Overview of the ITER Heating and Current Drive Systems

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for the

ITER Organization and the Domestic Agencies

ITER Organisation

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The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Baseline Heating and Current Drive Systems

73 MW to achieve H mode and Q=10

- 2 Heating (HNB) Neutral Beams at 1 MV (2X16.5 MW) and Diagnostic (DNB) Neutral Beam at 100 kV
- Electron Cyclotron System (EC) (20 MW at 170 GHz)
- Ion Cyclotron System (IC) (20 MW at 40-55 MHz)

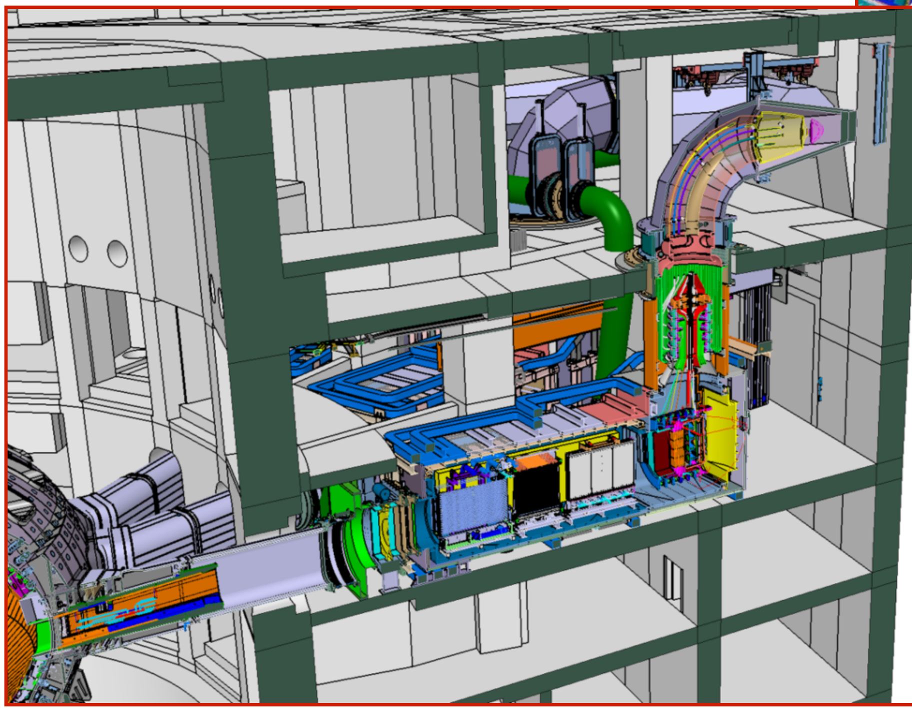
Upgrade for a later phase of Steady-State Operation

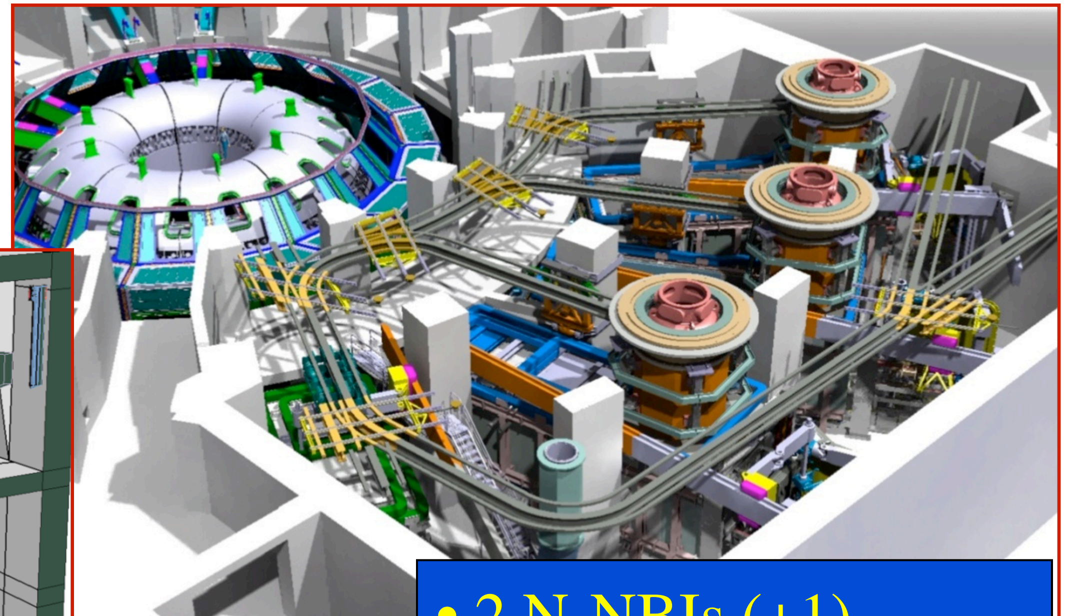
- Lower Hybrid Current Drive (LH) (20-40MW at 5GHz)
- Potential power increases for EC, IC and NB

– K.Ikeda et al., “Progress in the ITER Physics Basis”, Nuclear Fusion **47** (2007).
– F.Wagner et al., Plasma Phys. Control. Fusion **52** (2010) 124044.

Neutral Beam Systems

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



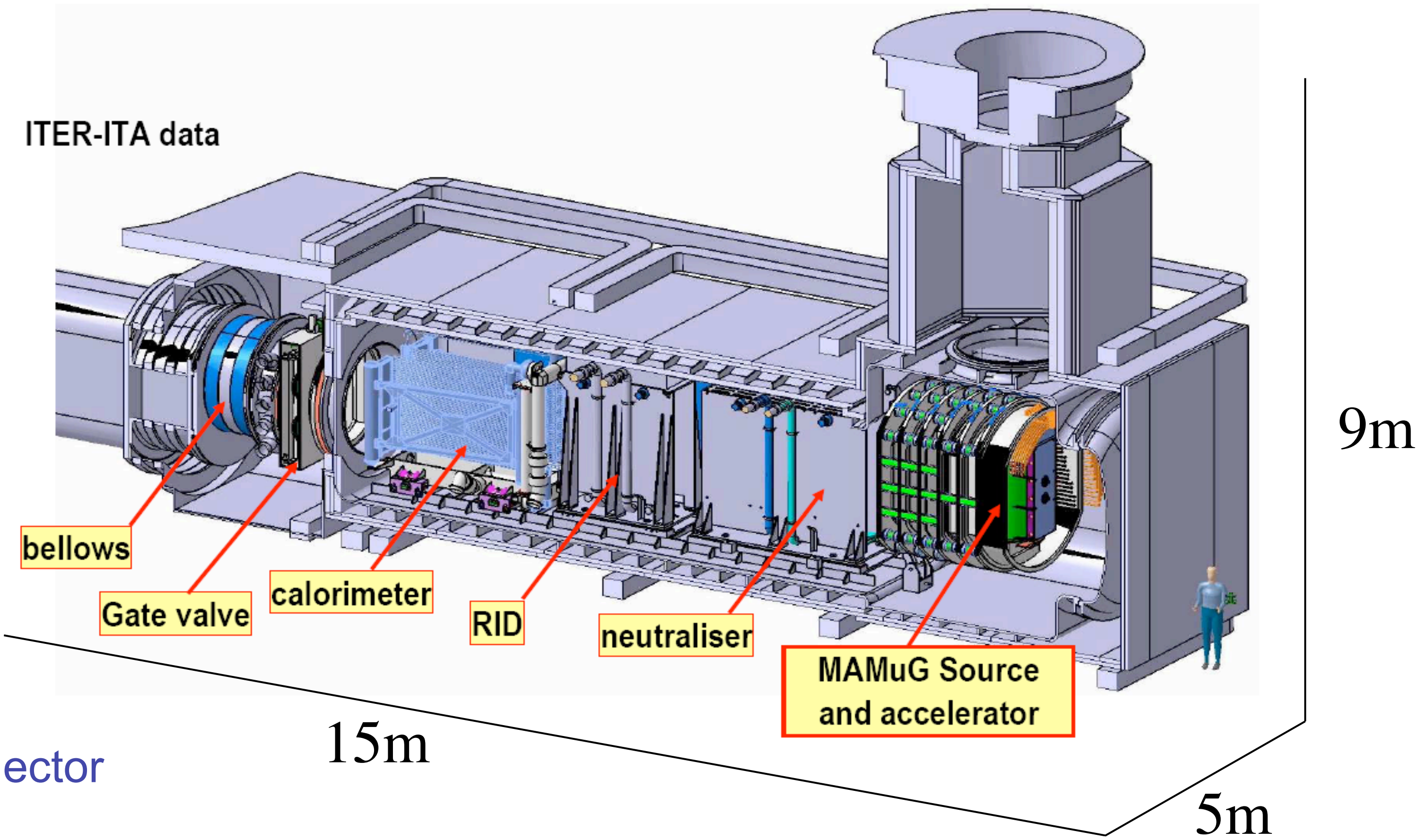


- 2 N-NBIs (+1)
- P_{beam} = 16.5 MW
- I = 40 A
- V = 1 MV
- T_{pulse} = 3600 s

- Requirements sunstantial advance on existing NBI so a Neutral Beam Test Facility is being prepared by Consorzio-RFX at Padua in Italy.
    - R Hemsworth et al., Nucl. Fusion **49** (2009) 045006

Neutral Beam Injector

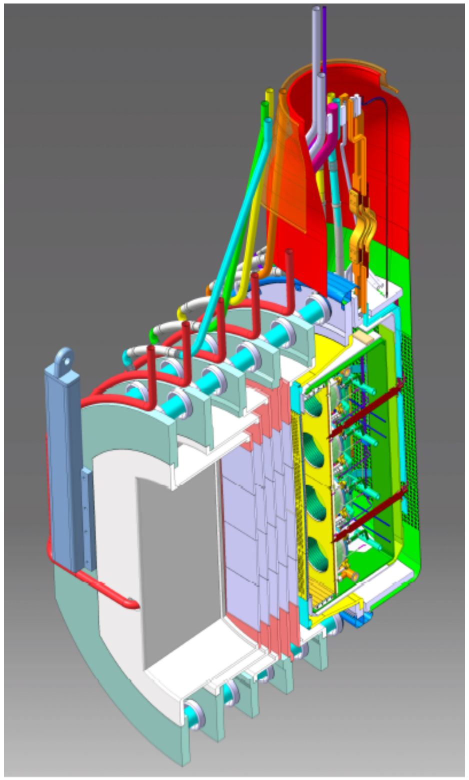
- The beamline components are identified below.
- Other important components include the cryo-pump, vessels fast shutter, duct, magnetic shielding, and residual magnetic field compensating coils.



HNB Injector
~1000t

Technical Challenges associated with ITER NB (i)

Large scale negative ion source



Challenges:

- High current density 200A/m^2 in D^- / 300A/m^2 in H^-
- High reliability / low maintenance frequency , 2years
- Stable long pulse operation (for 1hour ITER pulse)
- Spatial and temporal uniformity ± 10%

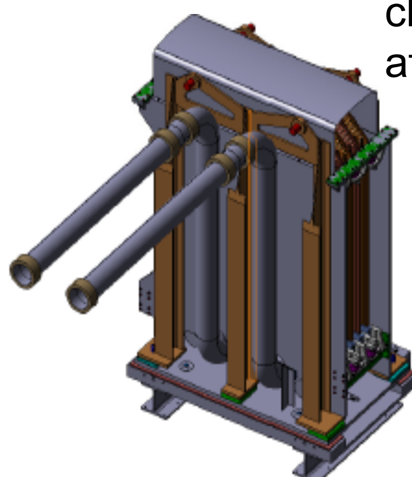
5 stage Multi Aperture Multi Grid accelerator

- 200kV per stage
- 1280 apertures in 4 x 4 matrix

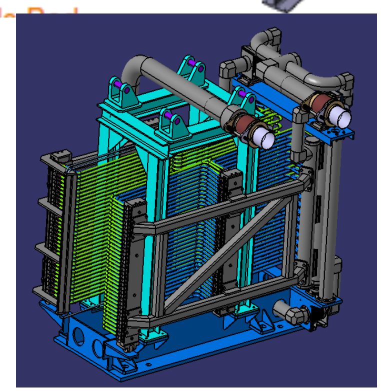
High heat-flux components, like calorimeter or Residual Ion Dump

- Hypervapotron or Swirl-tube technology
- Actively cooled
- CuCrZr

RID: Remove remaining charged ions in the beam after neutralisation



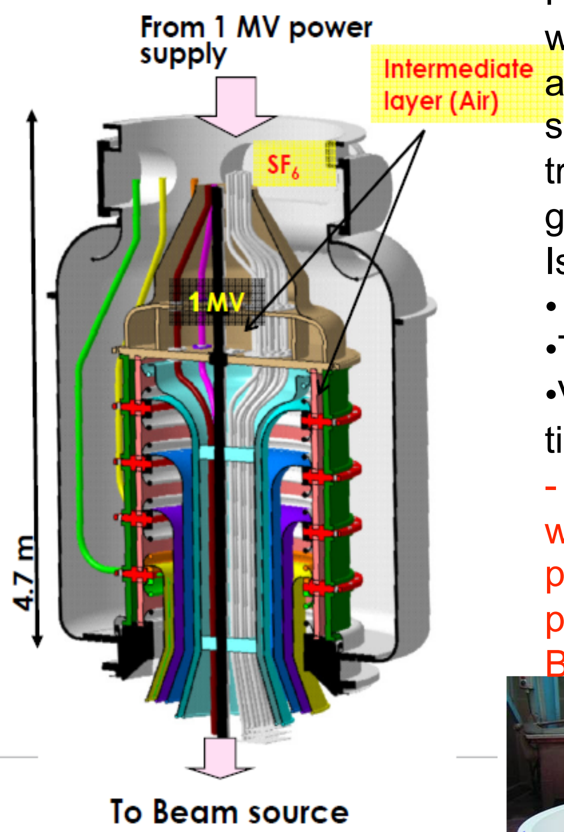
High Heat Flux Panels



Calorimeter: Used to measure beam power and profile

Technical Challenges associated with ITER NB (ii)

1MV HV Bushing for the Heating Neutral Beam Injector

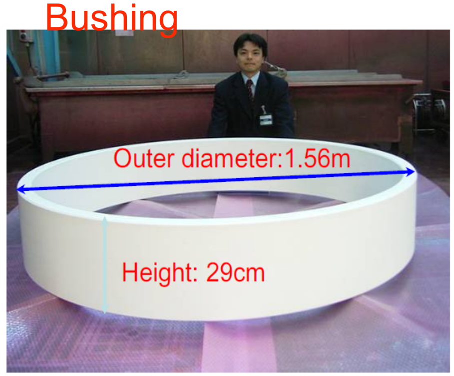


High voltage, cooling water and H_2/D_2 gas are fed to the beam source through HV transmission line (SF6 gas insulation):

Issues:

- HV Holding (1MV)
- Tritium confinement
- Vacuum leak tightness

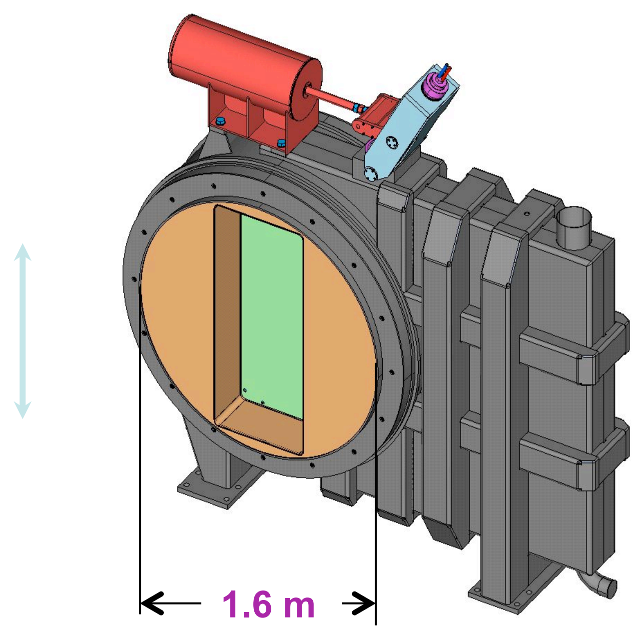
- Largest ceramic ring with brazed Kovar plate in the world produced for HV Bushing



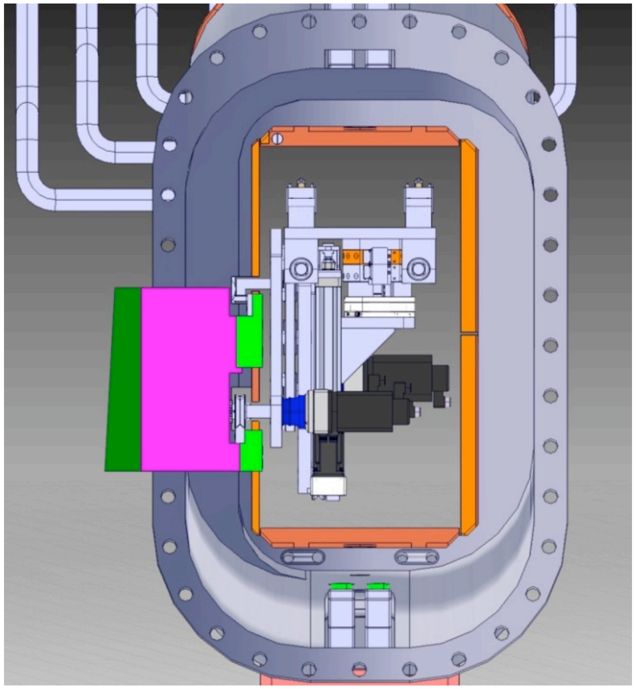
Development of an all-metal seal isolation valve of ~ 1.6m diameter

Used to isolate the injectors from the ITER vacuum vessel for interventions:

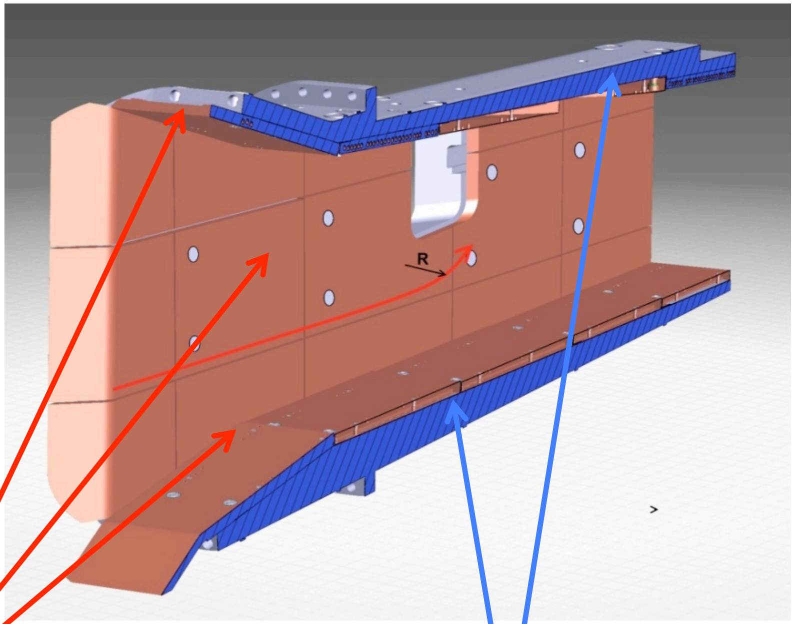
- Weight more than 14.5 tons
- Maximum permissible leak rate 1 x 10^{-10} Pa m^3 /s
- Has to withstand 20MPa in injector, vacuum in ITER vacuum vessel



Duct Liner Remote Handling



DLM Top/bottom Panel Transporter

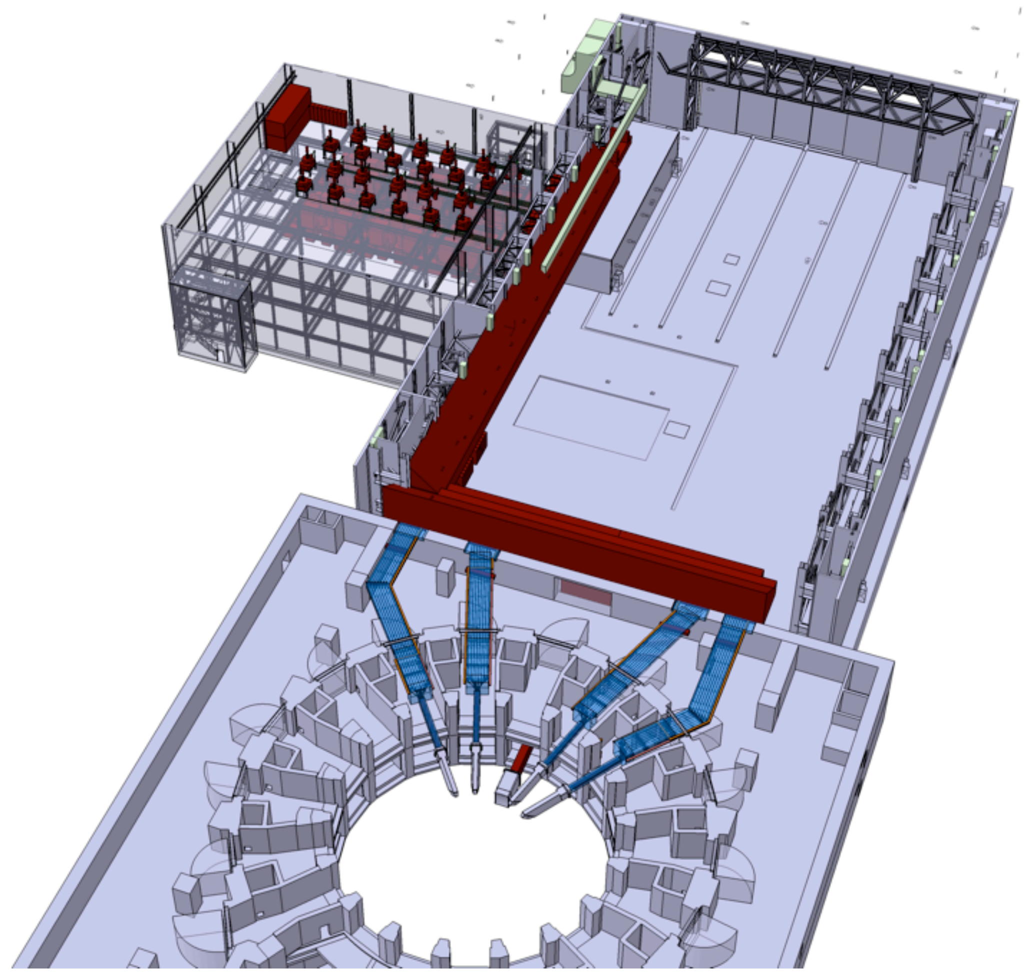


CuCrZr deep drilled panels
Top/bottom & sides

Neutron shield
316LN

170 GHz ITER EC System

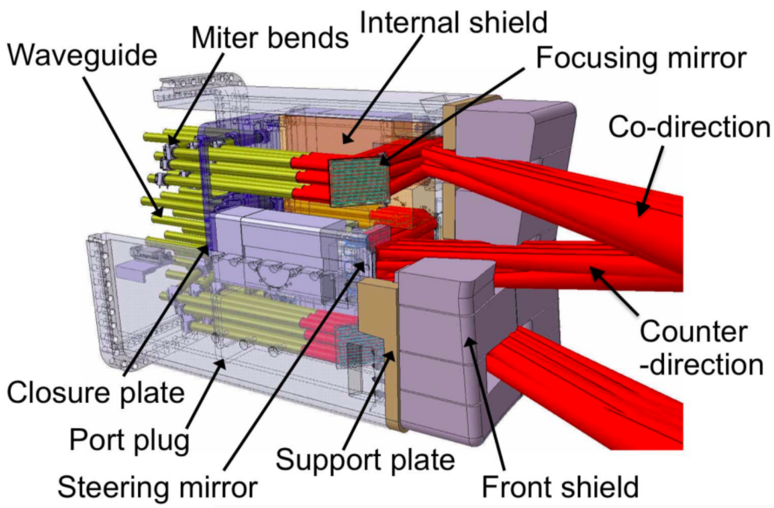
- Provide auxiliary heating (20MW) to assist in accessing H mode and achieve Q=10.
- Provide steady state on-axis and off-axis current drive in the range of $0<\rho_T<0.5$.
- Control MHD instabilities by localized current drive.
- Assist initial breakdown and heat during current ramp-up.

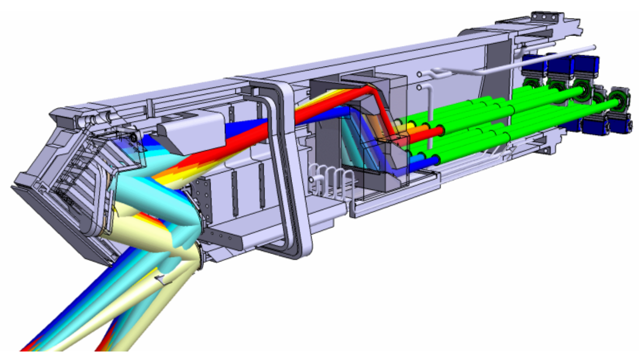


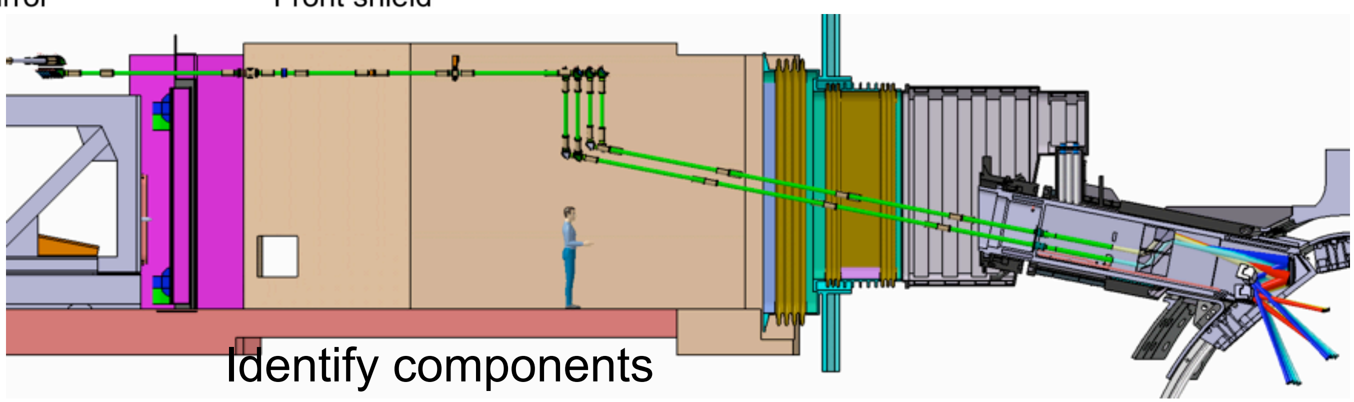
EC Launchers

Challenges include:

- •Transmit up to 20MW CW using rotating mirror systems
- •Provide nuclear shielding and confinement
- •Maintenance of in-vessel via remote handling operations





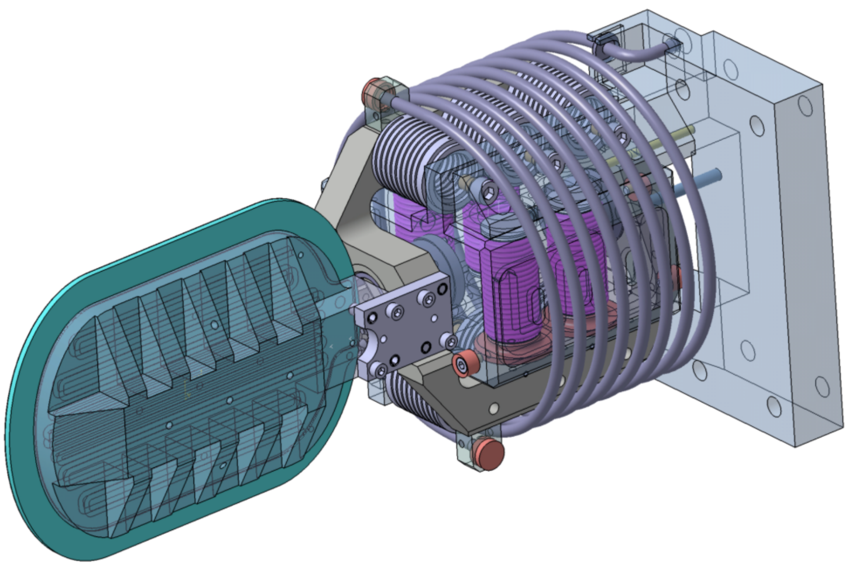


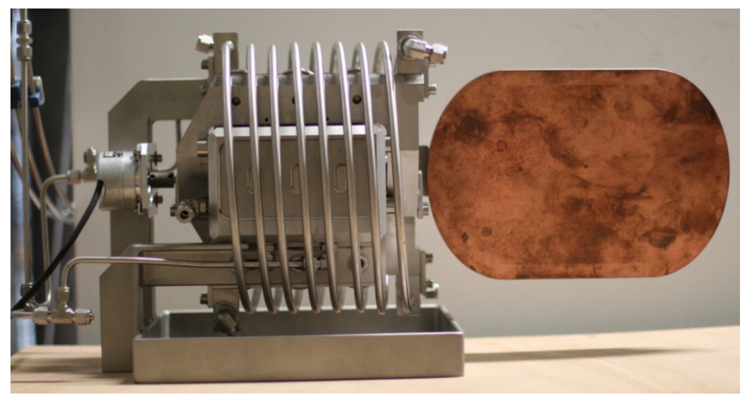
Identify components

Steering Mirror

EU developing novel frictionless back-lash free steering mirror

- Survive in ITER's nuclear environment
- Withstand up to 5MW/m^2 on mirror surface
- Steer beams over ≥24˚
- Reliably position beams with steering accuracy ˜0.025˚

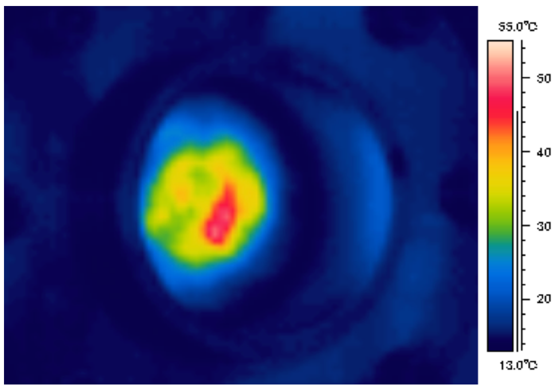


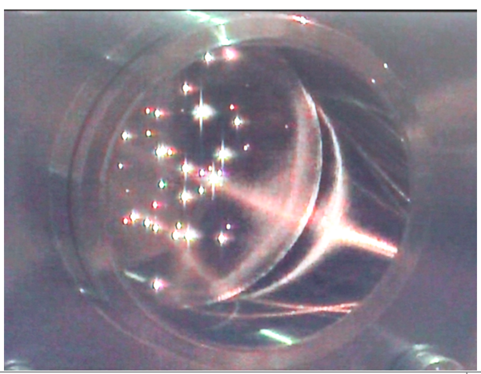


Diamond Window

Diamond window provides:

- ≥1.1mm thick disk ˜76mm in diameter
- Compatible with transmission of 2.0MW
- Provides confinement of tritium in ex-vessel waveguide
- Configuration allows in-situ leak testing and isolation with all-metal gate valve





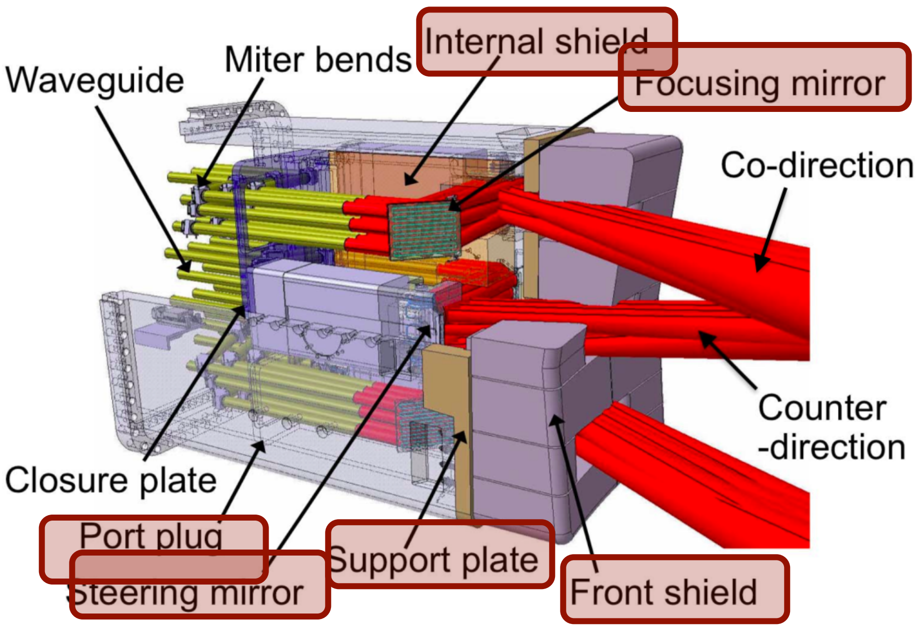
Two Diamond window housing designs (JAEA and F4E/KIT) being tested:

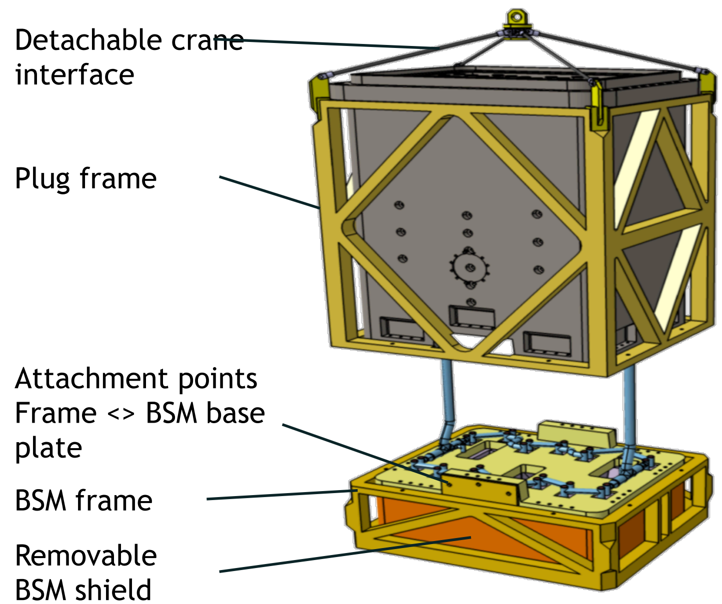
- Both using JAEA 170GHz 1MW CW test facility
- Achieved ≥0.5MW for ≥20s (limited by PS problems)
- Continued testing planned for November 2011
- Aim for ≥1MW and long pulse operation
- Concern for long term reliability of window (present experience is ≤4000sec integrated on-time)

Remote Handling

Critical component required to use RH for maintenance:

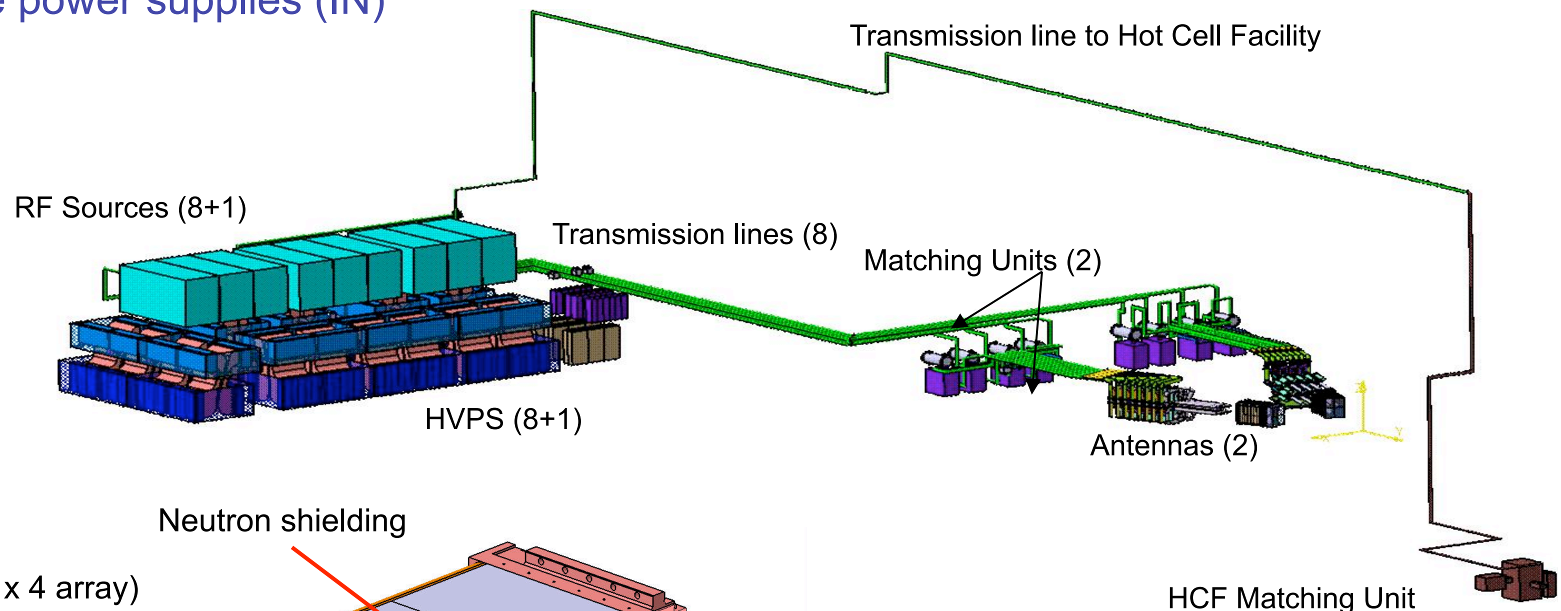
- Removal and re-insertion of launcher in Port
- Replacement of blanket shield module (in hot cell)
- Replacement of steering mirror assembly (in hot cell)
- Replacement of internal shielding blocks (in hot cell)

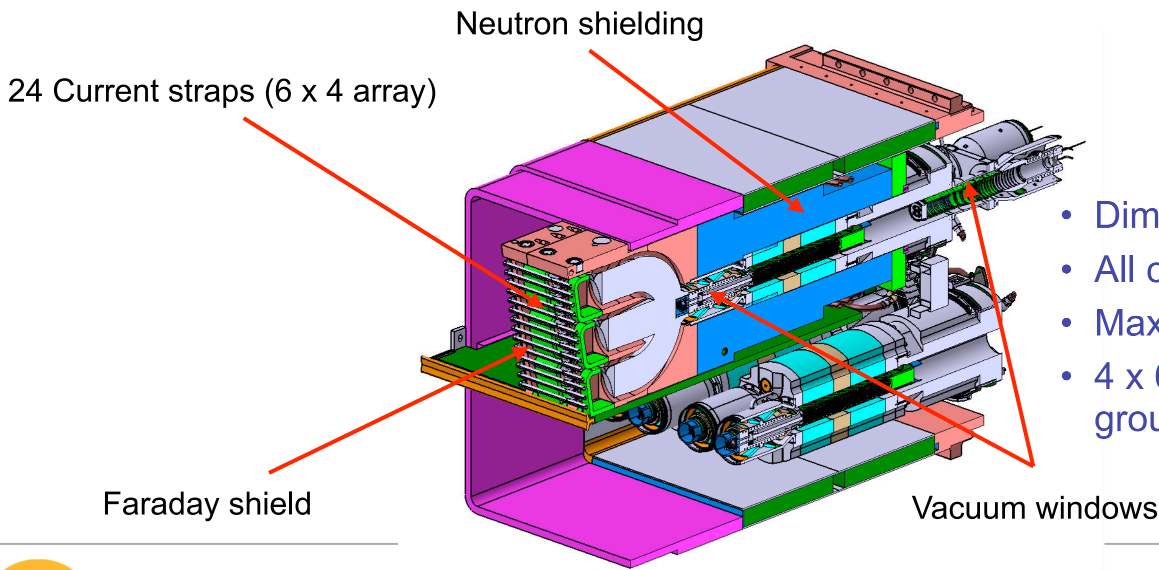




Ion Cyclotron H & CD System

- Two antennae (equatorial port plugs) (EU)
- Transmission and matching systems (US)
- RF sources (8x3MW + 1 spare, 40-55MHz, for 20MW in plasma) (IN)
- High Voltage power supplies (IN)



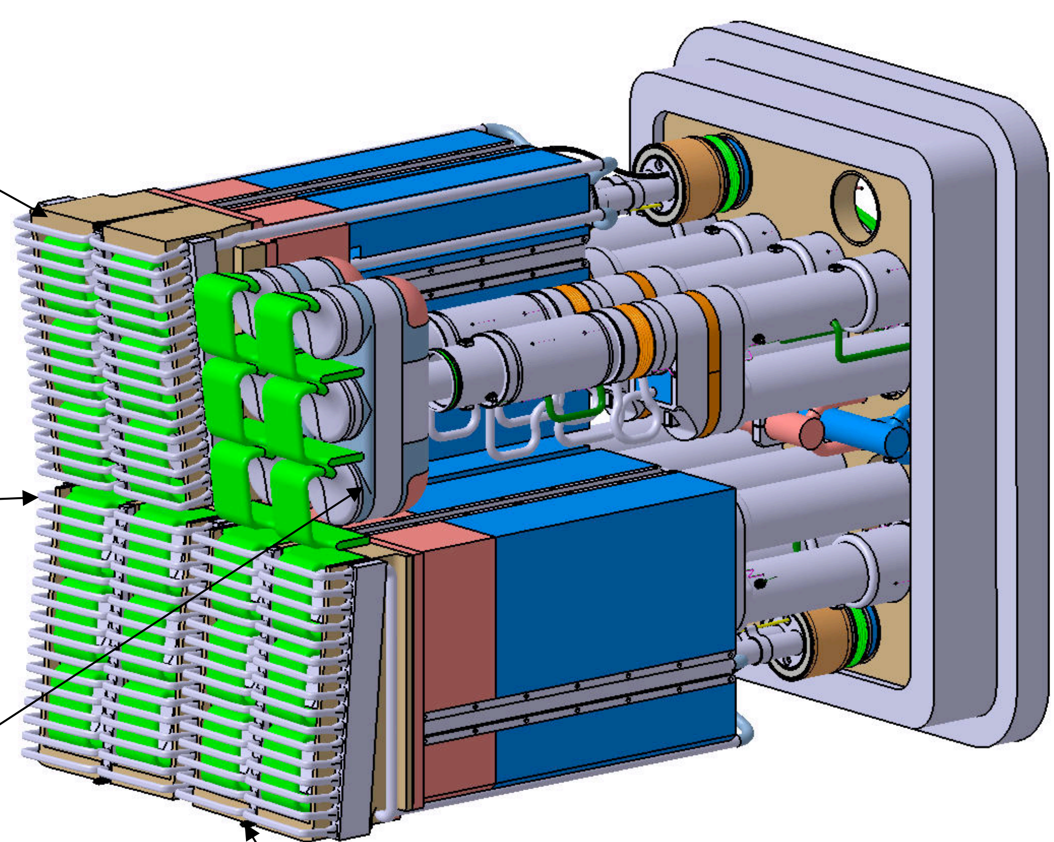


- Dimensions: 2.1 m H x 1.7 m W x 3.6 m L
- All components actively cooled
- Max. dry mass: 45 metric tons
- 4 x 6 radiating straps grouped in 8 poloidal triplets

IC Antenna: Key design developments(i)

Strap Housing / Straps
HIP solution with promising thermal / structural performance, manufacturing route explored, assembly sequence developed

Faraday Screen
Square channel design developed with supporting modelling



4 Port Junction
Deep drilled solution with full assembly sequence developed

Reflectometer
Routing through antenna developed, front horn positioning to be finalised

IC Antenna: Key design developments(ii)

Bulkhead Layout

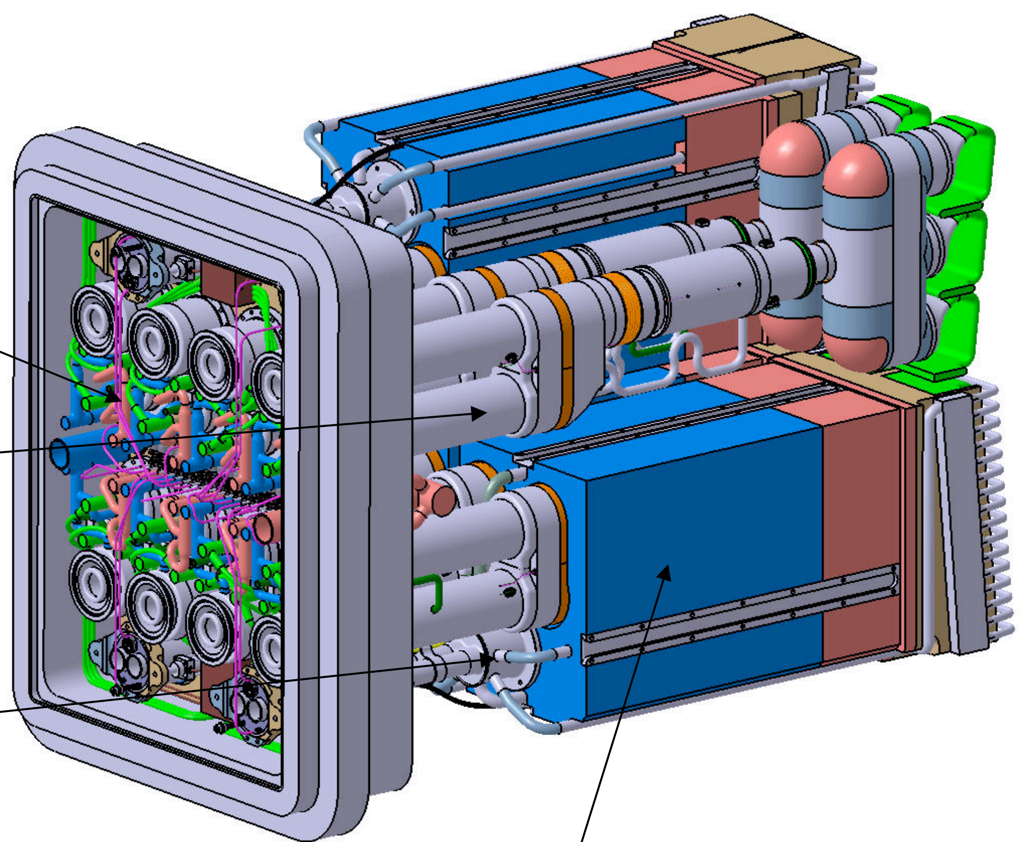
Extensive work laying out revised cooling water system, diagnostic feedthoughs, vacuum lines etc

RVTL

Dimension Changes in sympathy with RF design, development programmes underway, support on Window R&D

Shimming

Rear Hydraulic components optimised for layout, simplified 2 pipe supply shaft, reflectometry incorporated



Rear Shield Cartridge

Extended, with now deep drilled cooling solution developed to attenuate neutron streaming

IC Source Specifications

Specification	Level & Units
Nominal output power	2.5 MW CW/ 3 MW CW
Pulse duration	2000 s/3600s
Duty cycle	1/4
Maximum average VSWR	2/1.5
Transient VSWR at any phase	2.5 /2 (1 s max. & 10% duty cycle)
Accuracy of output power	5% max
Frequency Range	35-65 MHz / 40-55 MHZ
Power mod. range at the load	2kW-3 MW
Max amplitude mod. frequency	100Hz
Max. Output harmonic level	-20 dBc
Max phase mod. frequency	10kHz
Overall end stage electrical efficiency (%)	≥65 (matched) ≥45 (worst unmatched)
O/P impedance	50Ω

Specifications

Output power - qualification programme has been launched in INDA:

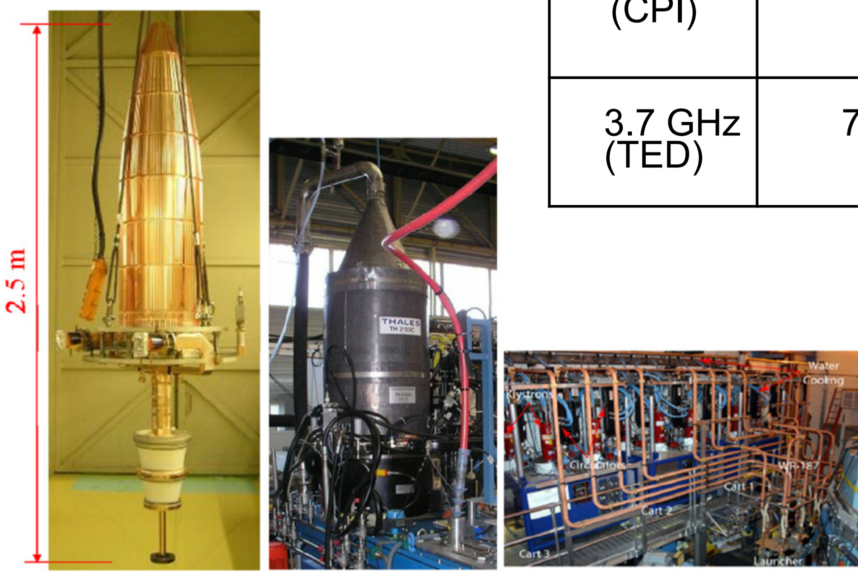
- Representative test of one chain up to final stage.
- ITER India is developing source chain up to predriver; an industrial partner develops the driver and endstage

Plan for the **combiner**:

- Definition of the design specifications and margins
- Definition of RF amplitude and Anode voltage regulations
- specific test plan - *this is not an unusual circuit configuration*

Future upgrade - LHCD

Klystron	Design Target	Achieved Performance of Prototypes	Comments
5 GHz (Toshiba)	500kW/ CW VSWR 1.4	303 kW / CW (VSWR=1) 508 kW / 0.5s (VSWR=1)	Development For KSTAR
4.6 GHz (CPI)	250 KW/ CW	Used in Alcator C-Mod	On going production for EAST
3.7 GHz (TED)	700kW / CW	767kW/CW (VSWR=1) 670kW/CW (VSWR= 1.4)	Installed and used in Tore Supra



(*a*) Prototype of 5 GHz tube and (*b*) prototype of 3.7 GHz; (*c*) 4.6 GHz tubes in operation on Alcator C-Mod.

- Progressed on voluntary basis by interested Parties
- Layout and interfaces ensured by IO

REF: G.T. Hoang, et al., A lower hybrid current drive system for ITER, Nucl. Fusion ***49*** *(2009), p. 075001.*

Procurement Status

	Reference	Signature Date	kIUA Value
16	5.3.P7A.IN.01 Diagnostic neutral Beam Power Supply	19 April 2009	9.70000
24	5.3.P6.EU.01 Power Supply for Heating Neutral Beam (Low Voltage)	13 July 2009	31.38200
31	5.1.P3.IN.01.0 IC H&CD RF Power Sources	5 February 2010	18.00000
35	5.3.P7B.IN.01 Diagnostic Neutral Beam Line	22 March 2010	13.10000
37	5.1.P2.US.01 IC Transmission Lines	30 April 2010	7.35400
41	5.2.P2.US.01 Electron Cyclotron Main Transmission Lines	12 May 2010	12.71700
46	5.3.P9.EU.01.0 Neutral Beam Test Facility Components	27 October 2010	27.00
47	5.3.P9.IN.01 Neutral Beam Test Facility Components (Spider and Calorimeter)	15 December 2010	0.91
3	5.1.P4.IN.01 IC H&CD Radio Frequency Power Supply	March 2011	6.9
30	5.2.P3.RF EC Gyrotrons	(sept 2011)	9.86
35	5.2.P3.IN.01 EC RF Gyrotrons	(oct 2011)	2.69
36	5.2.P3.EU.01 EC RF Gyrotrons	(oct 2011)	9.86
		Total	149.5

- Most H&CD functional specification PAs have been signed.
- Build-to-Print designs are in PDR or FDR phases.

Note: 1kIUA ~ 1.55M€

Thank you for your attention!

Associated presentations at this conference:

D. Rathi, DEVELOPMENT & INTEGRATION OF THE ICH & CD SYSTEM CONFIGURATION IN THE ITER TOKAMAK COMPLEX AND AUXILIARY BUILDINGS **(SP3-20)**

H.DECAMPS, THE -1 MV DC ITER NEUTRAL BEAM POWER SUPPLY **(SP3-48)**

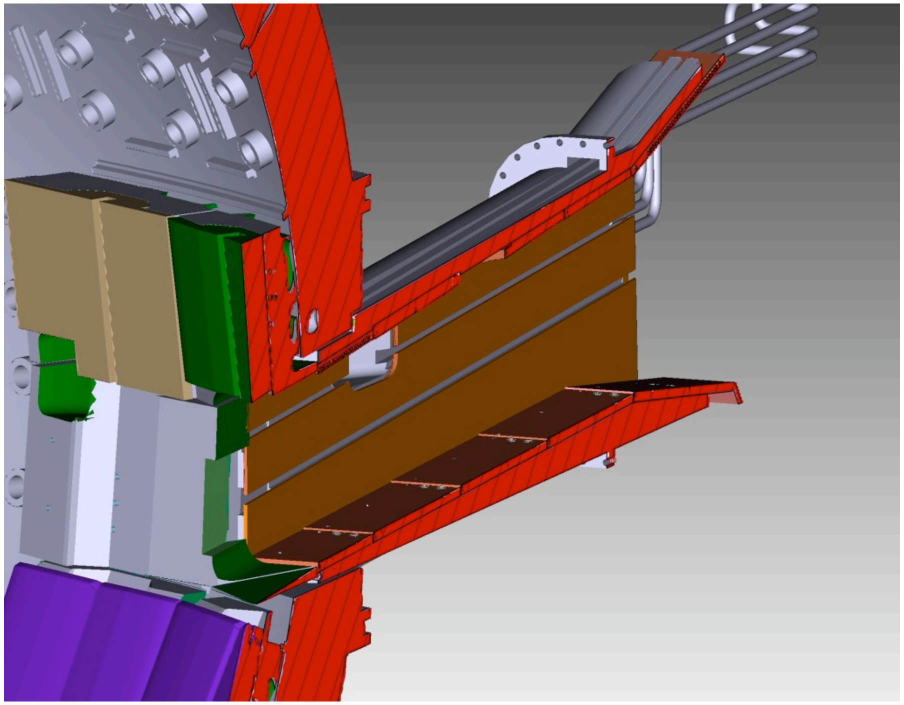
T.GASSMANN, PROGRESS IN CONCEPTUAL DESIGN OF THE HIGH VOLTAGE POWER SUPPLIES FOR ITER EC SYSTEMS **(SP3-44)**

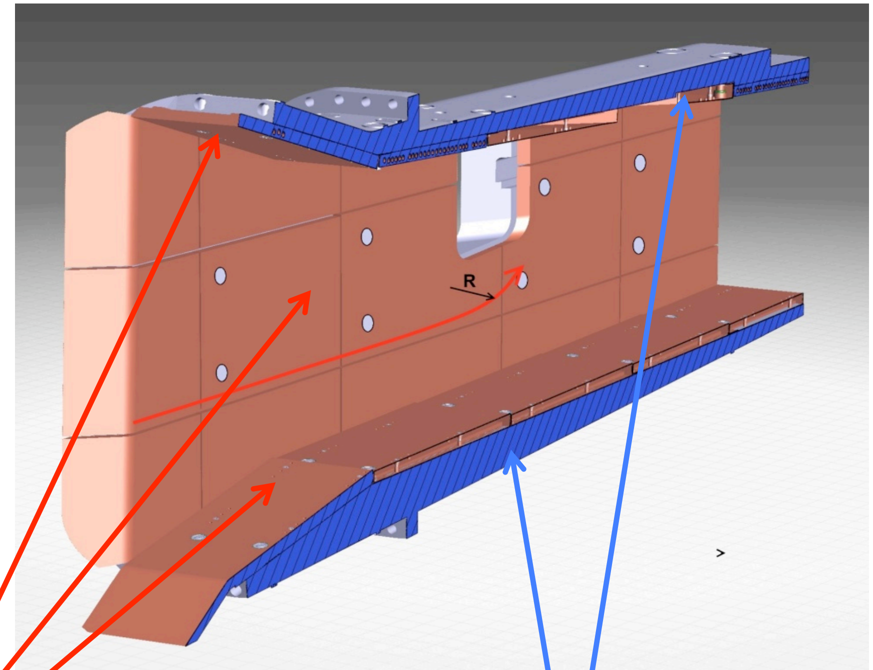
D.CAMPBELL, CHALLENGES IN OPERATION AND CONTROL OF ITER **(SO1B-1)**

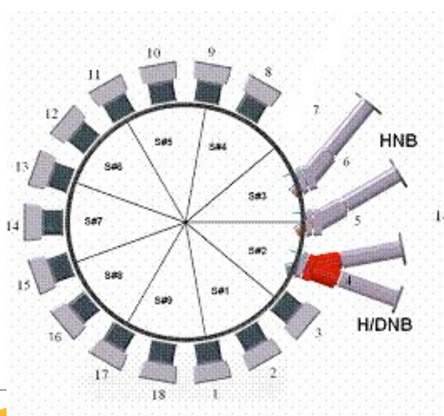
R.Hawryluk, PROGRESS TOWARD ITER **(SPL1-1)**

Spare Slides

The NBI Duct Liner







CuCrZr deep drilled panels
Top/bottom & sides

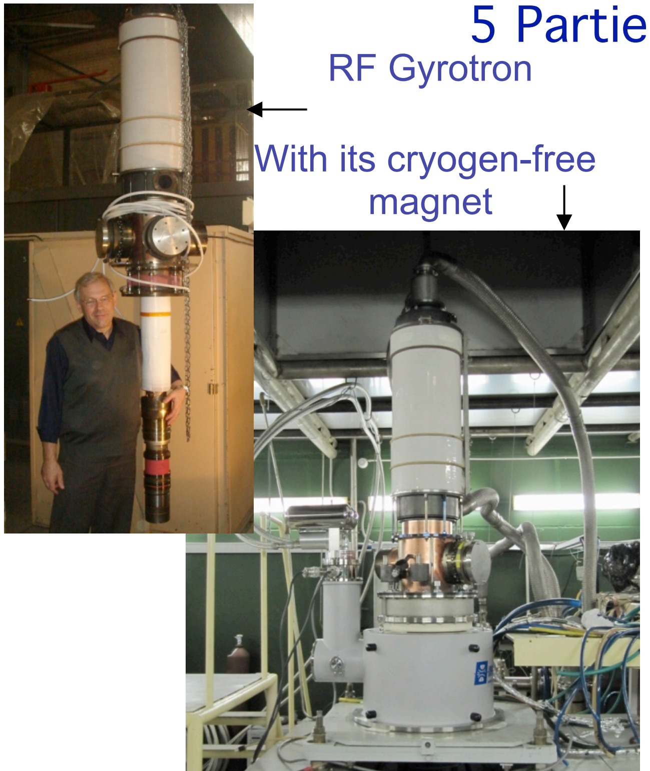
Neutron shield
316LN

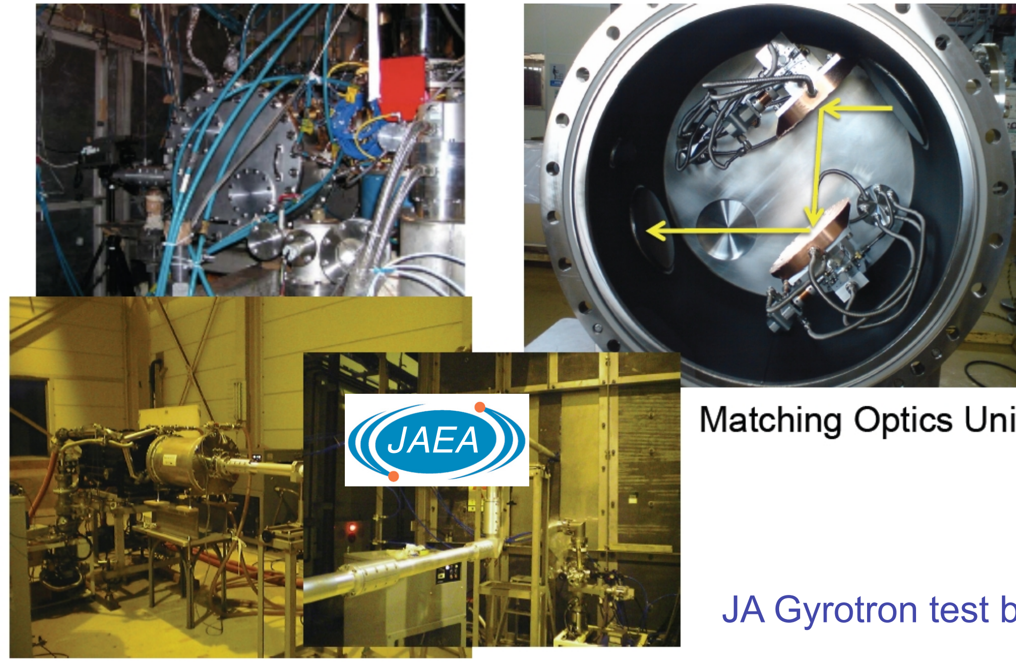
Electron Cyclotron H & CD System

5 Parties provide in-kind procurement of the 4 subsystems

RF Gyrotron

With its cryogen-free magnet





Matching Optics Unit

JA Gyrotron test bed

IAP RAS GYCOM INF

Evacuated Transmission Line

Cryogen free magnet for 1MW gyrotron (Cryomagnetics, Inc.)

- Cryo-magnets and condensors for gyrotrons (EU, JA, RF, IN)

- HV power supplies (60kV, 100A) and (50kV, <1A) (EU, IN)
- Evacuated waveguide components (US, EU, JA)
- Cooling manifold systems (JA, EU, RF, IN, US)
- Control systems (JA, EU, RF, IN, US)

IC Source Block Diagram