Update on the Negative Ion Based Neutral Beam Injectors for ITER

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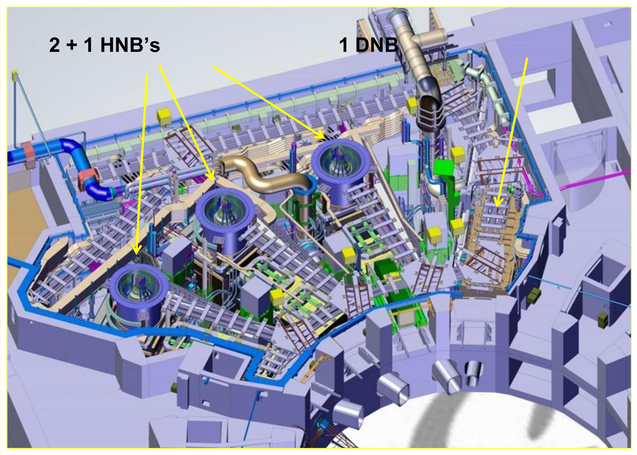
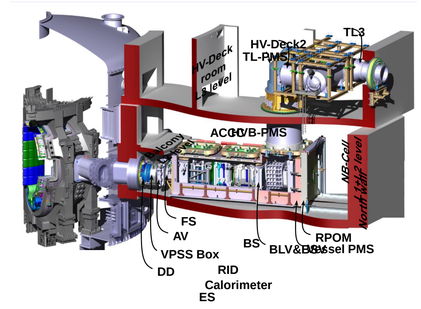
1. Introduction

NB injectors at ITER – NB Cell





$D^0 \Rightarrow$ 1 MeV 3600 s

$H^0 \Rightarrow$ 870 keV 1300 s

16.5 MW per HNB injector

$H^0 \Rightarrow$ 100 keV 3600 s

2.4 MW DNB

The ITER baseline foresees 2 HNB's operating at 1 MeV 40 A D^0, each capable of delivering 16.5 MW of deuterium ions to the plasma, with a 3rd HNB injector foreseen as an upgrade option that would bring up the total neutral beam power to 50MW [1]. In addition a dedicated DNB will be injecting 100 keV 60 A of H^0 for charge exchange recombination spectroscopy (CXRS) [2].

[1] R. Hemsworth, et. al., Nuclear Fusion, 49 (2009) 045006

[2] A. Chakraborty., et. al., IEEE Transactions on Plasma Science, 38 (2010) 2

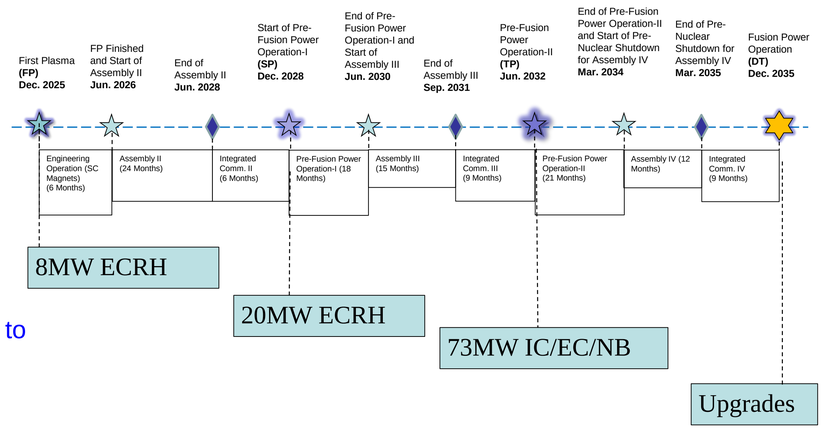
2. Recent developments – staged approach & new schedule

- The ITER Council has approved the Overall Project Schedule and – ad referendum – the Overall Project Cost: First Plasma in 2025, followed by a staged approach to DT Operation/full fusion power capability in 2035.
- There is strong progress in on-site construction and fabrication, matched by strong progress worldwide in component manufacturing.
- 19 of 20 milestones were successfully completed on schedule in 2016. The last milestone was delayed 3 months due to discovery of a flawed weld, but the welding was re-done with no impact to the overall schedule.

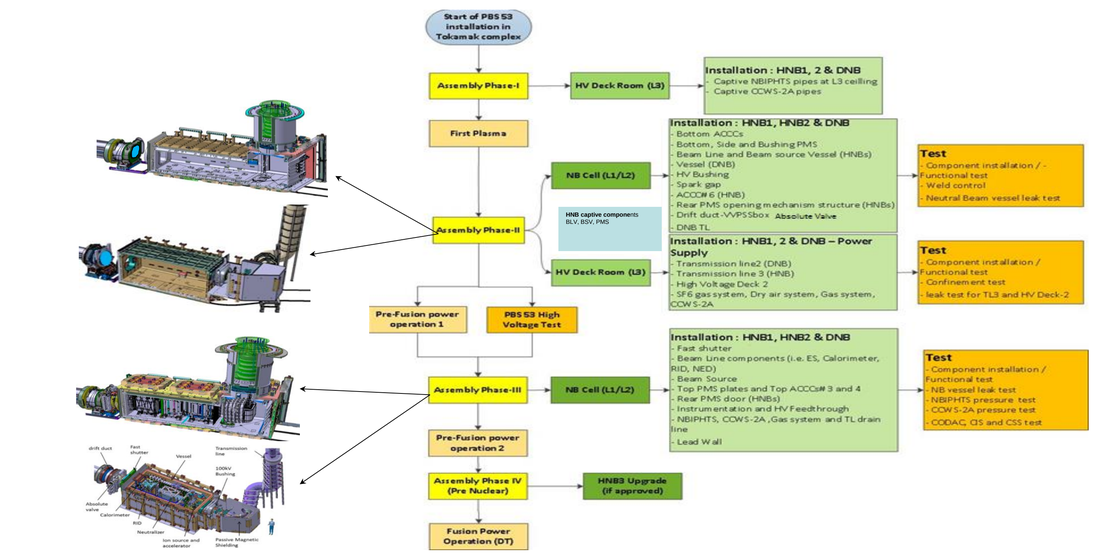
HCD configuration ''staged approach''

- IC November 2016
- RoD:…….

On this basis an acceleration proposal is being developed in order to accelerate the ICRH.



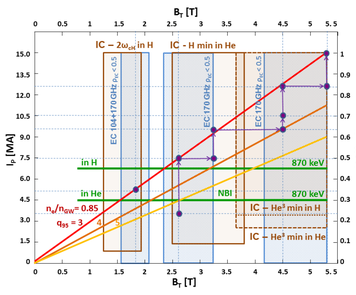
3. Staged approach: NB System Assembly Installation Plan



4. Third field operation and impact on NB heating system

Heating Neutral beams : PFPO-2 phase 2031 onwards; no hardware changes.

Physics analysis : by SCOD and HCD ongoing.



Diagnostic Neutral beam : No changes envisaged; but shine-through has to be checked

Shine through limits :

- Lower beam energies will allow operation at 1.8T respecting the shine-through density of the lower plasma density.
- Under discussion
  - Beam energies of 870kV several seconds pulse lengths, to limit damage to the blanket shield block 16 DS.
  - Beam energies of 650keV for helium plasmas and 600keV for hydrogen plasmas at pulse lengths > 100 s.

Operation at lower powers :

- Still considered interesting and as synergy with the IC coupling mechanisms at second harmonic Hydrogen in hydrogen plasmas.

The design of the front end components and duct:

- Designed for both half and full field operation. Full power load analysis in the duct pending to confirm compliance with maximum power loads.

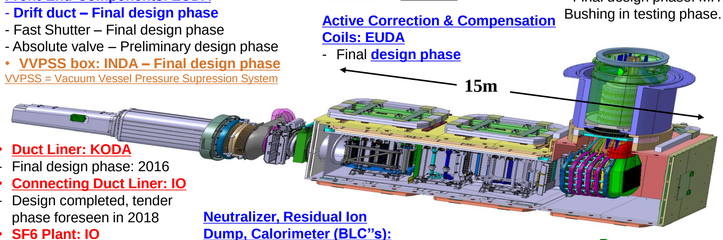
5. Overall Design Status and R&D Strategy

Front-End-Components: EUDA
- **Drift duct – Final design phase**
- Fast Shutter – Final design phase
- Absolute valve – Preliminary design phase
- **VVPSS box: INDA – Final design phase**

VVPSS = Vacuum Vessel Pressure Supression System

Active Correction & Compensation Coils: EUDA
- Final design phase

HV Bushing: JADA
- Final design phase. MITICA HV Bushing in testing phase.



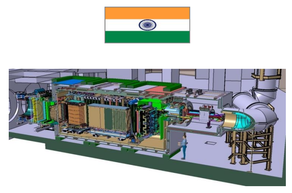
- **Duct Liner: KODA**
- Final design phase: 2016
- **Connecting Duct Liner: IO**
- Design completed, tender phase foreseen in 2018
- **SF6 Plant: IO**
- Conceptual Design Review completed.

Assembly Tools: EUDA
- Preliminary Design Phase.

Neutralizer, Residual Ion Dump, Calorimeter (BLC''s): EUDA
- MITICA BLCs in preparation for tender phase. HNB BLC final design similar.

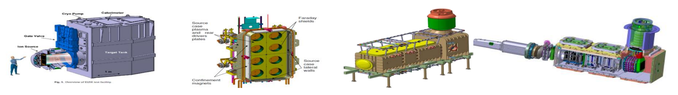
Vessel, Passive Magnetic Shield: EUDA
- Final design phase.

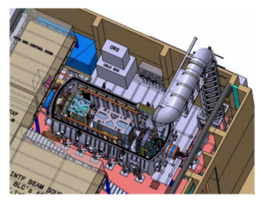
Beam source: EUDA/JADA
- MITICA Beamsource (BS) in tender phase. HNB BS final design similar to MITICA.



DNB INDA
- Beam Source, Residual Ion Dump, Neutralizer under manufacturing
- Acceleration Grid Power Supply installed in Indian Test Facility
- All components in final design phase except PS which are functional specifications.

	SPIDER	MITICA	ITER
Timeline:	2018-tbd	2022 - 2031	2031





Indian Test Facility INTF: ROBIN & Twin Source, Demonstration of DNB Performance including far-field divergence

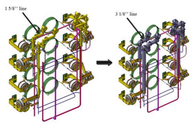
[3] A. Chakraborty, et.al, 1-6. 10.1109/SOFE.2015.7482367

6. Design updates and integration Issues

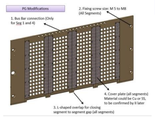
- **Update of reference beam source design based on ELISE results and manufacturing experience**

Electromagnetic shield for RF drivers

Increased RF Line size to 3 1/8'';



Plasma Grid (PG) Modification (shine-through prevention by cover plate between grid segments)

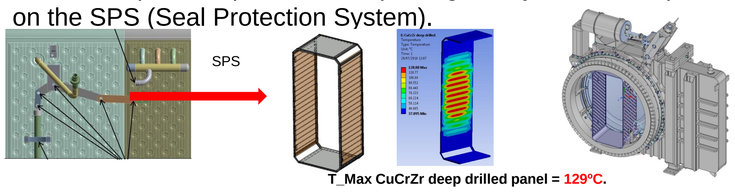


Implemented in SPIDER & DNB sources currently being manufactured and in reference source design (MITICA & HNB sources).

SPIDER source assembly being finalized, delivery to NBTF scheduled on 16/10/2017.
DNB beam source expected to be delivered to INTF in 2018.

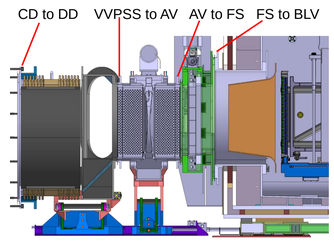
- **Absolute valve**

CuCrZr deep drilled panels are replacing the hydro-formed panels on the SPS (Seal Protection System).

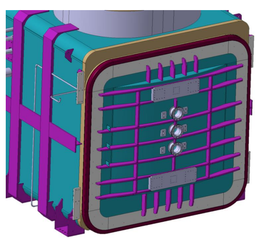


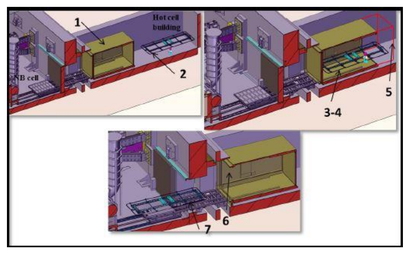
T_Max CuCrZr deep drilled panel = 129°C.

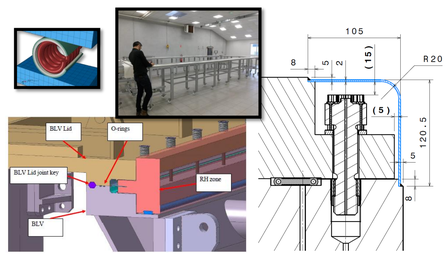
Double metallic seal for FEC's of HNB and DNB



- **Hybrid sealing solution for vessel** Double elastomer/metallic seal + welded solution
- Concerns about baseline lip solution – RH for welding and inspection not demonstrated, limited number of openings, no recovery in case of damage to lip.
- Double elastomer for testing, double metallic seal for pre-nuclear and welded cap for nuclear operation (configuration under design finalisation).

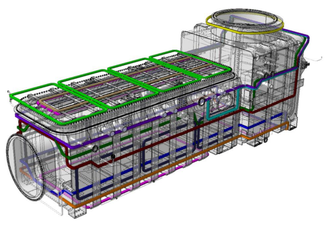






- **MFRS re-design after dynamic analysis** Currently ongoing

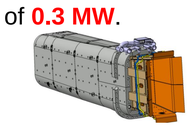
Dynamic analysis performed with updated building model to define the controller for the Magnetic Field reduction system => required coil currents required to meet the stringent residual field requirements exceed PS dimensions.
Redesign of coils under way. Options under investigation – additional active side coils and / or active coils inside the Passive Magnetic Shield
Work ongoing.



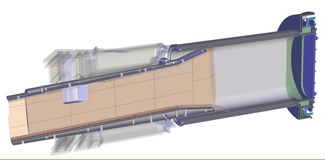
- **Preclusion of counter injection and Duct liner water connectors**

Detailed calculations of gas density and re-ionised power load profiles in the HNB duct have been carried out because of new information on the atomic flow from the Tokamak plasma into the duct.
HNB power deposition PD_{max} = 2.4MW/m² with a total integrated power of **0.3 MW**.

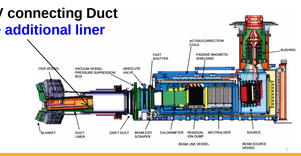
- The introduction of the VV connecting duct liner
- The preclusion of counter injection as protection not symmetrical.

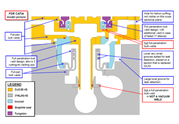


Improved hydraulics and simplified water connector.



VV connecting Duct
=> additional liner





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Presented by : B. Schunke

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