Progress of the Neutral Beam Test Facility Project

V. Toigo on behalf of NBTF team

Consorzio RFX, Padova, Italy

Heating systems at ITER - summary

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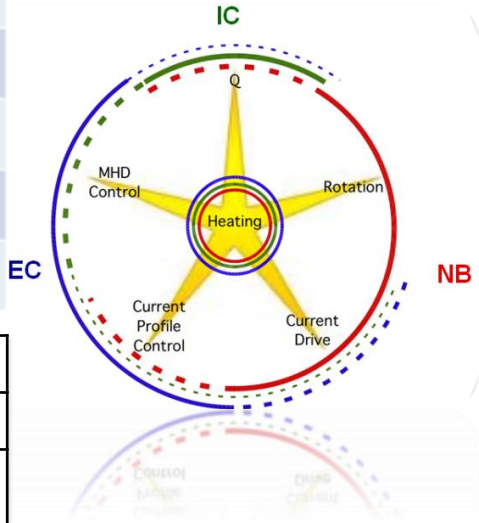
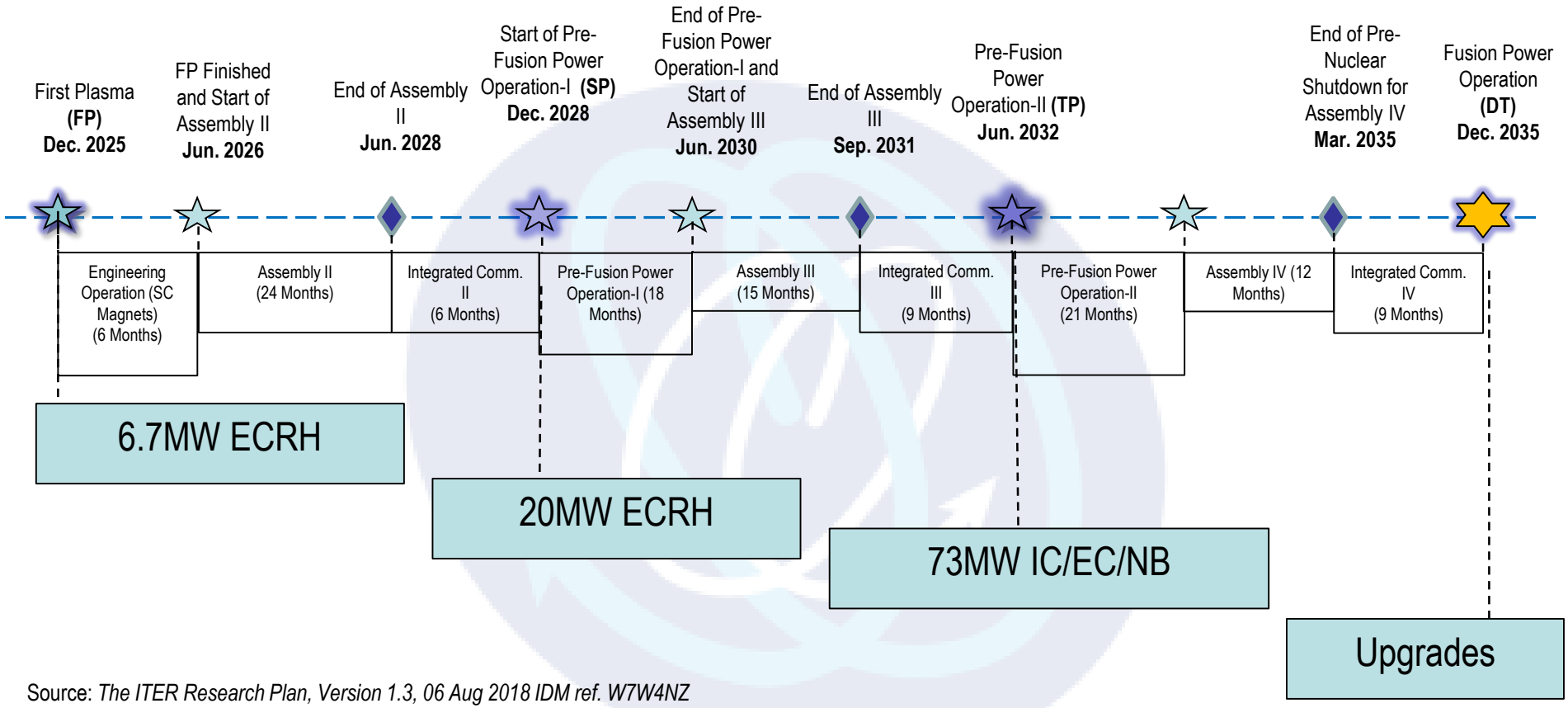
ITER operational phase	Time line	Power requirement (MW)			
		NB	EC	IC	LH
First plasma	2025		6.7		
Pre fusion power op. 1	2028 – 2030 (mid)		20		
Pre fusion power op. 2	2032 (mid) – 2034 (FQ)	33	20	20	
Fusion power op (DT)	2036 onwards	33	20	20	
Upgrade potential		50	40	40	40



EC system	IC system	NBI system
170 GHz	40-55 MHz	870 keV H^0, 1 MeV D^0
NTM, ST control, $j(\rho)$ control, EC-assisted startup,	High fusion gain, ST control, wall cleaning,	Bulk current drive, rotation,
24 gyrotrons (24 x 0.8 MW)	2 antennas (2 x 10 MW)	2 injectors (2 x 16.5 MW)

H&CD configuration for the Staged Approach



Source: *The ITER Research Plan, Version 1.3, 06 Aug 2018 IDM ref. W7W4NZ*

ITER H&CD systems

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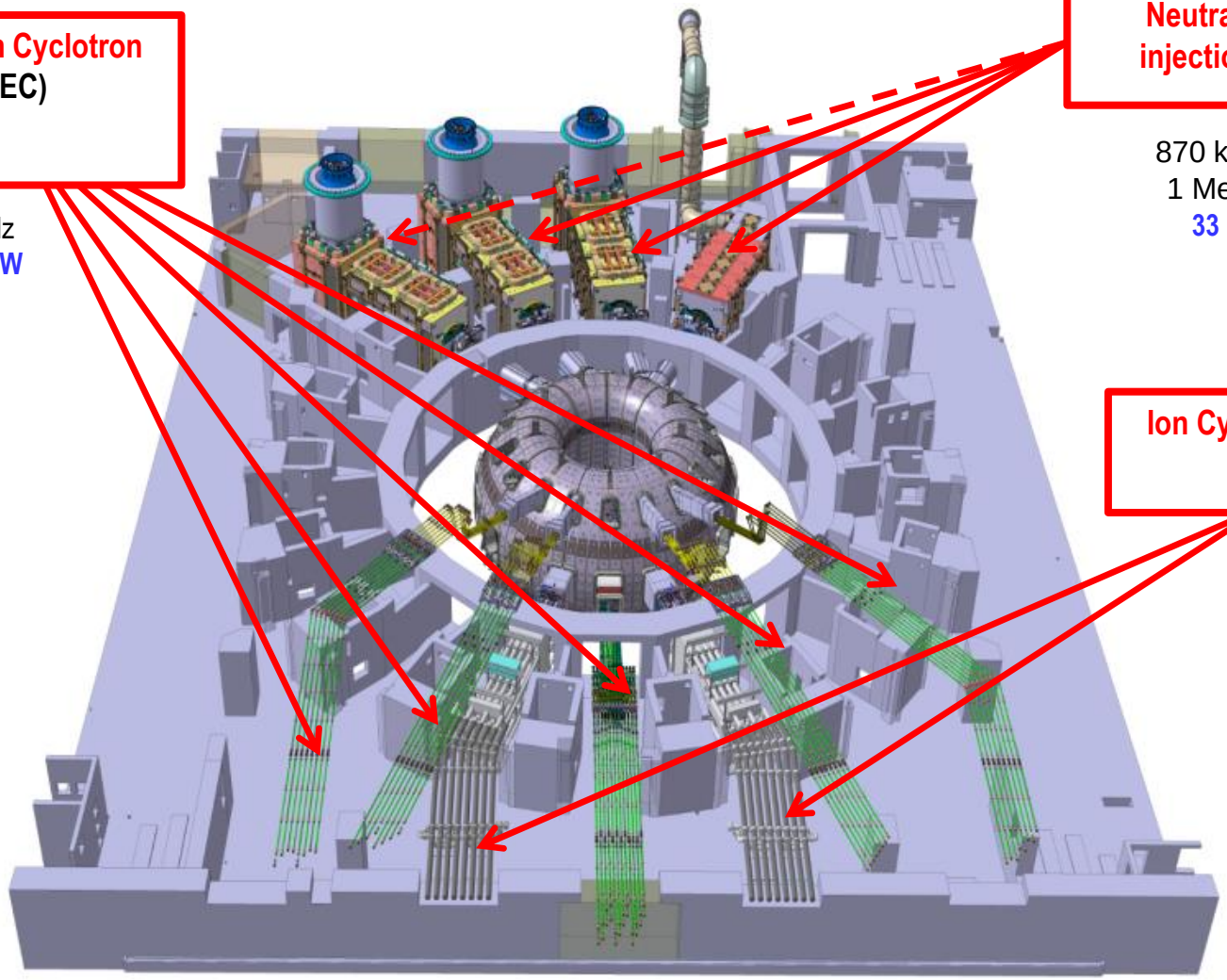
Electron Cyclotron (EC)

170 GHz
20-30 MW

Neutral beam injection (NBI)

870 keV H^0
1 MeV D^0
33 MW

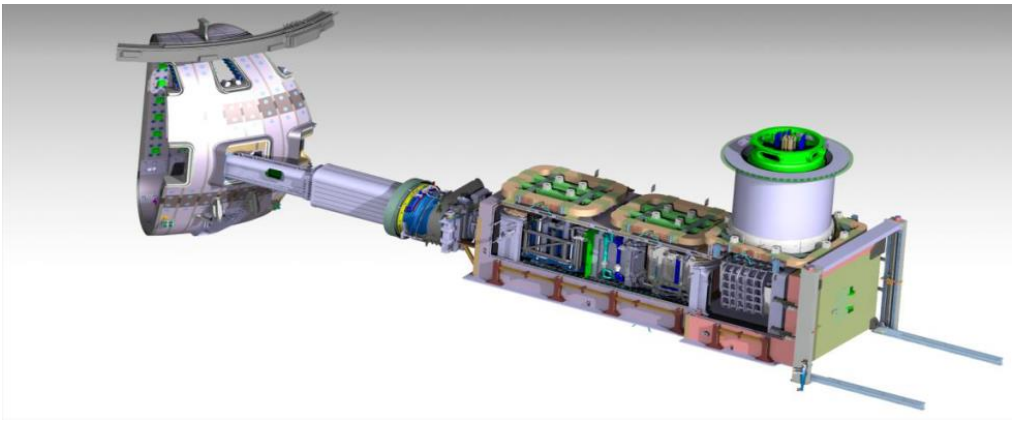


Ion Cyclotron (IC)

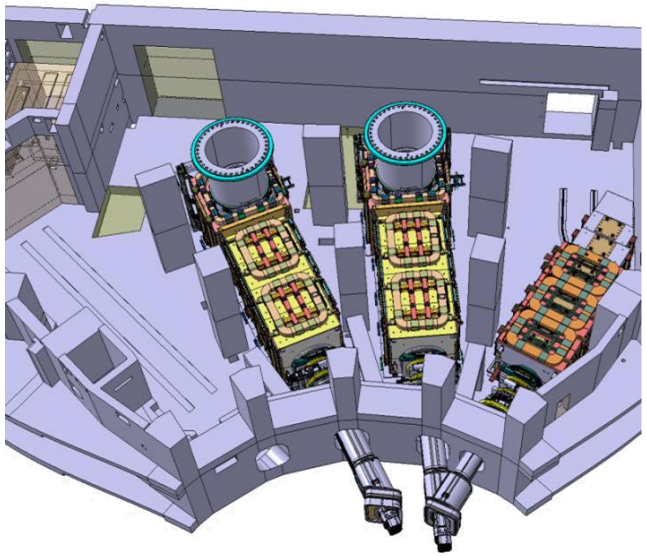
40-55 MHz
20 MW

Negative ion beams in ITER

- Additional heating: ECRH, ICRH, NBI



- 2 (+1) HNB: Heating Neutral Beam
- 1 DNB: Diagnostic Neutral Beam
- NBTF: Neutral Beam Test Facility



FUSION FOR ENERGY

ITER JAPAN

2 HNBs (+1): deuterium

- I_{acc} = 40 A
- V = 1 MV
- t_{pulse} = 3600 s
- P_{beam} = 16.5 MW
- divergence <7mrad
- aiming ±2mrad
- non-uniformity <10%
- e^-/D^- <1

EUDA & JADA procurement

Challenges of ITER NBIs

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- Generation, extraction, acceleration of 40A negative deuterium beam:
  - Non-uniformity <10%
  - Caesium distribution
  - Inductively coupled plasma: RF coupling to plasma; RF coils in vacuum
  - Co-extracted electrons; generation of electrons in accelerator
- 5-steps acceleration of negative deuterium ions to 1MV
  - Divergence <7mrad; aiming not exceeding ±2mrad range
  - Voltage holding at low pressure with free charges and radiation
- NBI operation for one hour (RAMI)
  - Thermal and thermomechanical issues
  - Beam stability
  - Radiation from ITER

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  - Beam stability
  - Radiation from ITER

Worldwide coordinated effort addressing these challenges: ITER-IO, QST, IPP, NIFS, IPR, Consorzio RFX and negative ion beam community

Aims of ITER Neutral Beam Test Facility (NBTF)

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- Accompanying facility in preparation and support of ITER operation:
  - To realise and commission prototype NBI systems: e.g. HV components @1MV, cryopumps, …
  - To achieve nominal parameters of source and beam
  - To optimize HNB operation
  - To improve reliability and availability of injectors
  - To finalise HNB design
  - To solve HNB issues during ITER operation

- NBTF hosts two experiments:
  - SPIDER: optimisation of ion source: current density, uniformity, stability
  - MITICA: full-size prototype of ITER NBI: high voltage holding, beam optics, aiming

ITER Neutral Beam Test Facility

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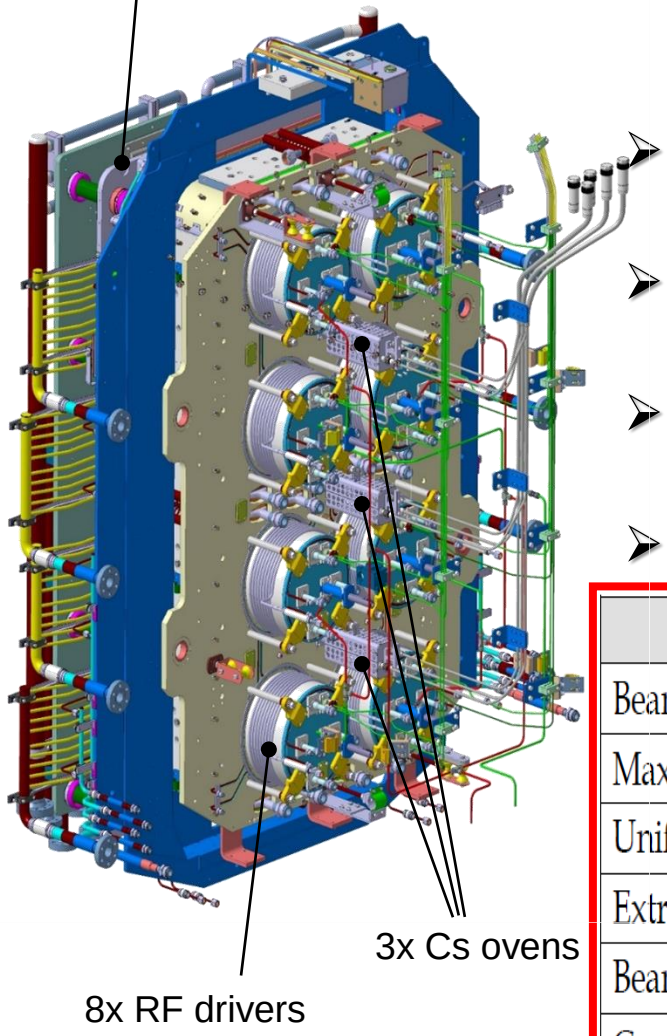
NBTF hosts the two experiments: the negative ion source **SPIDER** and the 1:1 prototype of the ITER injector **MITICA**

Each experiment is inside a concrete biological shield against radiation and neutrons produced by the injectors

Thanks to these shielding the assembly/maintenance area will be fully accessible also during experiments

SPIDER: full scale prototype of HNB/DNB source



- Optimisation of production of negative ions in terms of:
  - Density
  - Uniformity
  - Stability
  - Co-extracted electrons

	Unit	H	D
Beam energy	keV	100	100
Maximum Beam Source pressure	Pa	<0.3	<0.3
Uniformity	%	±10	±10
Extracted current density	A/m^2	>355	>285
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

SPIDER Components

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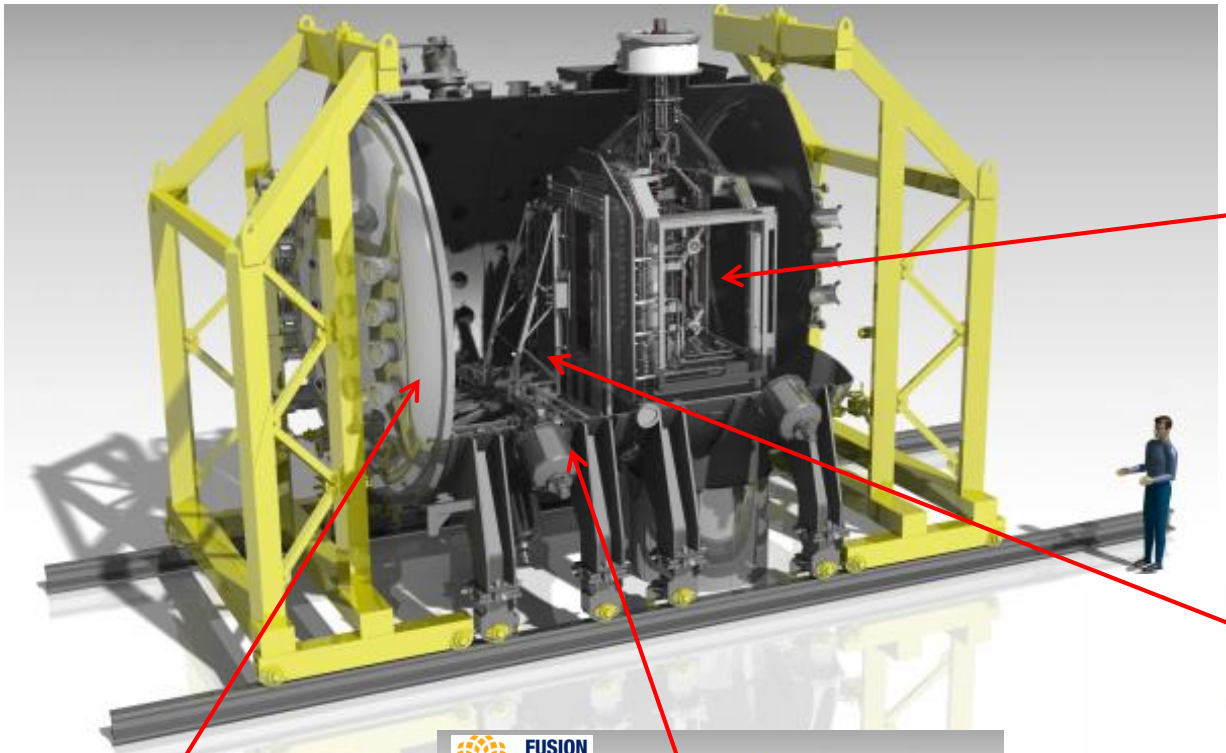
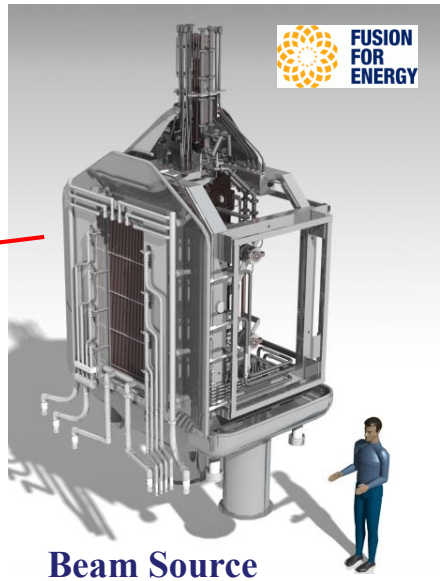
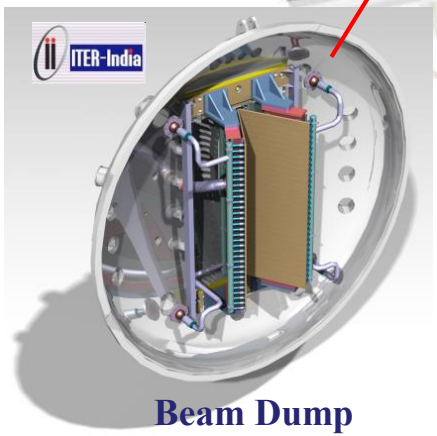
Vacuum-insulated beam source

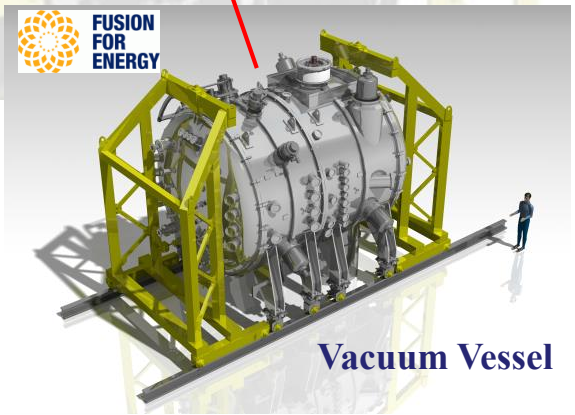




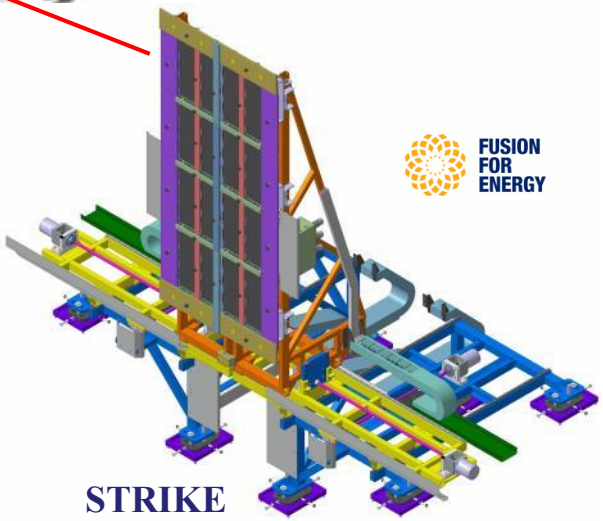
Beam Source



Beam Dump



Vacuum Vessel



STRIKE
High resolution calorimeter

SPIDER power supplies

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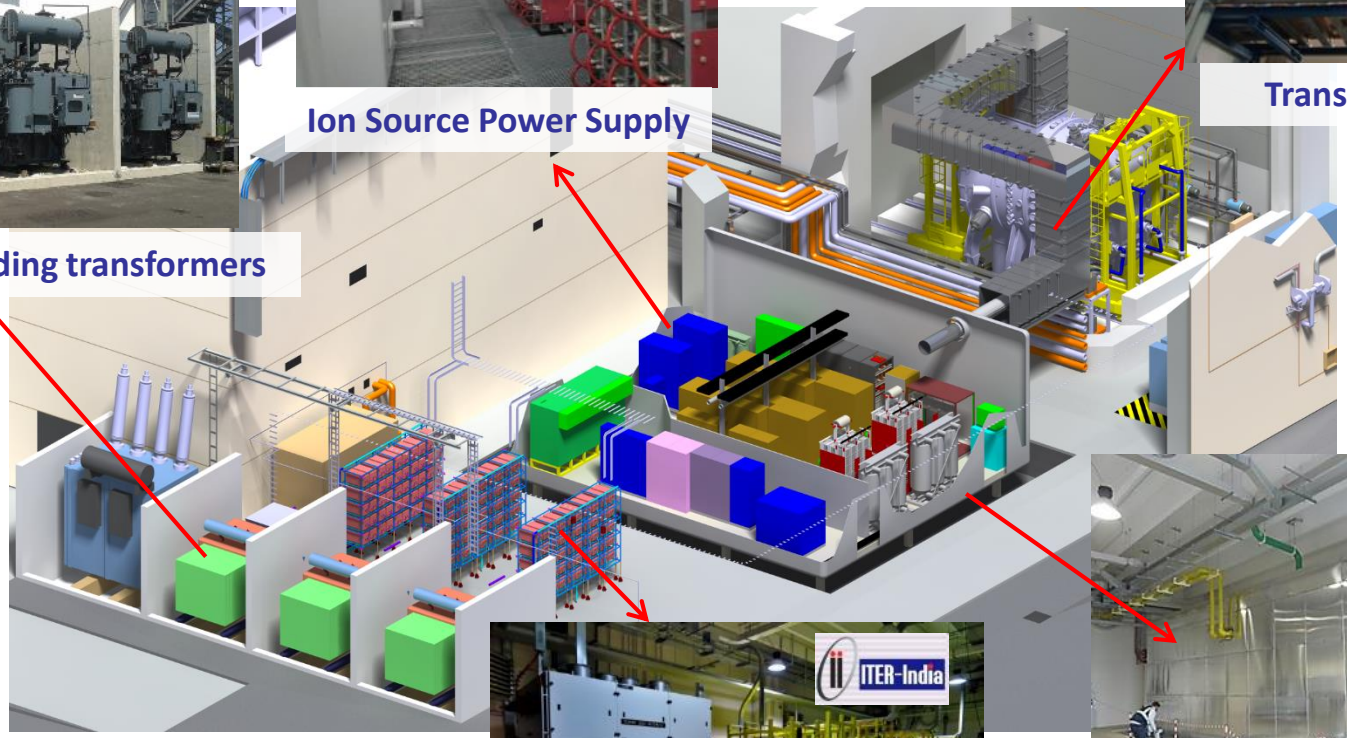
Multi-winding transformers

Ion Source Power Supply

Transmission Line



Acceleration Grid Power Supply

High Voltage Deck (HVD)

SPIDER beam source inside vacuum vessel

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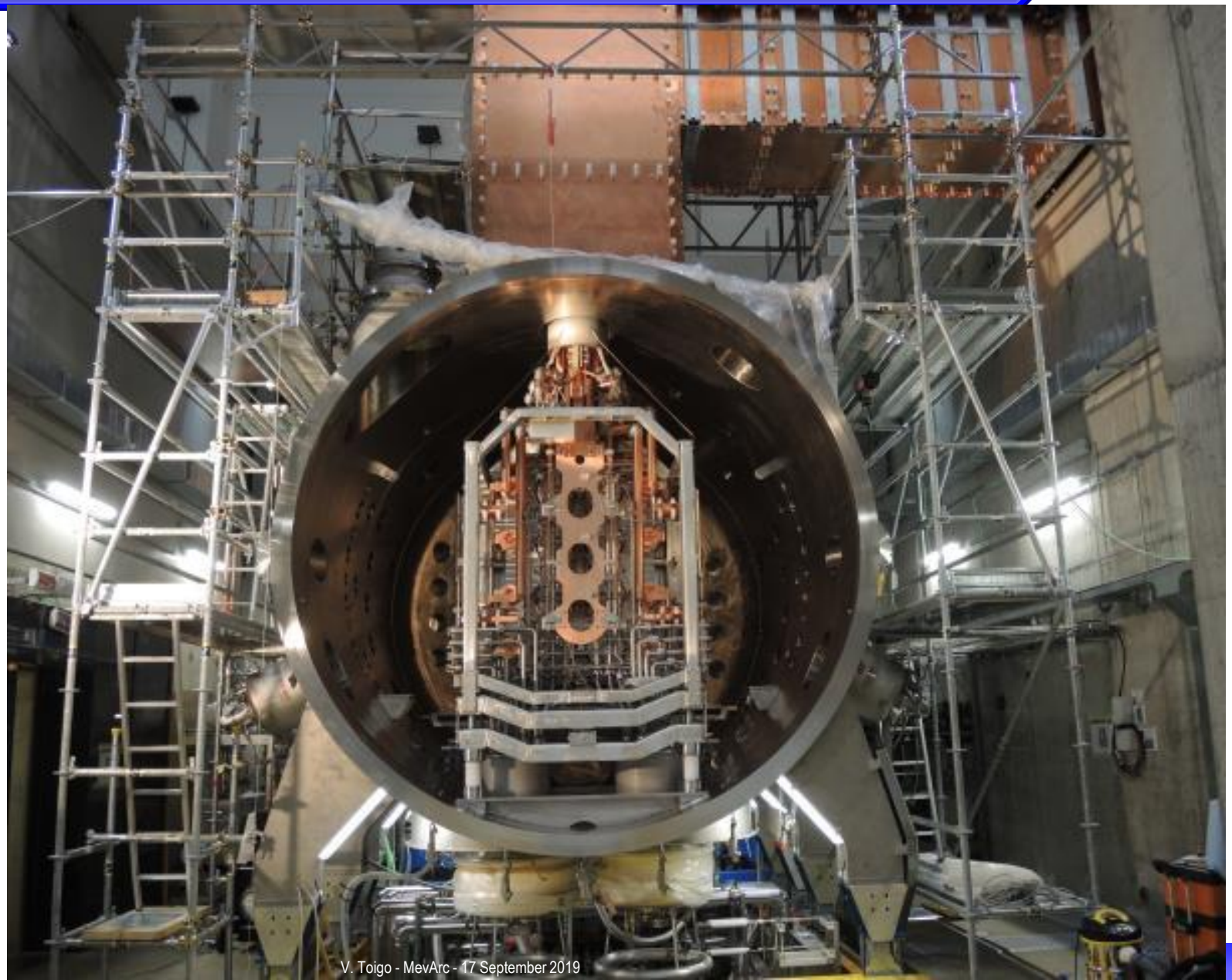

First SPIDER operations

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SPIDER operation started on 4 June 2018 …. just a few days before the official inauguration made in presence of the ITER DG, Dr. B. Bigot

MITICA full scale prototype of ITER HNB

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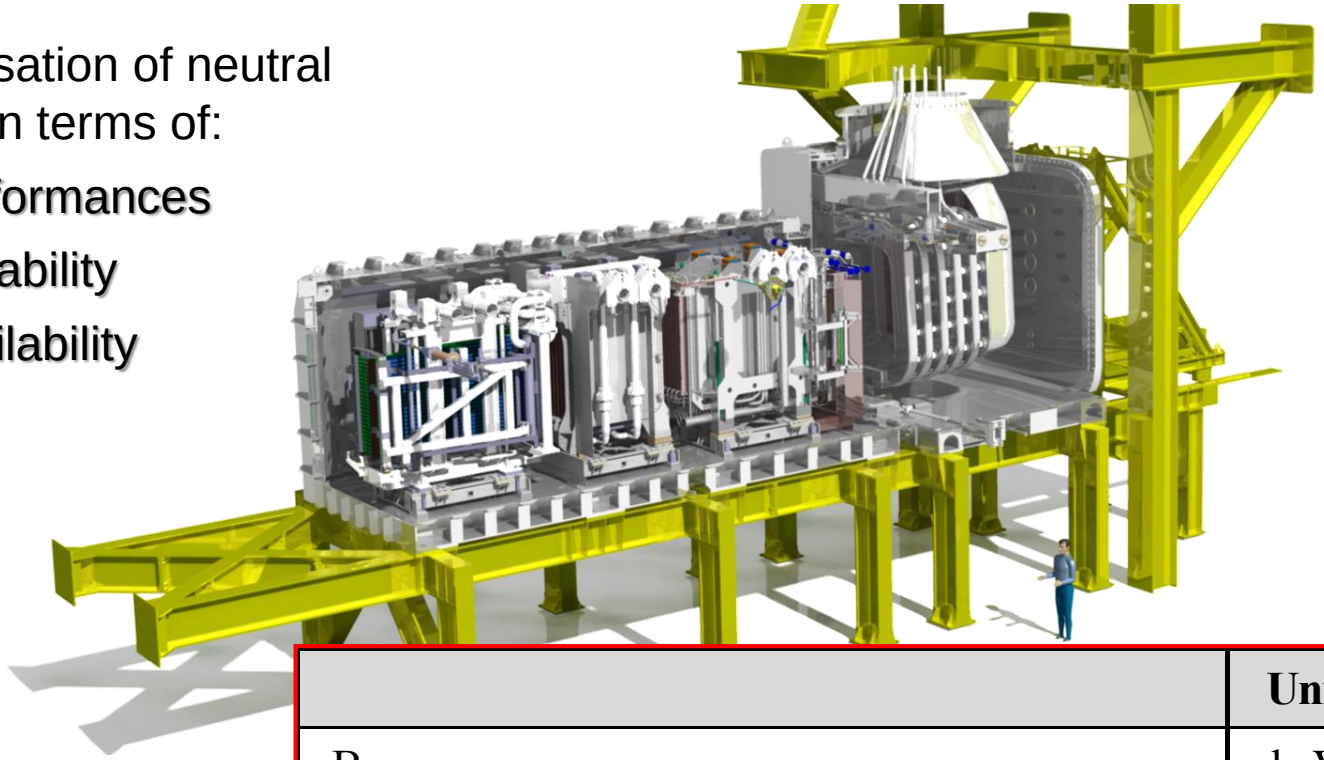
Optimisation of neutral beam in terms of:

- Performances
- Reliability
- Availability



	Unit	H	D
Beam energy	keV	870	1000
Acceleration current	A	46	40
Max Beam Source pressure	Pa	0.3	0.3
Beamlet divergence	mrad	≤7	≤7
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

MITICA components

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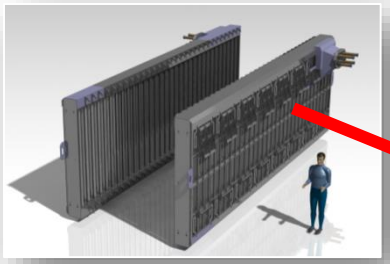
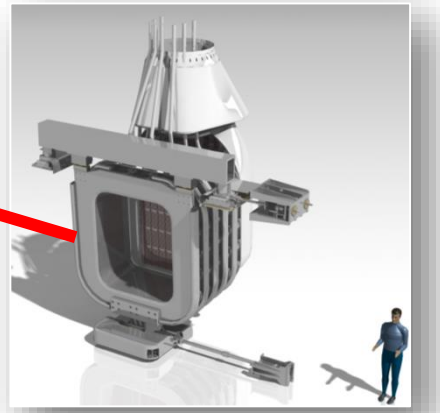
FUSION FOR ENERGY

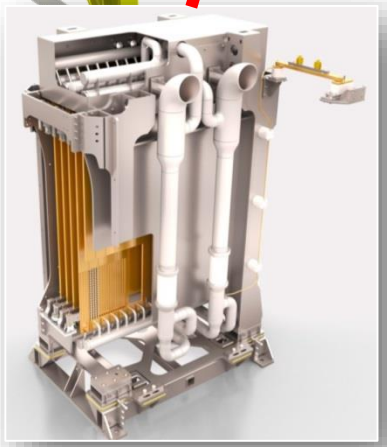


CRYOGENIC PUMPS

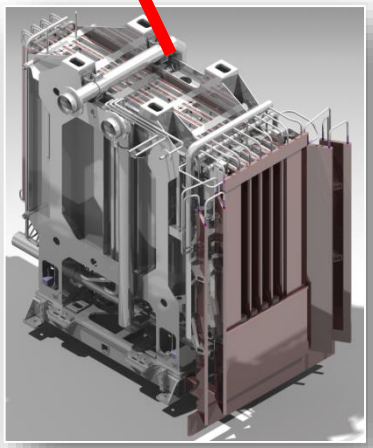


BEAM SOURCE

CALORIMETER

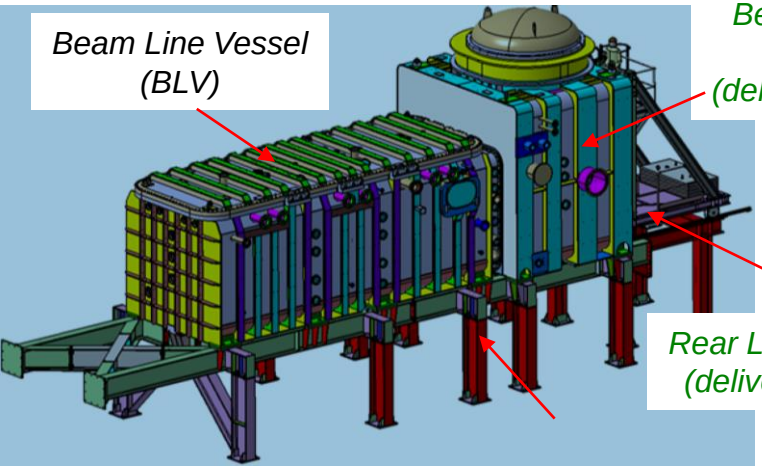


RESIDUAL ION DUMP



NEUTRALIZER

MITICA Vacuum Vessel



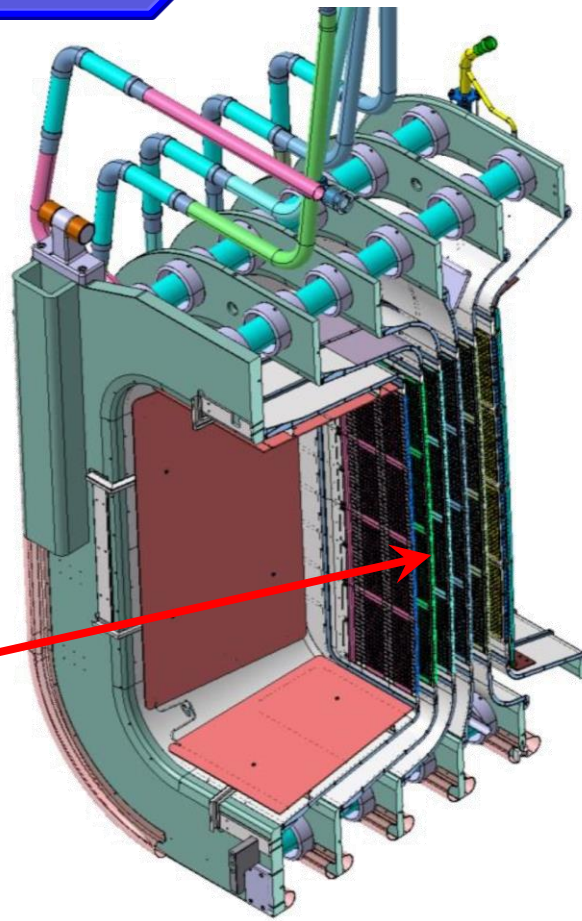
Vessel, made of Stainless Steel; 15m × 5m × 5 m; divided into Beam Line Vessel and Beam Source Vessel

BLV in Feb 2019: welding of ports and other internal supports, before final machining

BLV – On-going final machining

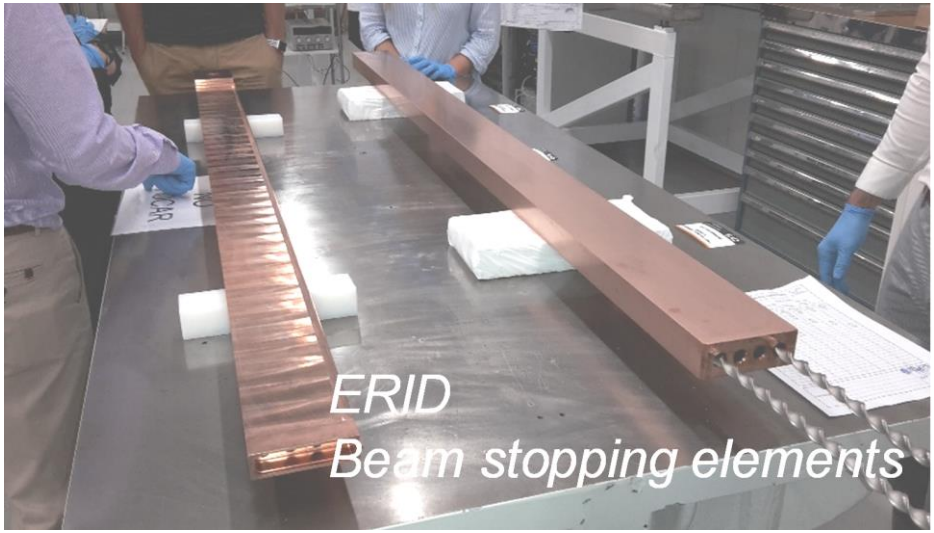
MITICA Beam Source

- Contract signed with Alsyom-Seiv (F) in Oct 2018
- Delivery on site by summer 2022
- Presently: realisation and test of prototypes of critical components

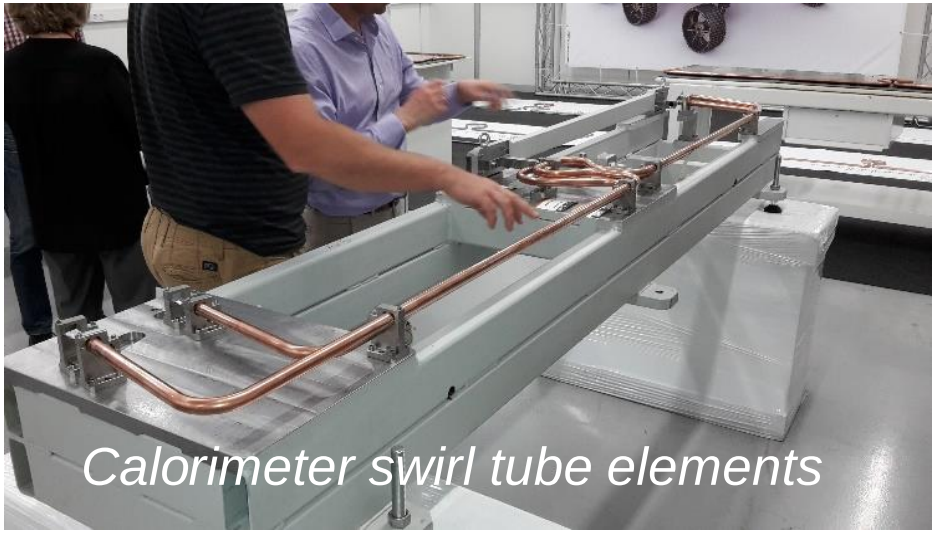


MITICA Beam Line Components

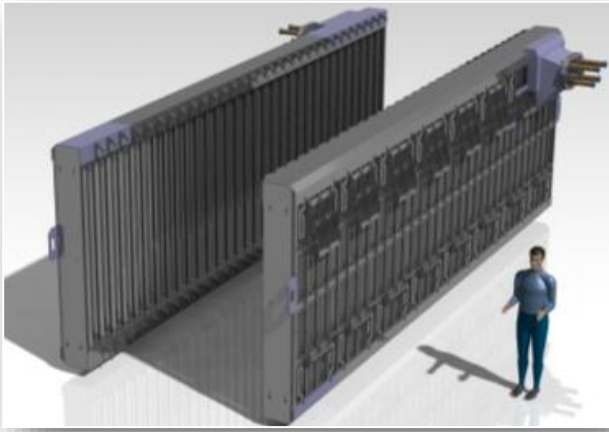
- Two-stages contract:
  - stage 1 completed
  - stage 2 under preparation
  - delivery planned for Q3 2023



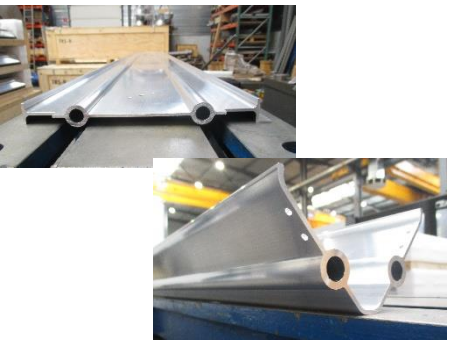
- Three suppliers awarded Stage 1:
  - AVS Tecnalia (E)
  - SIMIC (I)
  - De Pretto Industrie – ATT Angelantoni Consortium (I)



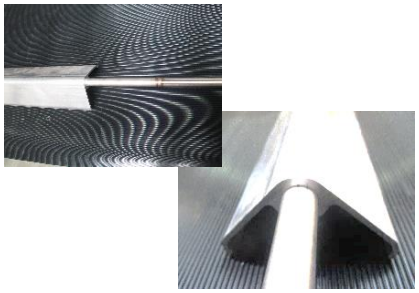
MITICA Cryogenic Pumps



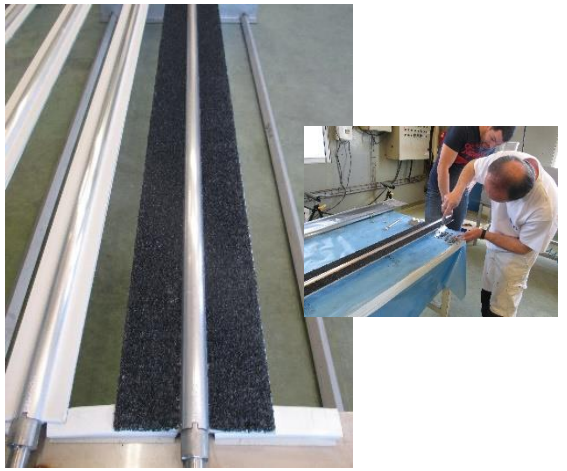
- Delivery planned for Q4 2020
- Cryopanel: 2 x 8m x 2.8m
  - 5000m^3/s in hydrogen; 3800m^3/s in deuterium
  - Cryogenic power at 4.5K: 800W (supercritical He)
  - At 81K (thermal radiation shield): 17.4kW (gaseous He)
- MITICA Cryopump procurement subdivided in three lots:
  - Support Frame and Assembly by SDMS (F)
  - Charcoal coating of pumping surfaces by SDMS (F)
  - Aluminium expansion profiles by Ravanat (F)



Aluminium profile extrusion (MGOP/SDMS)



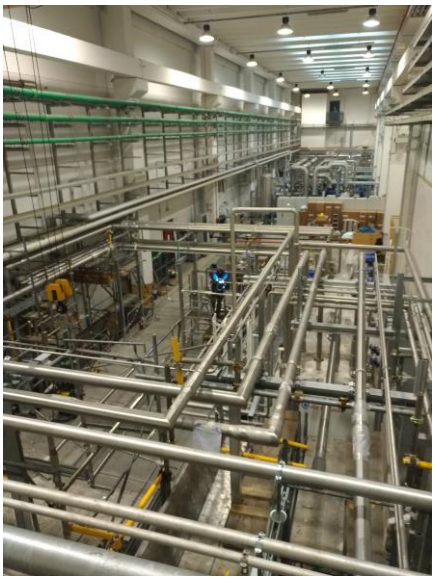
Hydroforming process (Ravanat)



Charcoal coating process (SDMS)

Auxiliary Systems

- Cooling plant for 70MW: 1000m^3 water basin; 17MW at cooling towers
- Cryogenic plant & cooling plant: installed; under test and commissioning
- Gas injection and vacuum system: GSD-Shared Plant Unit; 2 independent vacuum and gas injection systems; for MITICA under installation; for SPIDER operating



MITICA Cryogenic Plant components and piping inside Building 2 for production and distribution of 4 K SCHe and 80 K GHe

View of Cooling Plant Primary Circuits inside MITICA Neutron Shield

MITICA Power Supplies

1MV Faraday Cage
(hosting Ion Source PSs)

1MV Insulating Transformer

1MV
AGPS-DC
Generator

HV Bushing

Vacuum Vessel

≈ 100m

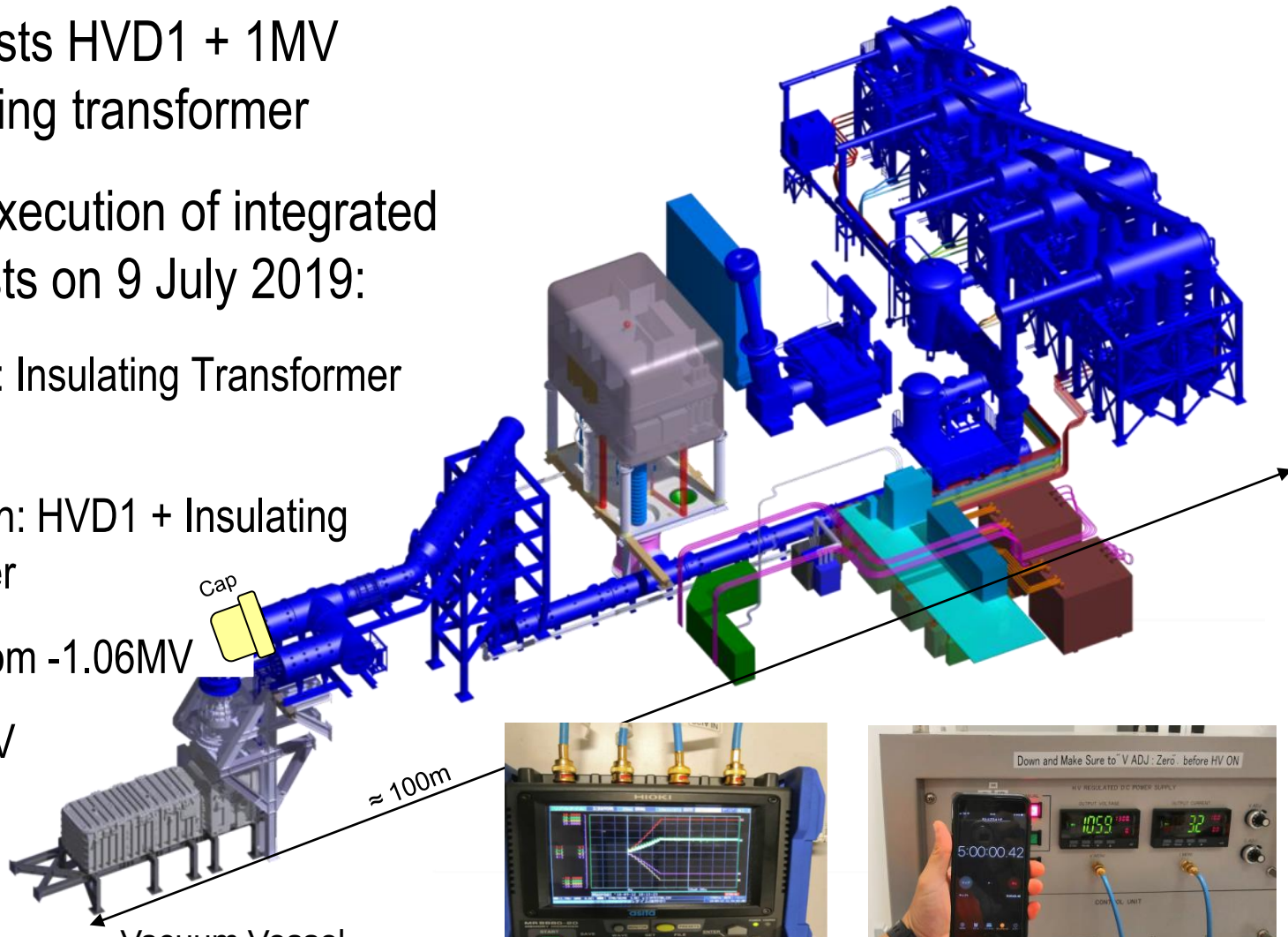
HV Transmission Line

RIDPS

AGPS
Conversion
system
60MW CW

MITICA: Commissioning of HV components

- Combined tests HVD1 + 1MV JADA insulating transformer
- Successful execution of integrated insulation tests on 9 July 2019:
  - -1.2MV, 1h: Insulating Transformer (via HVD1)
  - -1.06MV, 5h: HVD1 + Insulating Transformer
  - 5 pulses from -1.06MV to -1.265MV



1st STEP 1200kV-1 HOUR

2nd STEP 1060kV-5 HOURS

MITICA: BSV – HVB Integration

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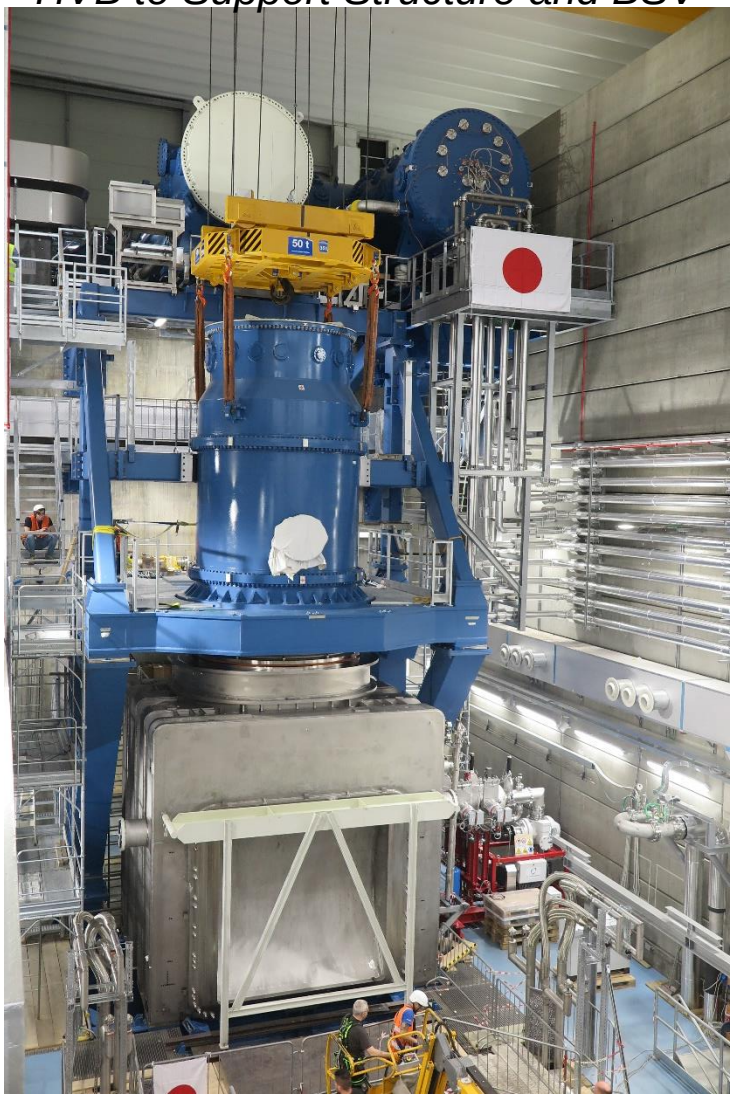
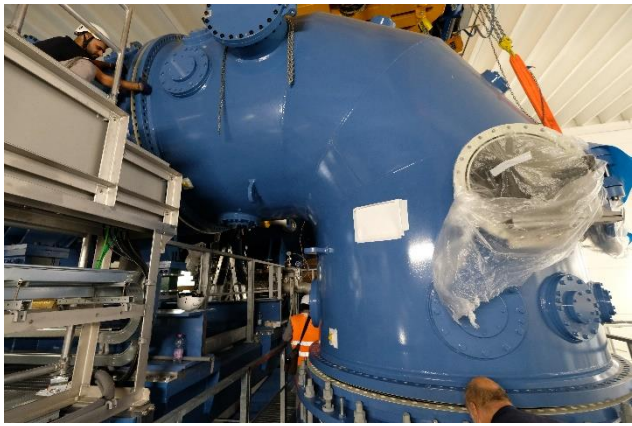
HVB transport

Short-circuiting device inside BSV

Lowering, positioning and fixing of HVB to Support Structure and BSV



Final positioning of curved element



Final insulation tests planned for autumn 2019

MITICA timeline

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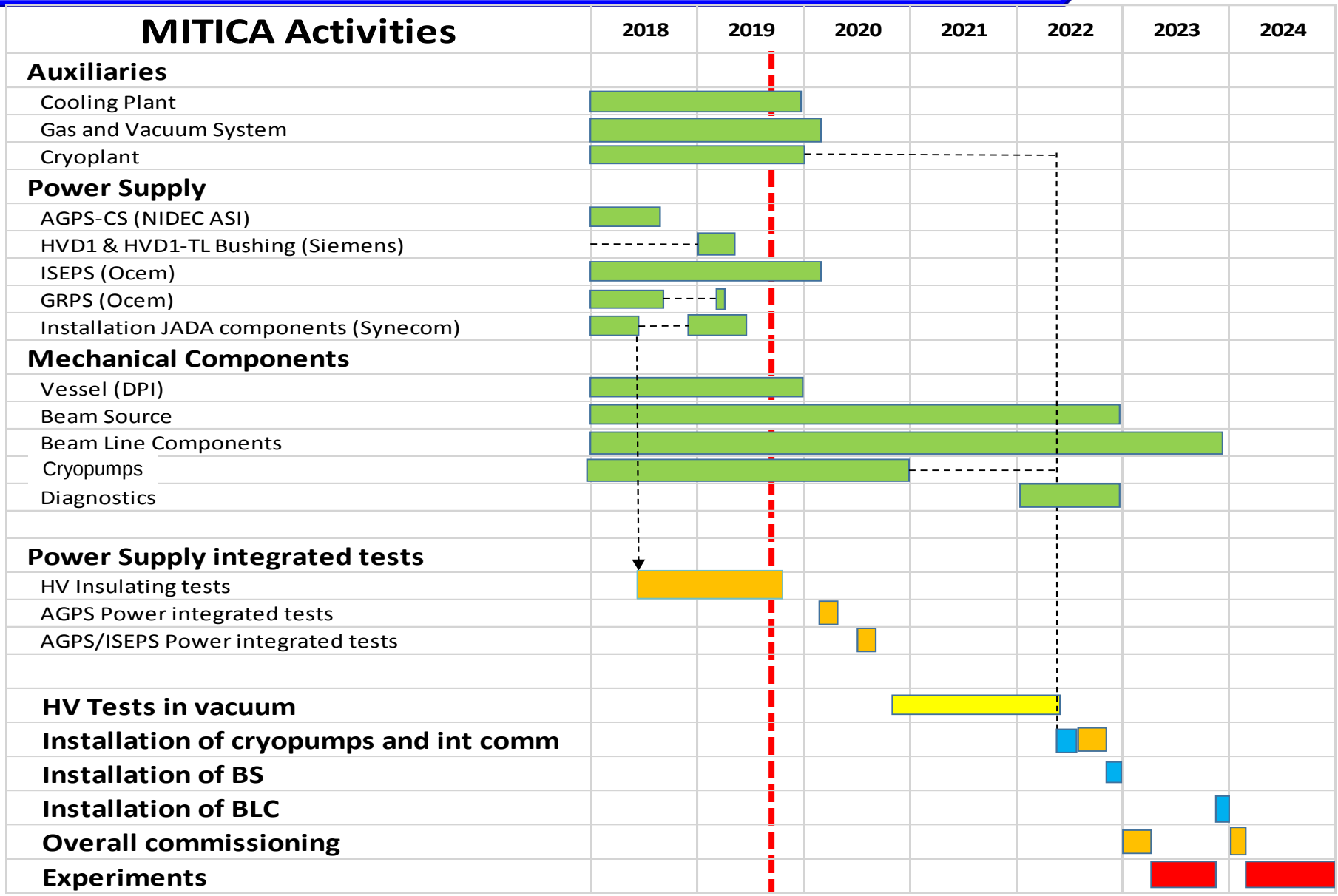

प्लाज़्मा अनुसंधान संस्थान
Institute for Plasma Research

Thank you for your attention

Overall planning of development of NBI for ITER

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