMO design)
→	Divertor & PFCs	***	++
→	Tritium Plant	***	+++
→	Breeding Blanket System	***	+++
→	H&CD: Neutral Beam	*** (NBTF)	+++
→	Diagnostics	***	+++
→	Control and Analysis/operational/simulation tools	***	++ (+++ for some control aspects)
	H&CD: Electron Cyclotron	**	++
	H&CD: Ion Cyclotron	** (present operation in present facilities)	+
→	Neutronics, Waste and Radiological Protection	**	+++
	Vacuum Vessel	*	+
	Remote Handling Equipment	*	+
	Vacuum Pumping & fueling	*	+
	Building and Electrical Power Supply & Distribution System	*	+++ (for DEMO design)

(+++): Unique, (++) High, (+) Significant

(\*\*\*) Strong: Organized team with defined commitments, (\*\*) Organized team, (\*) Expertise for follow-up

# Work Breakdown Structure - 5 Sub-Projects



**TSVV#11**

# 2022 Milestones and Grant Agreement Deliverables



Milestones Table	
PRIO.M.03	Establishment of the EUROfusion Operation Network
PRIO.M.04	Coupling of existing breakdown/burn-through models to the European Plasma Simulator (together with TSVV11)
PRIO.M.14	Preliminary analyses of measurements and simulations of JET nuclear quantities (neutron flux, dose rate, neutron induced activation, radiation damage) in DT
PRIO.M.15	n/T validated data with detectors for the breeder blankets at JET during DT
PRIO.M.16	Completion of collection of Occupational Radiation Exposure and waste data
PRIO.M.17	Completion of calibration verification at JET in DT operations

Deliverables Table	
PRIO.D.01	European Plasma Simulator (Python workflow) released to the EUROfusion community including all available IMAS modules and a user friendly interface (TSVV11)
PRIO.D.02	Report on the procedure for an automated and systematic validation of predictive integrated modelling including uncertainty quantification (TSVV11)
PRIO.D.12	Report on EUROfusion participation in ITER NBTF, ELISE and BUG activities
PRIO.D.13	Report on long pulse operation 1000s extraction of H- on ELISE facility
PRIO.D.22	Report on testing of n/T detectors in JET DT for breeder blanket
PRIO.D.23	Report on Occupational Radiation Exposure and waste data collected at JET in DT operation
PRIO.D.24	Report on calibration verification at JET in DT operation

# SP-1 Project Management and coordination

## New coordination activity related to ITPA



- **WPrIO keeps track on the PrIO Wiki page of the TG group meetings, list of EU members, ITPA-JEX etc**
  - <https://www.iter.org/org/team/fst/itpa>
- **WPrIO organises with the other relevant WP Leaders and PMU coordinators meetings with the EU TG members between two ITPA meetings**
  - Improve the scientific coordination between ITPA and EUROfusion
  - Get feedback on the important ITER priorities
  - Review/comments the main ITER ‘hot topics’ that could influence the WP activities (ITPA experiment, joint analysis ...)
  - Prepare EUROfusion inputs for the next TG meetings
- **WPrIO funds (with extra resources) and validates missions of the EU experts and keeps track of scientific mission reports**

# SP-2: Plasma initiation



- Complete the development of plasma volume evolution model (circuit equation) in DYON and validate against experiments
- For ECH pre-ionization modelling, localized electron avalanche to be modelled with a Particle-In-Cell code.
- Automate the scenario optimization workflow in DYON, validate it against experiments and apply it to ITER
- Adaptation of the simulation codes to IMAS (CREATE-BD/BKDO/GRAY)
  - Support from ACH is formally requested
- Operational window for ITER, i.e. a scan in ( $P_{EC}$ ,  $n_{neut}$ , impurities...)
- Benchmark CREATE-BD/BKDO/GRAY workflow with Dyon
- Link with TSVV11
  - Breakdown database for direct comparison to modelling
  - Procedure for the transition from plasma initiation to ramp-up

# SP-2 : development of IR temperature synthetic diagnostic for ITER real-time application and offline analysis



- **1: Development of ray tracing codes**
  - Benchmarking codes Raysect (open-source) vs ANSYS-SPEOS: application to ITER antenna heat flux
- **2: Characterization of optical properties of materials**
  - investigation of detailed numerical models of Bidirectional Reflectance Distribution Function and emissivity for implementing in IR synthetic diagnostics
- **3: IR experiments in tokamaks**
  - comparison of photonic models and experimental results
  - Include transient events (Disruption , ELM) in the IR synthetic diagnostics and simulation. This may require to run predictive codes for transient events (JOEKE simulations) and coupling to SPEOS (IR image simulator)



# SP2 : Development of a wall thermal events & hot spot monitoring system for ITER



- **2022 : Demonstration of a data pipeline for processing thermal events in a thermographic movie operating off-line. Key actions: detection, data enrichment and classification.**
- **2023 : on-line test**
- **2024 and beyond : Algorithm to be developed for ITER and tested with synthetic data**

# SP-2: Preparation of ITER first experimental campaigns (PFPO-1/2) : **Proposed new activities-**



- **Scenario design for ITER first experimental campaigns**
  - ITER preparation of first campaigns and simulations using existing tools liaising with IO
  - Extrapolation based on lessons learnt from EUROfusion results : e.g. isotope effects, H and He campaigns, transition from H, D, DT
  - Support TSVV11 development activity
  - Synergy simulation DEMO Central Team:
    - Simulation ITER, DEMO by same team
  - **Improved coordination with F4E needed**
  - **Needed resources : 18PM/year + new call**
- **EUROfusion databases**
  - Add L-H transition database with a focus on new results from JET, AUG on isotope effects , He campaign
  - Transfer to IMAS, include new data
  - Support to TSVV#11
  - **Needed resources : 2PM/year + new call**
  - **IMAS support formally requested**

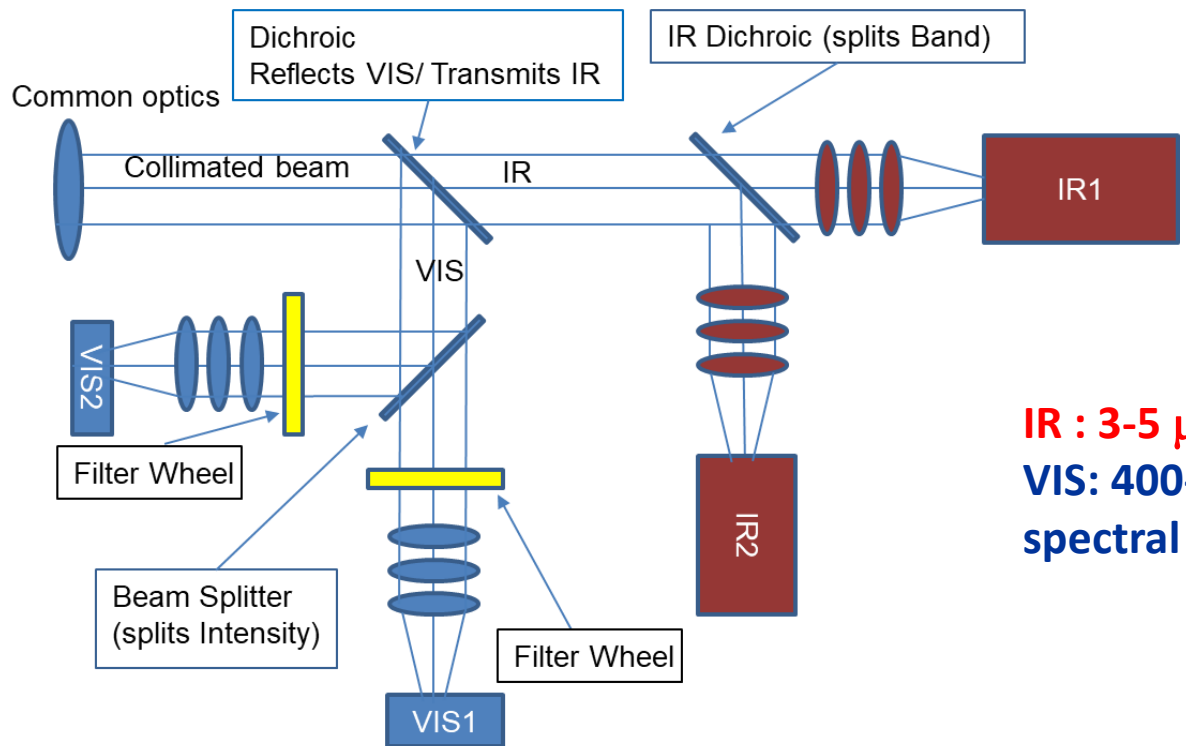
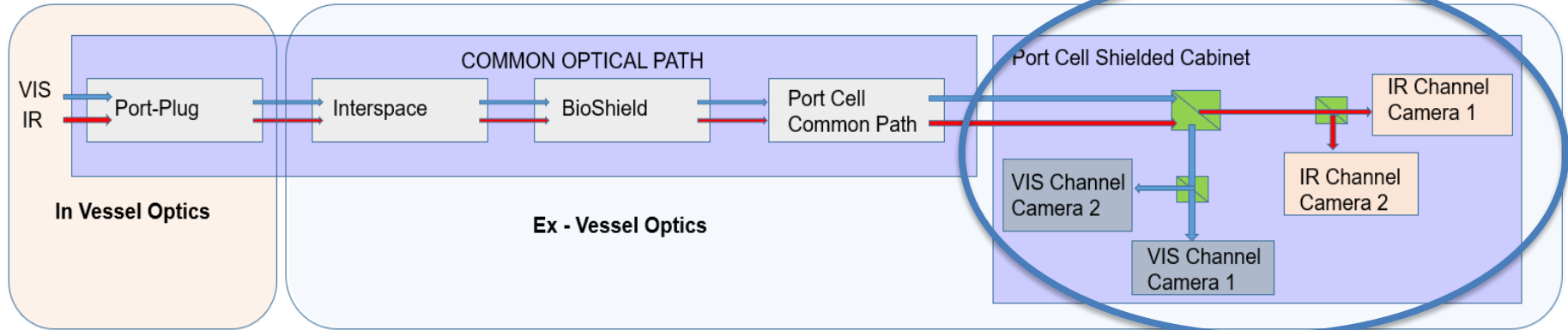
# SP-2: Preparation of ITER first experimental campaigns (PFPO-1/2) : **Proposed new activities-**



- **IR and visible** diagnostics for ITER

- Expand the 2021 activity to visible light with the new capabilities of WAVS (c.f. next slides) and AI/Deep Learning techniques of large databases of visible images
- **Needed resources : 18PM/year + new call**
- **improved coordination with F4E needed**

# ITER Wide Angle Viewing System: IR and Visible lines open new capacities for physics studies



**IR : 3-5  $\mu\text{m}$**   
**VIS: 400-700nm optimised in the spectral band for H/D $_{\alpha}$  656nm**

# Visible lines open new capabilities for physics studies (ITER Wide Angle Viewing System)



- **Further explore new capabilities for 2D characterization of Be and W erosion / transport studies in synergy with WPPWIE and in coordination with F4E**
  - based on experiments in EUROfusion facilities [e.g. 1,2]
- **Development of advanced automatic image analysis tools using IA /Deep Learning techniques in synergy with effort on IR**
  - Analysis of ITER Big Data (~ 2 PB per day !) will require to develop automatic process
  - Automatic search for patterns in large database of visible images [e.g. 3]
  - Many physics applications to the physics breakdown, disruption and mitigation with SPI (c.f. JET fast camera), fast ion losses
  - Application to other diagnostics (2D data of ITER Thomson Scattering): automatic filtering of stray lights using Deep Learning techniques

[1] J. Karhunen et al. Nuclear Mat. and Energy **25** (2020) 100831

[2] A. Huber et al. Nucl. Mat. and Energy **18** (2019) 118

[3] A. Bustos et al. PPCF **63** (2021) 09501



- **Participation in ITER plant & integrated commissioning/operation**
  - **Preparation** of ITER superconducting magnets IC as a pilot project
    - Thermohydraulic, structural, electromagnetic and control **modelling**
    - Instrumentation and interpretation
    - Control, responses to Faults and Off-normal behaviour
  - strong expertise & synergy with WPJT-60SA activity, knowledge transfer to DTT and WPMAG for DEMO design
  - Ensure transition from JT-60SA to ITER and ITER to DEMO
  - Initiate the work in 2022 with reduced level of resources
  - **Needed resources growing up to 12 PM + new call**
- **Diagnostics:**
  - Participation in ITER FILD diagnostic design
  - Resources already attributed but on hold pending IO review: reciprocating scintillator detector or dedicated IR based solution.
  - IO Decision by end of October 2021.

# SP-3: Plant systems and plasma operation



## Proposed new activities

**EUROfusion Operations Network (EON):** share operational experience, operator trainings and identify joint activities on EUROfusion and ITER-relevant operational issues

- European members meetings of the ITER Operations Network (ION) to coordinate our activities prior and after ION meetings (like ITPA)
- Set-up new **EON competency-based subnetworks** with workshops on high-priority operational topics for EUROfusion and ITER
  - Pilot subnetwork: NBI seminar series (starting in 2021)
    - online and open to EUROfusion experts incl. QST/JT-60SA staff, F4E and IO
  - New subnetwork areas in 2022 to be defined (vacuum conditioning, ECRH, ..) based on EUROfusion and F4E/ITER priorities -> 2-4 events in 2022
- Create **knowledge base for Operations** (contribute to knowledge management activities and platform managed by the PMU)
  - Agreed Knowledge Management pilot with the PMU on NBI.
  - Build Session Leader knowledge base



**EUROfusion Operations Network (EON): Support operator training in EUROfusion on ITER-relevant operational issues**

### 1. On-site participation in local operator training courses

- e.g. external participants in Session Leader courses
- Needed resources: 1 week participation for ~20 candidates (WPPrIO) and mission for selected SL during Campaign (WPTE ?)

### 2. Pilot project on Session Leader Subnetwork

- Beginner course on session leading (15 topics x 2 hour): new SLs, SCs, EEG, ...
- Advanced workshops for current session leaders and operations experts to discuss and share experience across all EUROfusion devices (incl. JT-60SA, invite IO/F4E)

- **Support short-term missions of technical experts to EUROfusion facilities to support commissioning of plant systems and plasma operations on ITER related issues**

- Topics to be identified where we have a gap and level of support
- Needed resources: 6 PM (6-12 experts for 2-4-weeks)



# SP-4: Neutral Beam Test Facility and R&D for ITER Neutral Beam: ELISE & BUG



- Symmetrisation and reduction of the current of co-extracted electrons
- Stable long pulse operation: stable co-extracted electron current
  - Routine operation of the new CW power supply on ELISE
  - up to 1000s in H on ELISE and BATMAN, initial test in D
  - CW diagnostic calorimeter (ELISE)
  - New Cs management approaches on BATMAN
- Detailed studies of beam optics
  - Continuation of study of beam optic dependencies on various source parameters
  - Characterisation of the beam as well single beamlets with an extended set of

	Q1	Q2	Q3	Q4
<b>ELISE</b>				
Fine-tuning cw-PS operation	■			
Commissioning and data acquisition of cw-calorimeter	■	■		
Stepwise increase of pulse length in H		■	■	■
Initial test on increasing pulse length in D			■	
Optimisation of potentials and filter field		■	■	■
<b>BATMAN Upgrade</b>				
Beam optics studies	■	■	■	
Test of Cs management approaches		■		
Experiments in D			■	
Installation of cw cooled plasma grid and bias plate			■	
Stepwise increase of pulse length in H				■

summer break

# SP-4: Neutral Beam Test Facility and R&D for ITER Neutral Beam: SPIDER



- **SPIDER entered in a long shut down to improve future operation**
- **Improvement interventions :**
  1. Upgrading of the pumping system
  2. Replacement of RF oscillators with solid state amplifiers
  3. Maintenance and improvement of the Beam Source
- **Start of the experimental phase expected in December 2022**

# SP-4: Neutral Beam Test Facility and R&D for ITER Neutral Beam: MITICA



- **Background** : In 2021, failures occurred during the 1MV power integrated tests due to BreakDowns (BD) that damaged two components of the power supply system:
  - Diode bridge of stage DCG1 (800kV-1MV)
  - HV bushing of the 1 MV insulating transformer
- **The 2022 MITICA schedule is being updated taking into account** :
  - Repair and improvement of the MITICA power supply system
  - Completion of the integrated power tests of MITICA's power supplies
- **An updated MITICA schedule will be developed in October and presented to the NAC**

# Scientific activity: EUROfusion team fully integrated to NBTF team



## ➤ Experiments:

- Analysis of data collected in 2018-2021:
  - Operation without and with caesium
  - Assessment of main issues emerging from experiments
- Characterisation of caesiated samples in CATS

## ➤ Modelling:

- Simulations of SPIDER plasma and beam operations for preparation of tests and modifications and for diagnostics improvement
- Simulation of initial MITICA beam operations in view of parameter setting and diagnostics
- Tuning of caesium model with experimental data
- Tuning of BIRD model with experimental data

## ➤ HV holding:

- voltage holding tests of MITICA
- tests of electrodes with HV Short Gap Test Facility



- **Structure the activity along 4 thrusts for JET/ITER**
  1. Neutronics code simulations and development
  2. Neutron activation and damage in materials
  3. Nuclear measurements and instrumentation
  4. Nuclear safety and waste
- **JET DTE2:**
  - analysis in 2022 and 2023 after completion of DT campaign under PrIO
  - Re-assess/re-scope the analysis needs following DTE2
  - Organise the hand-over from JET3 (2021) to PrIO
- **JET DTE3 (pending JET extension) : New activity (extra resources)**
  - New resources (80 PM/y – Ref. JET3 140-180PM/y) to be allocated for the elaboration of DTE3
  - Assess possibility of Water Activation Experiment
- **EUROfusion activities for ITER: New activity**
  - High Impact level on ITER and on the EU DEMO design
  - On-going selection by a joint working group with EUROfusion, F4E and IO
  - Activity within resources attributed to SP-5



- **Working group (EUROfusion, IO, F4E) to define the 2022-2025 activities on EUROfusion activities for ITER**
  - Rosaria Villari ENEA Chair
  - Yannick Penelieu CEA
  - Lee Packer CCFE
  - Rafael Jaurez CIEMAT
  - Maurizio Angelone ENEA
  - Jerzy Mietelski IPPLM
  - Luka Snoj JSI
  - Dieter Leichte KIT ( link with DEMO aspects)
  - Theodora Vasilopoulou NCSR
  - Anders Hjalmarsson or Göran Ericsson VR
  - **M. Loughlin, IO & M. Fabbri, F4E**
- **4 Workshops on 4 high priority topics (01 & 02 Sept.) High participation and interest**
  - Neutronics code simulations and development
  - Neutron activation and damage in materials
  - Nuclear measurements and instrumentation
  - Nuclear safety and waste
- **13 & 16 September 2021: Review and selection of proposals within the resources**
- **High interest from all EU labs and oversubscription by a factor 5 vs SP-5 resources**

# Topics for ITER – High priority



1. Neutron and gamma source in early ITER operations
2. Activation corrosion products  
methodology/assessment/experiment
3. Fluid activation methodology/assessment/experiment
4. Shielding measurements under 6 MeV photons emitted  
from water activation
5. Measurements of low dose levels in DD and DT plasmas
6. Beryllium and Tritium contamination

**Even if PrIO selects only these 6 high priority ITER topics out of  
~35 topics proposed we are still oversubscribed**

# Training : EUROfusion Engineering Grants AWP2022



- EEG21-17 Development of Infra-Red monitoring system using artificial intelligence techniques in view of ITER application
  - Formally in WPW7X but in strong connection with WPrIO
- EEG21-18 Engineering support on the wall conditioning and ITER GDC design
  - Candidate did withdraw at last minute
  - To be proposed in 2022 call



# International Collaboration for 2022 – **New activities**



- **EU-Korea**
  - Collaboration on DYON upgrade developments for breakdown simulations
- **EU-US-DOE**
  - Extend collaboration agreement :
  - For JET beyond 2021 and JETDTE3
  - Other neutronics simulation activities and ADVANTAGE support in EU



# Interfaces/Synergies , Resources



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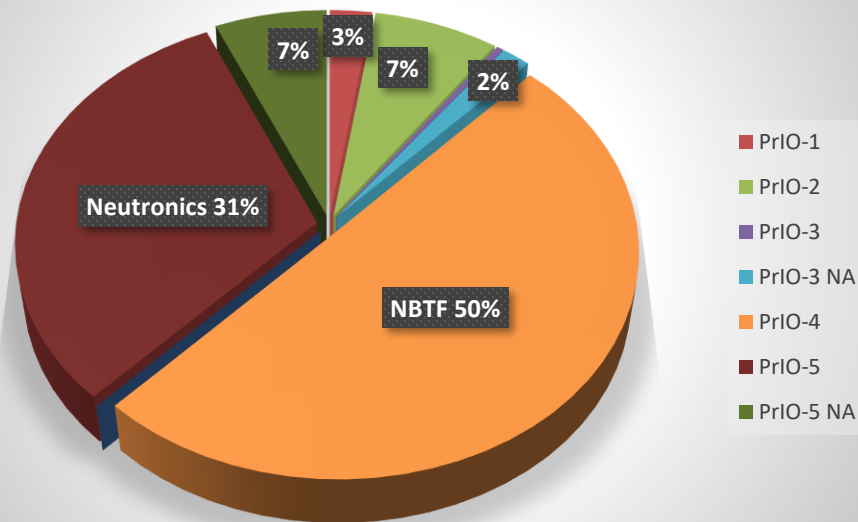
- Scenario modelling with TSVV11, FDT-CDT
- Breakdown simulator activity in synergy with TSVV, WPSA and WPTE (Tokamak Exploitation)
- Development of synthetic diagnostics (WPSA, WPTE, WPAC/TSVVs...)
- Development of reduced model (WPAC/TSVV)
- Real time protection of the plasma facing components (WPTE, WPW7X)
- Multi-machines databases (WPTE, ITPA)
  - JT-60SA disruption database could be connected to the EUROfusion database
- Wall conditioning topics (WPPWIE, WPTE, WPW7X)
- EUROfusion Operations Network: seminars, workshops, trainings open to IO & JT-60SA staff
- Interface with IO is working well
- **Low level of interaction/communication with F4E except on neutronics**

# 2022 Indicative Resources per sub-project

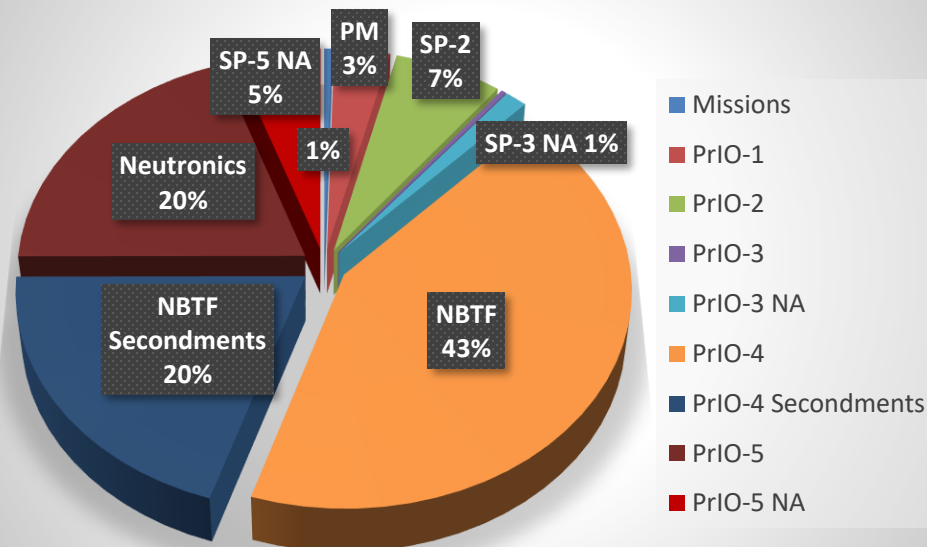


	Total Cons. Contr. (k€) 2022
PrIO-1	83,093
PrIO-2	161,596
PrIO-3	7,740
PrIO-3 NA	33,789
PrIO-4	1012,813
PrIO-4 Secondements	541,875
PrIO-5	489,365
PrIO-5 NA	128,906
Missions	10,938
<b>Total</b>	<b>2470,114</b>

2022 Total Manpower = 502 PM



2022 IR Total CC 2470,1 k€



Extra budget for new activities: 252k€  
~10% Total WP PrIO budget

# Summary of new activities and required resources for 2022-2025



Sub project	Task	Required PM / y	Total CC cost
SP-2	Scenario design for ITER first experimental campaigns	18	
SP-2	L-H transition database	2	
SP-2	visible synthetic diagnostics for ITER	18	
SP-3	Session Leaders training	5	~14 k€ (3 months secondment Unit Cost)
SP-3	Participation in ITER IC commissioning and operation of superconducting magnets	12	
SP-3	Mission of technical experts in support to commissioning and operation	6	
SP-5	JET DTE3 (pending JET extension)	80 ?	
SP-5	EUROfusion Neutronics, Nuclear Waste and Safety activities for ITER	30	Included within SP-5 NA 105 k€/y on average
	<b>TOTAL</b>	<b>61 PM w/o JET</b>	<b>Extra ~252 k€ requested ~10%</b>

**Activities and resources should grow when approaching ITER operation**



# Back-up



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# SP-2 pedestal database : future plans



- JET:
  - The tools for the database creation are ready and the scripts to transfer the database to IMAS have been finalized. So the future will focus on:
    - extend to the database to TT and DT pedestal and to the new campaigns
    - make the local JET version easily available to JET users
  
- AUG, TCV, MAST-U:
  - The tools for the database creation are ready. The future will focus on:
    - finalize scripts to transfer data to IMAS
    - Extend the databases
  
- People involved via WP PrIO:
  - Only the database coordinator: L. Frassinetti
  - Other personnel will be involved via WPTE



- **0D:**
- JET, in collaboration with the contact person to be appointed:
  - include pulses from C38A forward from JET data, especially DTE2 data;
  - include He pulses from C31 forward;
  - include pellets fueled pulses;
  - include high radiative discharges;
- AUG, in collaboration with the contact person:
  - include pulses from more recent campaigns;
  - increase the number of discharges with isotopic mixtures;
  - Increase the number of high radiative discharges;
- WEST, in collaboration with the contact person:
  - Include data in stable H mode phase
- Scientific exploitation of collected data within the EUROfusion framework, then transfer to ITPA group
- **1D:**
- Start building the DB.



# SP2 : Development of a wall thermal events & hot spot monitoring system for ITER



Year	Milestones
2021-2022	Demonstration of a data pipeline for processing thermal events in a thermographic movie operating off-line. Key actions: detection, data enrichment and classification.
2022-2023	Same as 1 but including the additional constraints of being interfaced with WEST and W7-X pulse management infrastructure and operating in between experiments. Investigation of real time application.
2023-2024	System engineered data pipeline for processing thermal events in ITER, equipped with a wide angle tangential viewing system. Specification and objectives, expected ground truth made from both events extrapolated from current devices and simulated events.

Year	Deliverables
2022	<ul style="list-style-type: none"> <li>• Off-line data pipelines, including algorithms, methods and computer vision solutions.</li> <li>• Source code(s).</li> <li>• Technical report(s) describing methods and rationale for the technical choices.</li> </ul>
2023	<ul style="list-style-type: none"> <li>• On-line data pipelines, including algorithms, methods and computer vision solutions.</li> <li>• Source code(s).</li> <li>• Technical report(s) describing methods, rationale for the technical choices.</li> </ul>
2024	<ul style="list-style-type: none"> <li>• ITER data pipelines, including algorithm, methods and computer vision solutions. Data set extrapolated to ITER wide angle viewing system.</li> <li>• Source code(s).</li> <li>• Technical report(s) describing methods, rationale. System engineering documentation (mission goal, technical requirements, interface management).</li> </ul>

## EEG programme proposed in 2022 (joint WPW7X-WPPRIO)

# Potential Session Leader Foundation Course Topics (machine independent, beginner level)



- Introduction, Operations Management
- Coils and power supplies
- Plasma shape control
- Vacuum conditioning
- Fueling (gas and pellet injection)
- Heating systems (NBI, ECRH, ICRH)
- Disruptions, predictions and mitigation (MGI, SPI)
- Diagnostic setup
- Breakdown and current ramp up, runaways
- Protection systems
- Real-time networks (scientific)
- Termination and event handling
- Operational tools (editors, data/plant viewers, event handlers)
- Operation of stellarators
- Scaling up operation (small, medium, large to ITER)

## Target:

- Students (MSc, PhD, Post-doc)
- EEGs and ERGs
- Scientific Coordinators
- Engineers, Researchers
- Generic interest

## Aims:

- > Recruit session leaders
- > Improve preparation of experimental proposals and experimental sessions
- > Improve interaction between control room competencies

# SP-4: Neutral Beam Test Facility and R&D for ITER Neutral Beam: MITICA



- In 2021, failures occurred during the 1MV power integrated tests due to BreakDowns (BD) that damaged two components of the power supply system:
  - Diode bridge of stage DCG1 (800kV-1MV)
  - HV bushing of the 1 MV insulating transformer
- In 2021, inspections and analyses using high frequency models were carried out to determine the root cause
- The 2022 MITICA schedule is being updated taking into account :
  - Repair and improvement of the MITICA power supply system
  - Completion of the integrated power tests of MITICA's power supplies
- An updated MITICA schedule will be developed in October and presented to the NAC