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Heating & Current Drive and Diagnostics Systems in ITER

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Heating & Current Drive and Diagnostics systems in ITER

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August 03, 2007

Plan of talk

- Introduction
- Work Areas

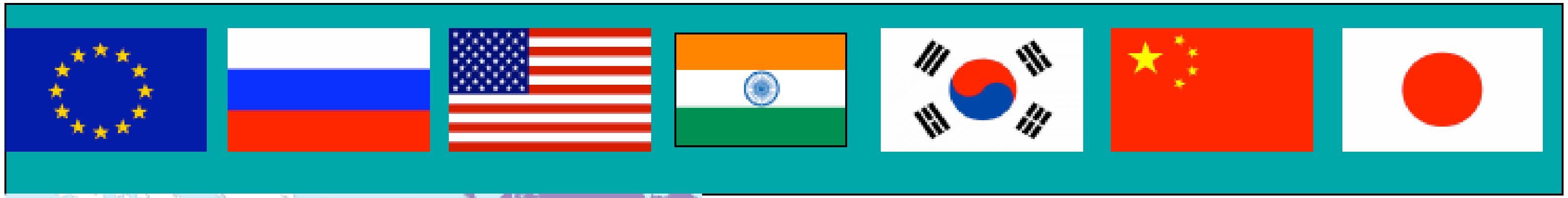
  a) HNB & DNB

  b) ICH

  c) ECH and Startup system

  d) Diagnostics
- Summary

ITER



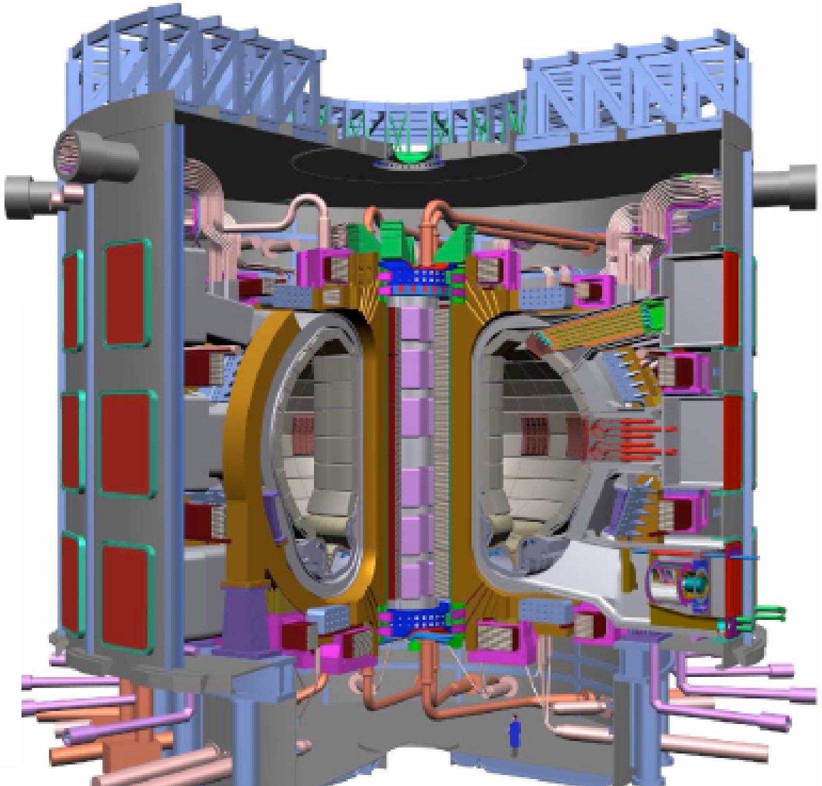
10 Giga-Euros to build&operate

10 years to build

Startup 2016

18 buildings

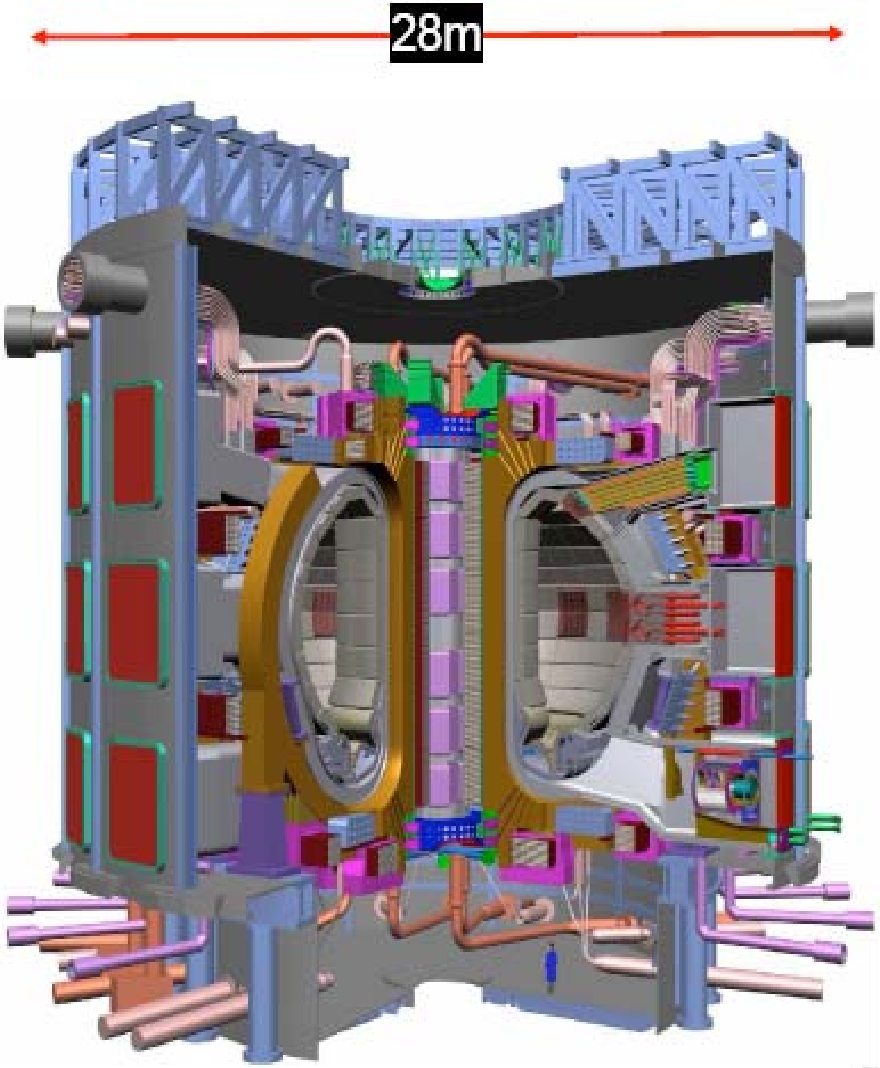
180 hectares being cleared



ITER SITE

ITER – some numbers

Fusion power	500MW
Heating power	73 MW
Pfus / Pheat	Q>10
Neutron wall load	0.57 MW/m^2
Major radius	6.2 m
Minor radius	2.0 m
Plasma current	15 Megamp
Toroidal field	5.3T
Plasma volume	837 m^3
Pulse length	300 - 5000 s
PF SC coils (**NbTi**)	925+6*130 t
TF SC coils (**Nb_3Sn**)	18*312 t
Vacuum vessel	9*575 t
Load assembly	23,350 t

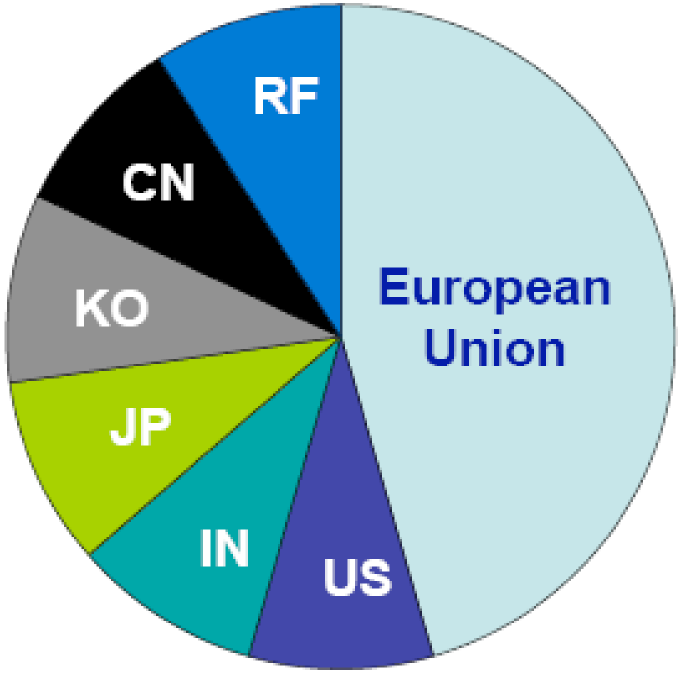


Construction Sharing

Overall sharing: EU 5/11, other six parties 1/11 each

Overall contingency of 10% of total.

Total amount: ~ 5079 MEuro(2007)



Total procurement value : 3021

Staff: 477

R&D: 80

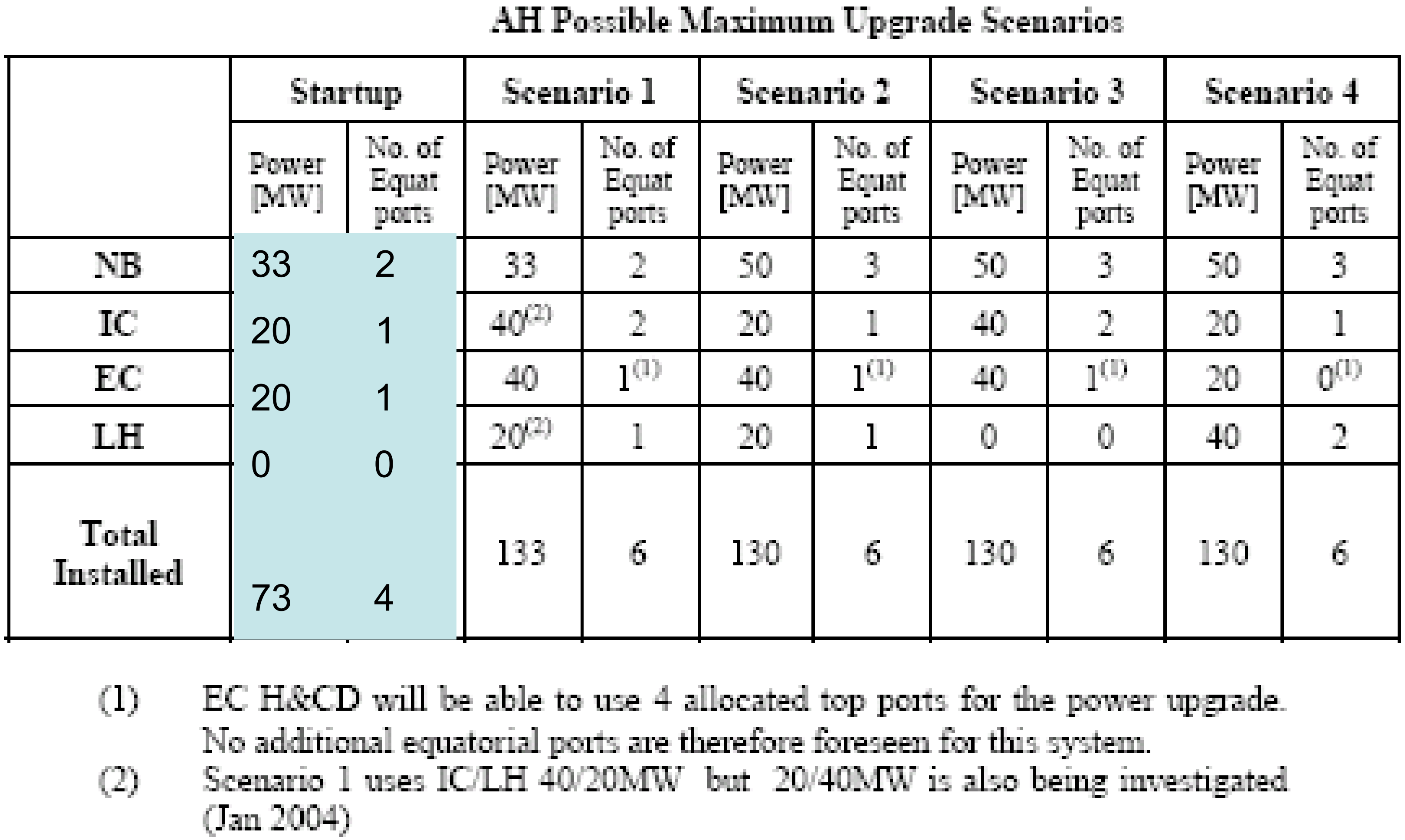
Total = 3577

Heating & current drive systems on ITER

Design scenarios

- Plasma operation has been designed with variable combination of heating and current drive systems: 2 (3) NB H&CD injectors 33 – 50 MW, 20~40MW ECH, 20~40MW ICH, 0~40MW LH, 3 MW ECH for start up, 3.5 MW DNB.

- **Baseline: The start-up configuration requires 33 MW NB,20MW ICH, 20MW ECH,0MW LH, 3 MW ECH for start up, 3.5 MW DNB.**



AH Possible Maximum Upgrade Scenarios

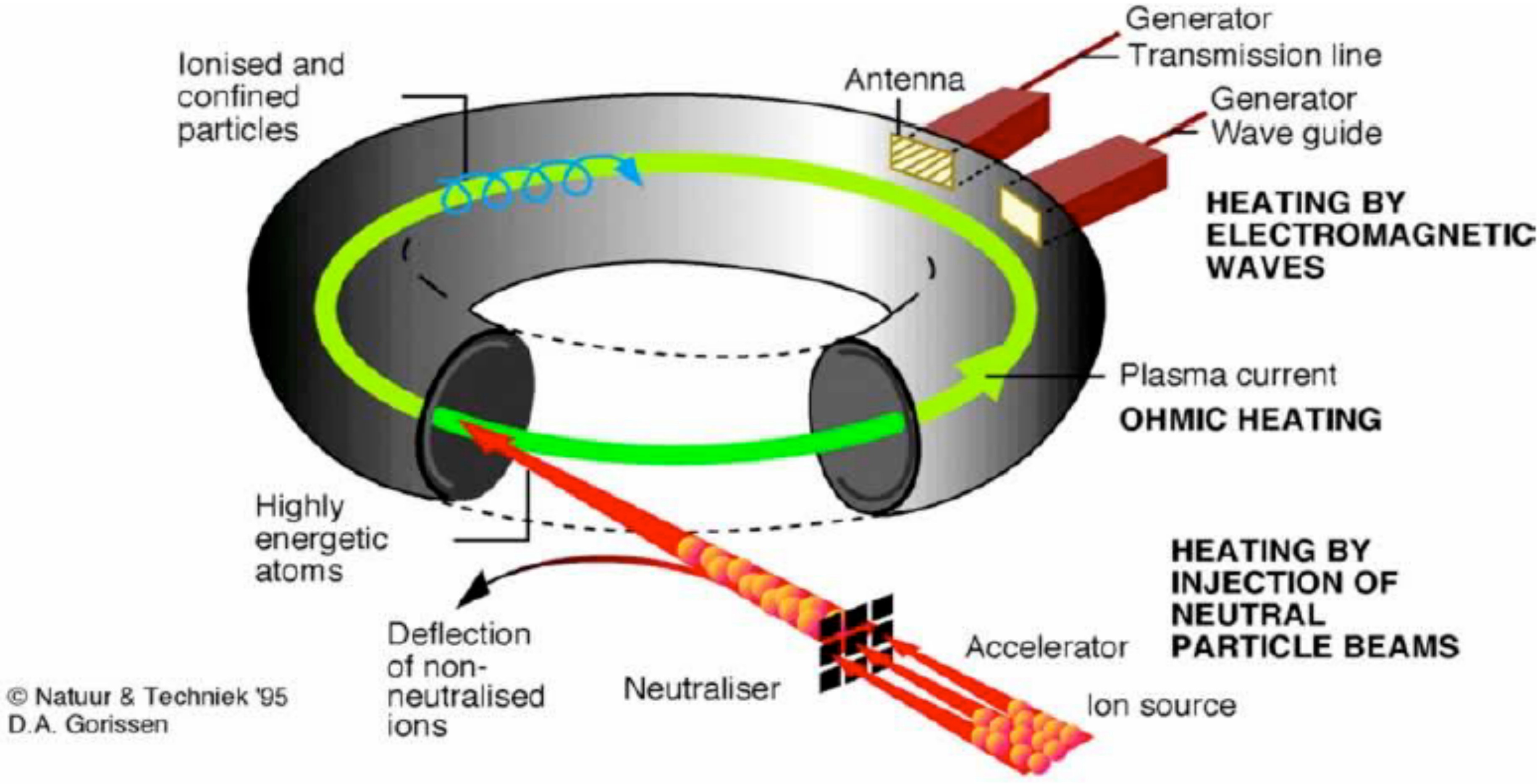
	Startup		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports	Power [MW]	No. of Equat ports
NB	33	2	33	2	50	3	50	3	50	3
IC	20	1	40(2)	2	20	1	40	2	20	1
EC	20	1	40	1(1)	40	1(1)	40	1(1)	20	0(1)
LH	0	0	20(2)	1	20	1	0	0	40	2
Total Installed	73	4	133	6	130	6	130	6	130	6

(1) EC H&CD will be able to use 4 allocated top ports for the power upgrade. No additional equatorial ports are therefore foreseen for this system.

(2) Scenario 1 uses IC/LH 40/20MW but 20/40MW is also being investigated (Jan 2004)

How to obtain the ultra high temperatures needed ?

Ohmic heating: $\eta \propto T^{-3/2}$ => limited to T~1keV, additional heating needed



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D.A. Gorissen

Neutral Beams for ITER

Summary of the design parameters for heating and current drive (H&CD) & Diagnostic NBI system for ITER.

Power delivered to the plasma per injector	HNB 16.7 MW	DNB 3.6MW (excl. duct losses)
Beam energy	1MeV (D-) / 870keV (H-)	100 keV (H-)
Accelerated ion current	40 A (D-) / 46 A (H-)	60 A (H-)
Average accelerated ion current density	200 A/m2 (D-) / 300 A/m2 (H-) ****	300 A/m2
Current density uniformity over the extraction area	± 10 %	± 10 %
Pulse length	≤ 3600 s	5Hz mod. 1/6 ITER pulse
Beamlet divergence	< 7 mrad	7 mrad

**** achieved **280 A/m2 of H for <5s**

NBI energy range for effective hydrogen operation

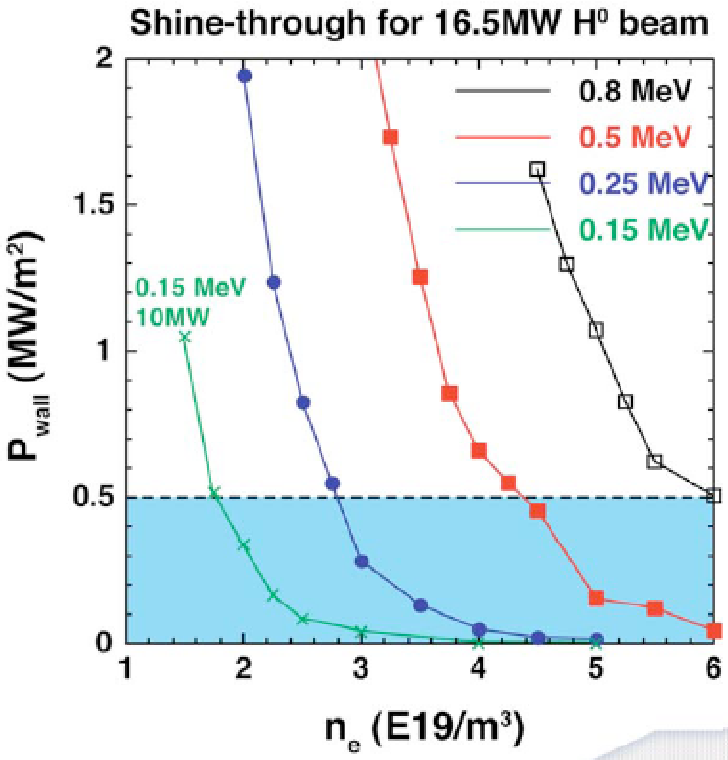
A neutral beam energy of 1MeV will lead to substantial shine through in the initial hydrogen phase. It is therefore proposed to use an initial beam energy of 500-600keV in the hydrogen phase, to be upgraded to 1MeV for the subsequent deuterium and tritium operation.

NB Shine-through sets minimum density:

Power load on the far wall is evaluated with varying EB and ne.

- Ref. Scenario 2, Zeff=1.6
- Acceptable power load on FW Pwall < 0.5 MW/m2

\ corresponds to 1% shine through of NB power.

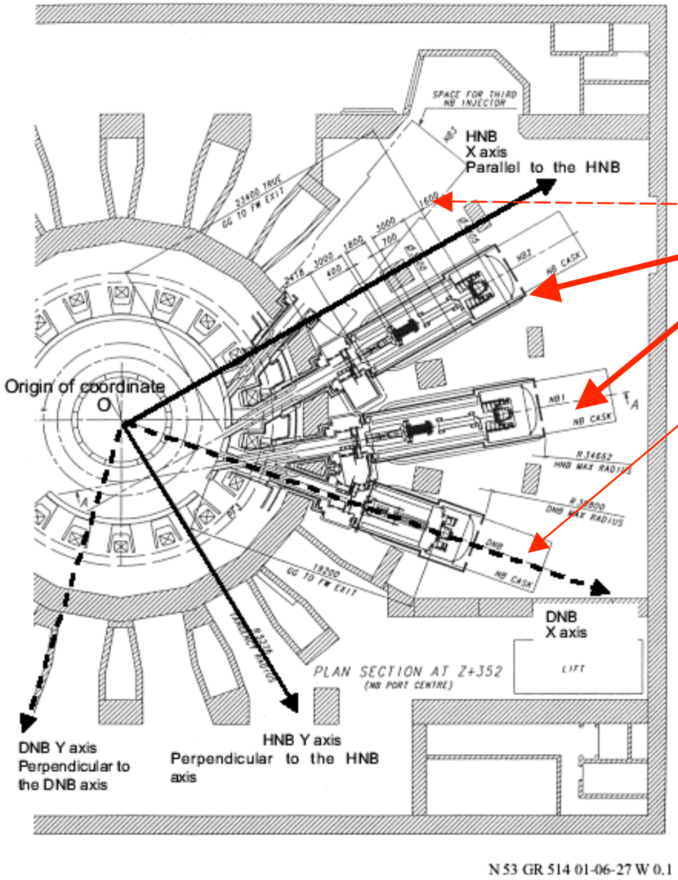


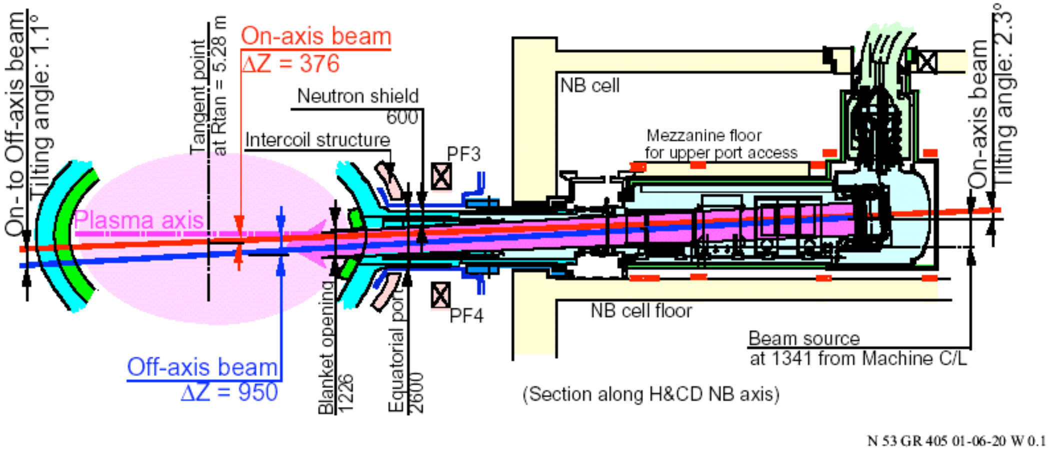
NBI injectors in ITER

2+1 NBI

DNB

tangential injection





Plan view

Vertical cross section view

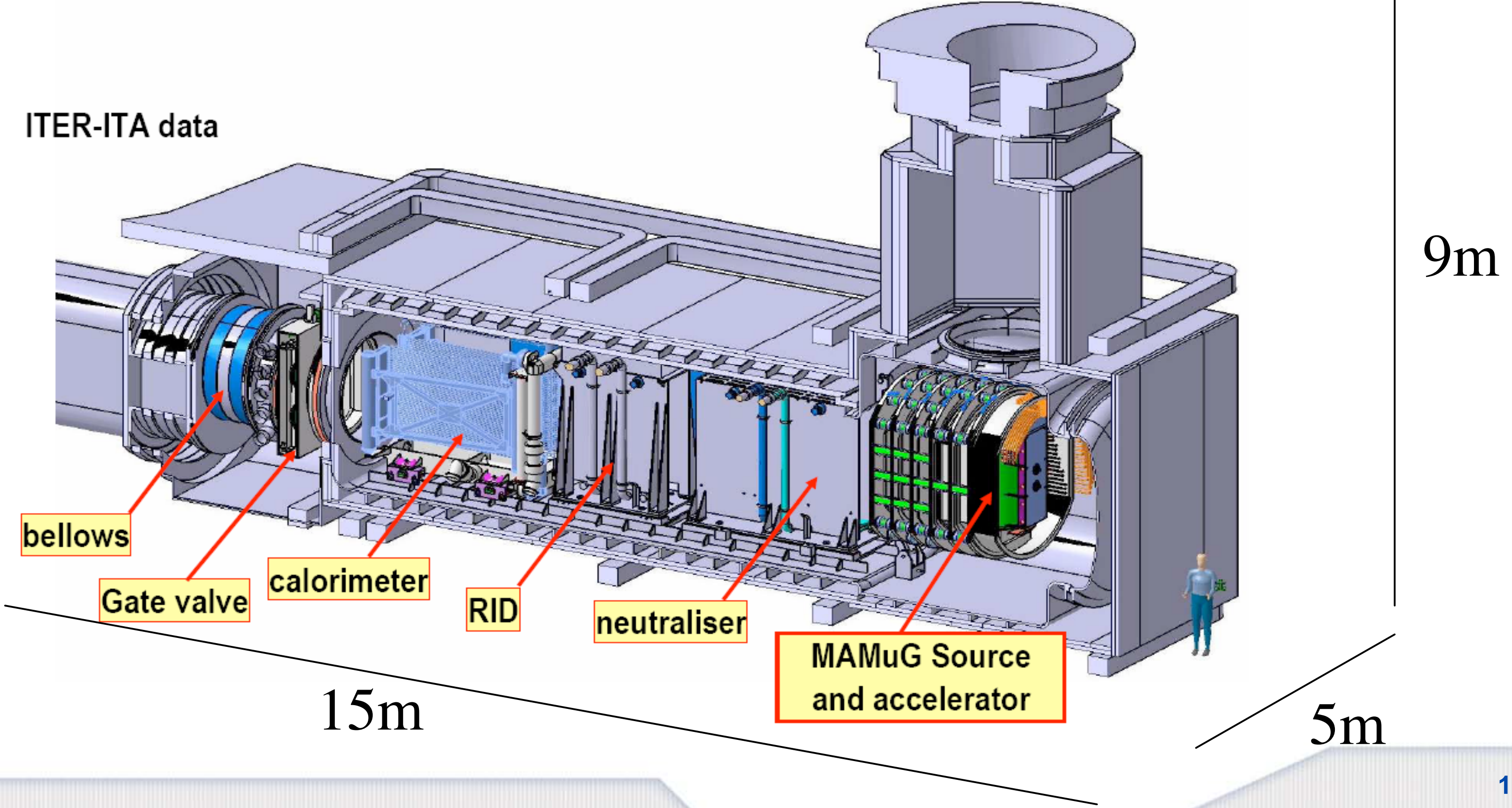
On/off axis injection by tilting the beam axis vertically

The injector

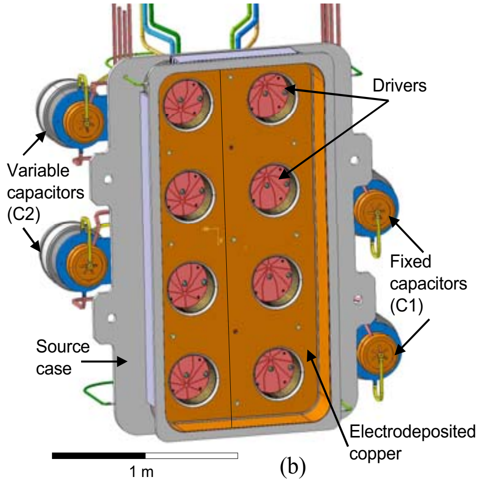
The Injector can be separated in

beam components (**Ion Source, Accelerator, Neutralizer, Residual Ion Dump** and Calorimeter)

other components (cryo-pump, vessels, fast shutter, duct, magnetic shielding, and residual magnetic field compensating coils)

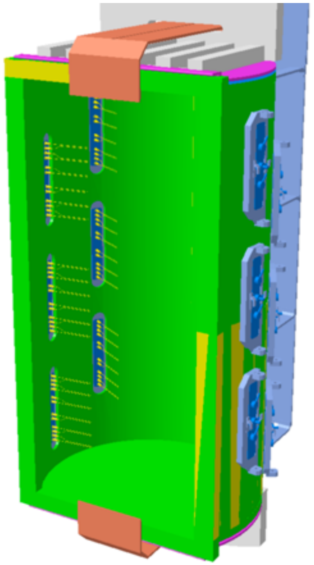


Ion source design



RF driven

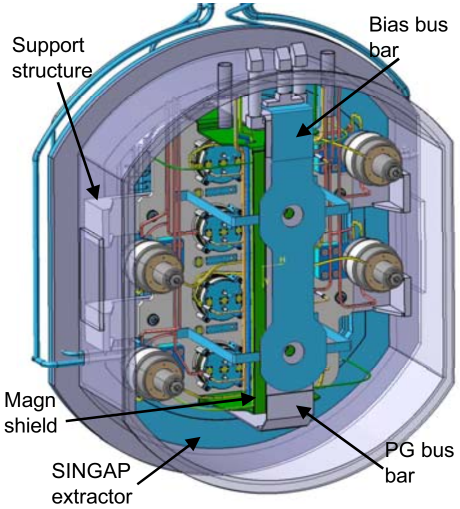
Arc driven



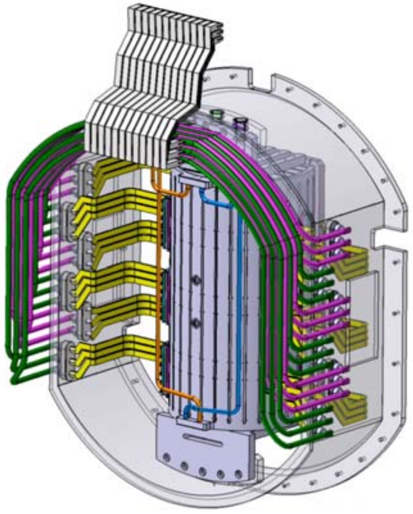
Front view

8 RF drivers

72 filaments

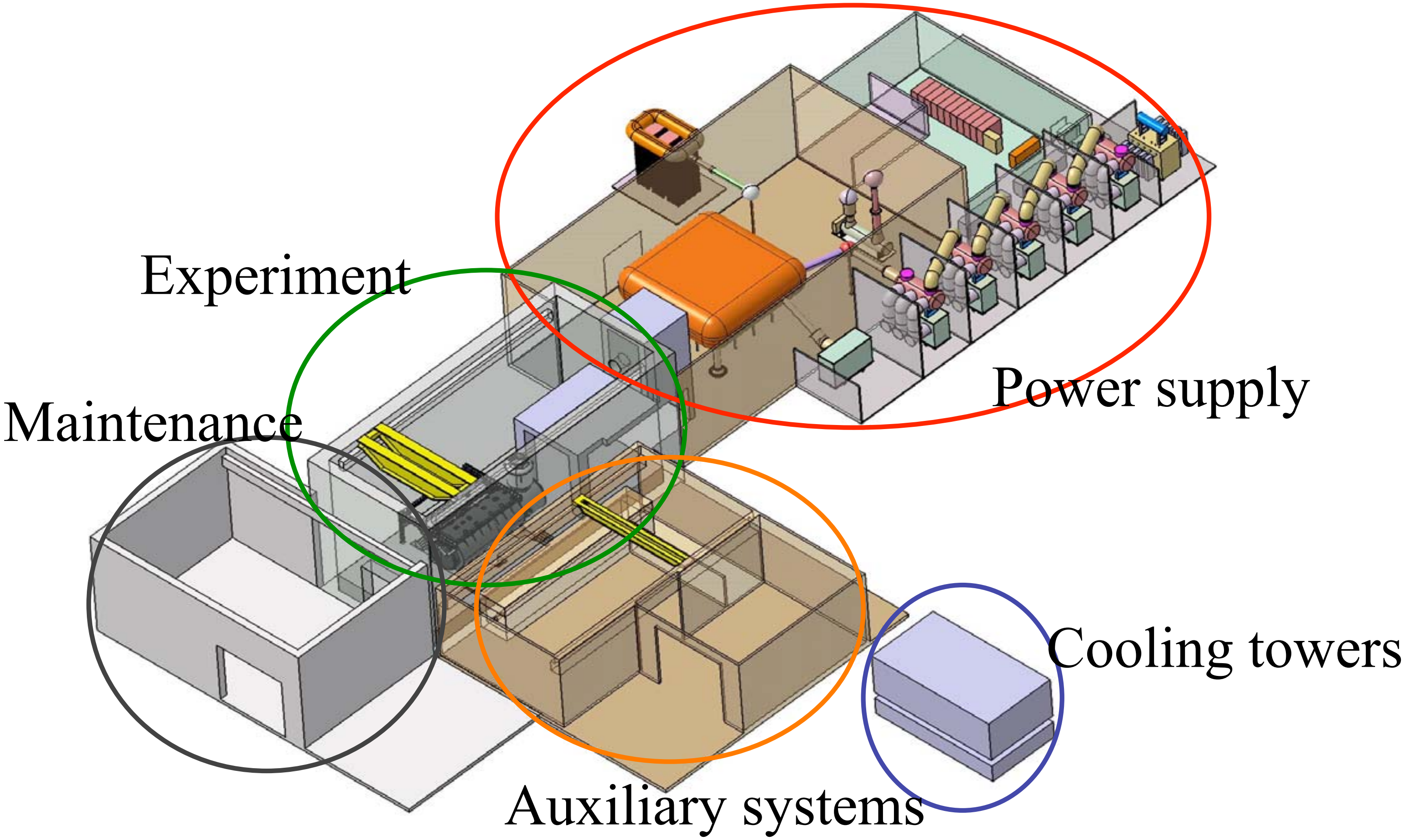


Integrated design



Both sources mechanically compatible with reference and alternative accelerator

Test Facility for a generic site



At present work is in progress to adapt the generic site to Padova site, which has been proposed by EU as the Test Facility site

Neutral Beams for ITER

- The ITER NB presents a formidable challenge. No such system exists in operation, the closest are JT60U and LHD

- Issues require large R&D effort on –ve ion source, accelerator, power supply (at 1MV), transmission lines (at 1MV), NB optics, long pulses, remote handling, activation of components, compensation of magnetic fields.

- A complete R&D program is being organized to solve these issues in a NB test facility, as proposed by EU.

Present plan

- Establish NBTF at Consorzio RFX, Padua, Italy
- The present plan is to start very early (tendering Jan 2008), the procurement of a full body of one injector and install in Padua for a total time of 10 years. Approximately 5 yrs for construction and 5 yrs for operations.
- Additionally there will be a second test line devoted to the development of the NB source, common between HNB and DNB, and the testing of DNB (possible in India).

ICH Requirements

- Basic requirements
  - Deliver 20 MW *to H-mode ELMy plasma*
  - 40-55 MHz operating frequency range
  - ~140 mm avg. distance between antenna and separatrix
    - Typical dist. is 50 – 80 mm in most present-day machines
- Heating and current drive
  - Provide ion and electron heating in 50-50 DT plasma and during early non-activated H operation
  - Drive current up to 1 MA of current near plasma center
- Other
  - Assist in plasma startup
  - Use for wall conditioning with H and other gases, with and without full field (may use dedicated system)

–Constraints : coupling is dependant on plasma configuration (geometry, density, shape, composition,ELMs, etc…)

ICH & CD system

- Upgrade possible by doubling the equipment to 40 MW
- System is composed of:

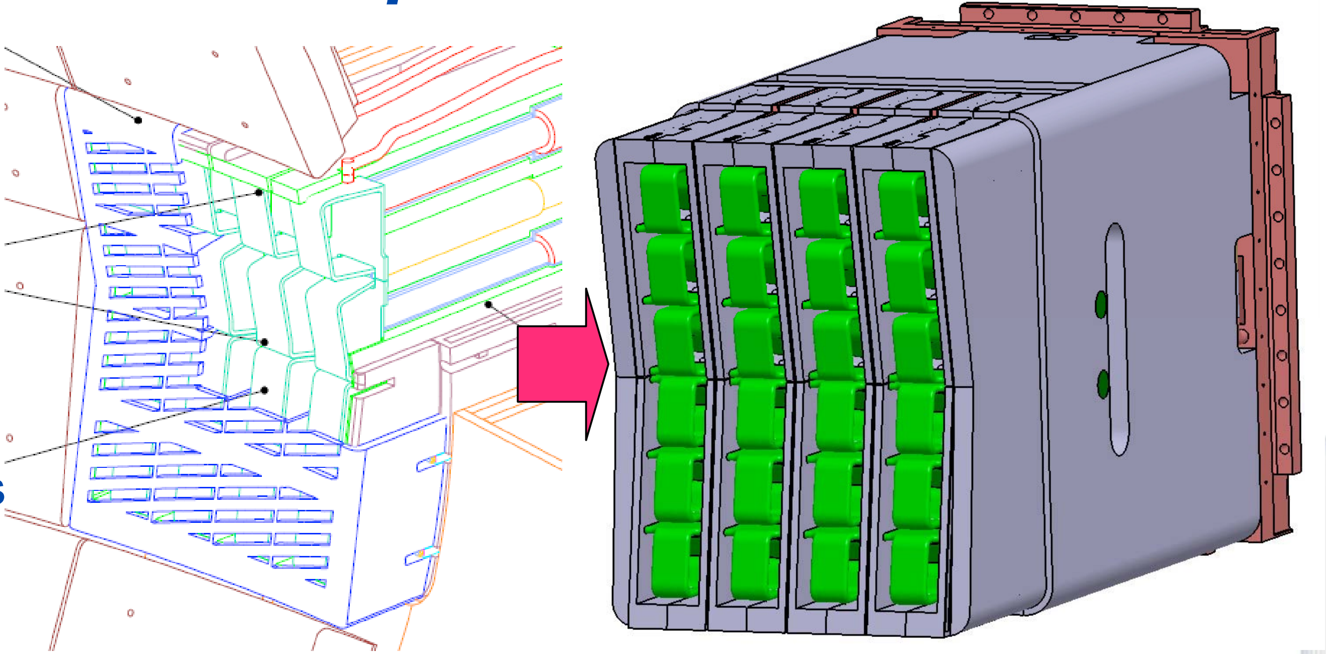
– AC/DC power supply system,	IN	(no R&D)
– DC/RF converters system, control system	IN	(little R&D)
– Transmission line system,	US	(little R&D)
– Antenna system	EU	(lot of R&D)
+ interface with Tokamak		IO

IC Antenna Design

IC antenna conceptual studies have shown that the DDD version needs to be updated.

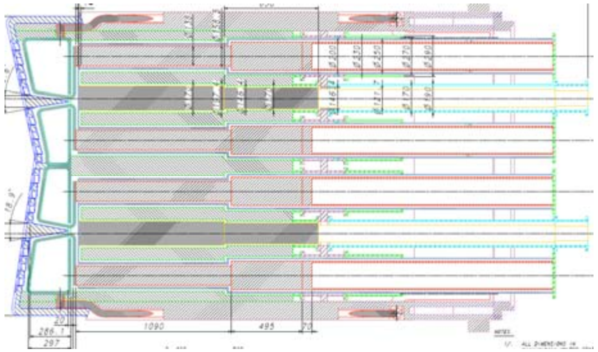
Now, antenna will be an array of 24 straps radiating to the plasma, and the tuning and matching components have been moved out of the plug and the interspace.

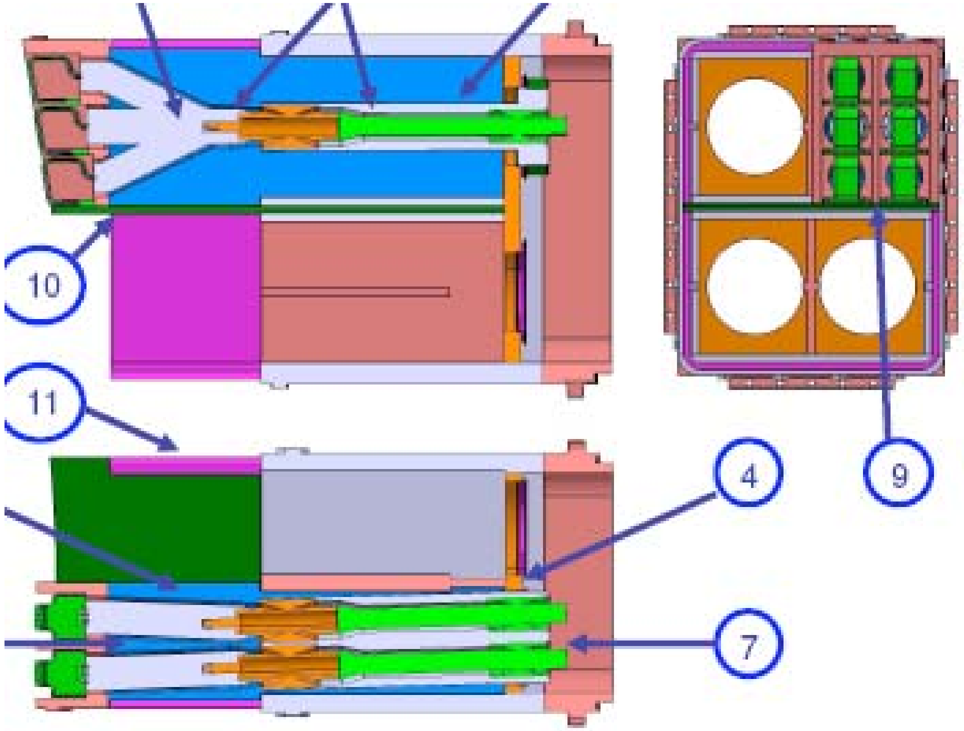
- 24 straps maximizes the power coupled at given voltage(16 in DDD)
- No moving parts in antenna plug
- Modularity
- Removable feedthroughs



IC Antenna Design Update

- **DDD:** port plug incorporates all-metal matching system with many movable elements (sliding contacts), 8 input transmission lines for 16 straps
- **Update:** matching moved out of port plug, modular plug elements, no moving parts, (private) vacuum transmission lines with ceramic supports separately removable, 8 input transmission lines for 24 straps



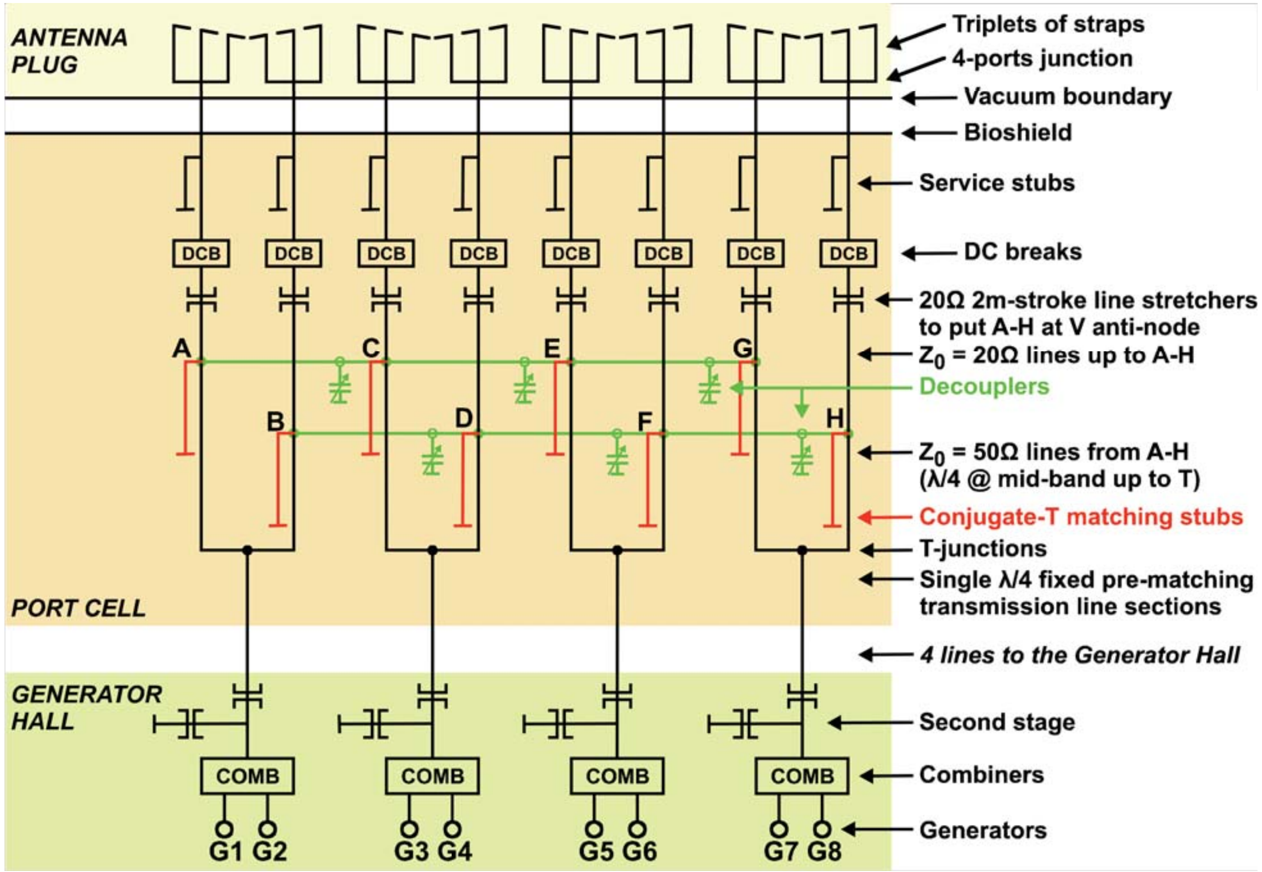


Concept simpler and more robust

IC Antenna Design Update

Matching principle: ELM-resilient conjugate-T

- Kept from DDD but all tuners moved outside port-plug



Triplets of straps

4-ports junction

Vacuum boundary

Bioshield

Service stubs

DC breaks

20Ω 2m-stroke line stretchers to put A-H at V anti-node

$Z_0 = 20\Omega$ lines up to A-H

Decouplers

$Z_0 = 50\Omega$ lines from A-H ($\lambda/4$ @ mid-band up to T)

Conjugate-T matching stubs

T-junctions

Single $\lambda/4$ fixed pre-matching transmission line sections

4 lines to the Generator Hall

Second stage

Combiners

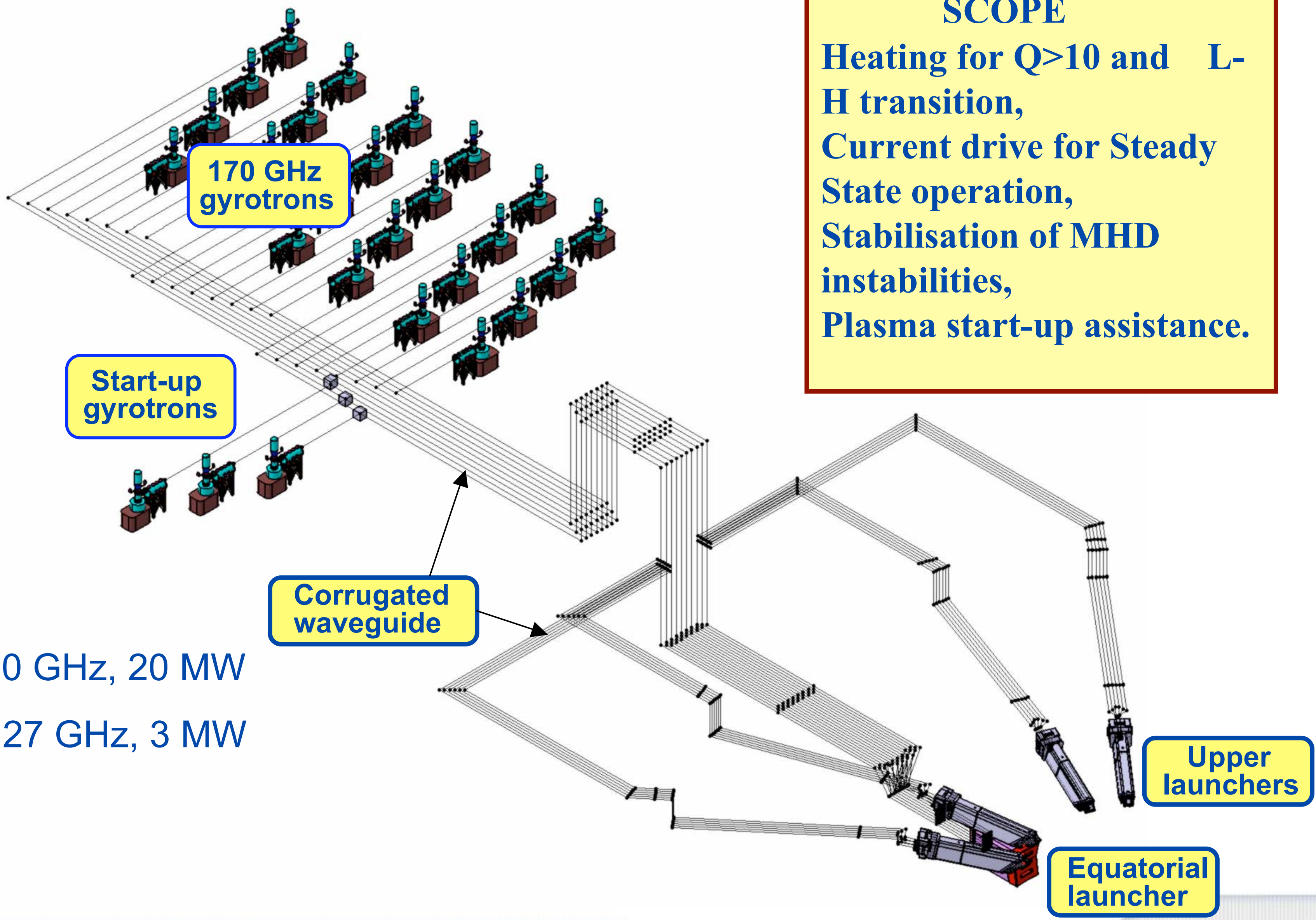
Generators

More flexible, allows alternative matching schemes, like ELM-dump if 8 TL’s installed

ITER ECH&CD System

SCOPE

Heating for $Q>10$ and L-H transition,
Current drive for Steady State operation,
Stabilisation of MHD instabilities,
Plasma start-up assistance.

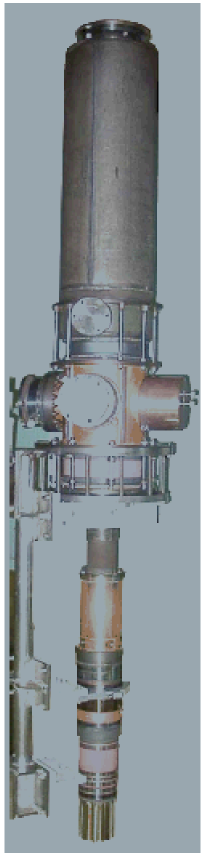


f= 170 GHz, 20 MW

f= ~127 GHz, 3 MW

R&D Status of 170 GHz gyrotron

Specifications :RF output power≥1MW, Pulse duration=400s~3600s (CW), Efficiency≥50% with depressed collector.

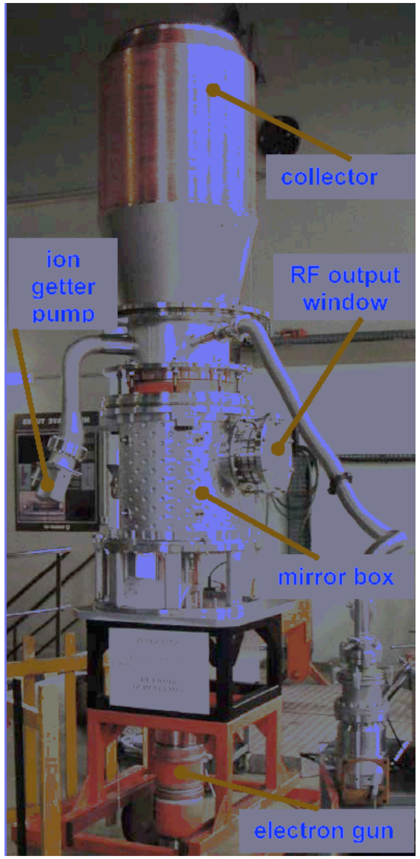


Gyrotron (RF)

0.6MW/250s,
0.5MW/300s,
0.95MW/70s.

Gyrotron (JA)

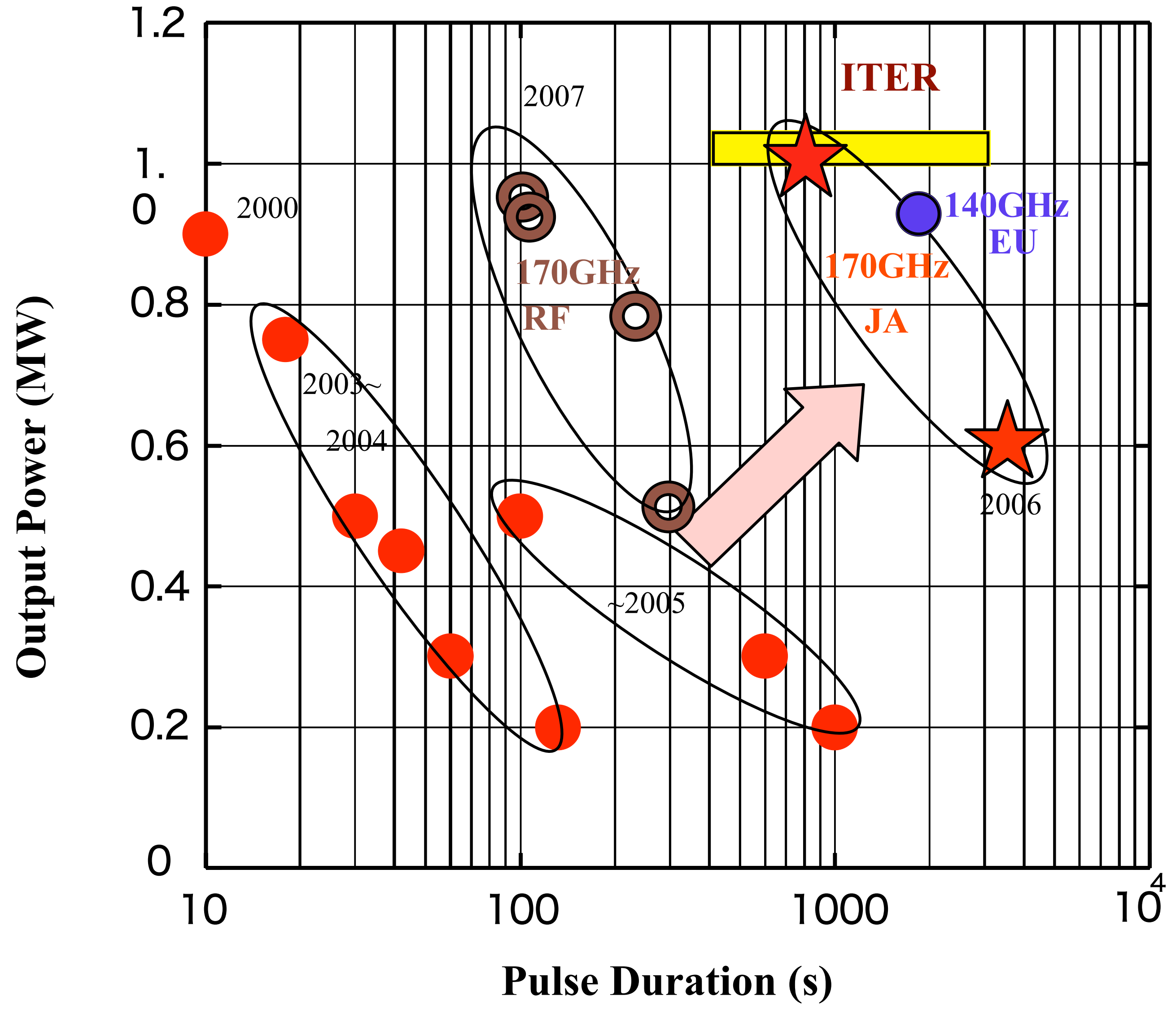
0.6MW/1hr/46%, 0.82MW /600s/56%, 1MW /800s /55% (ITER spec. OK).



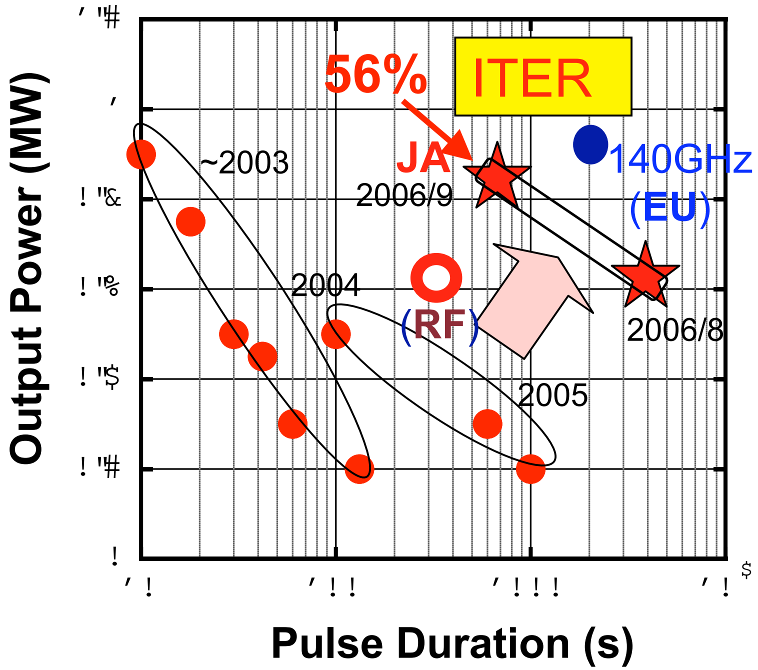
Coaxial Gyrotron (EU)

CW tube was constructed.
High power test in 2007.

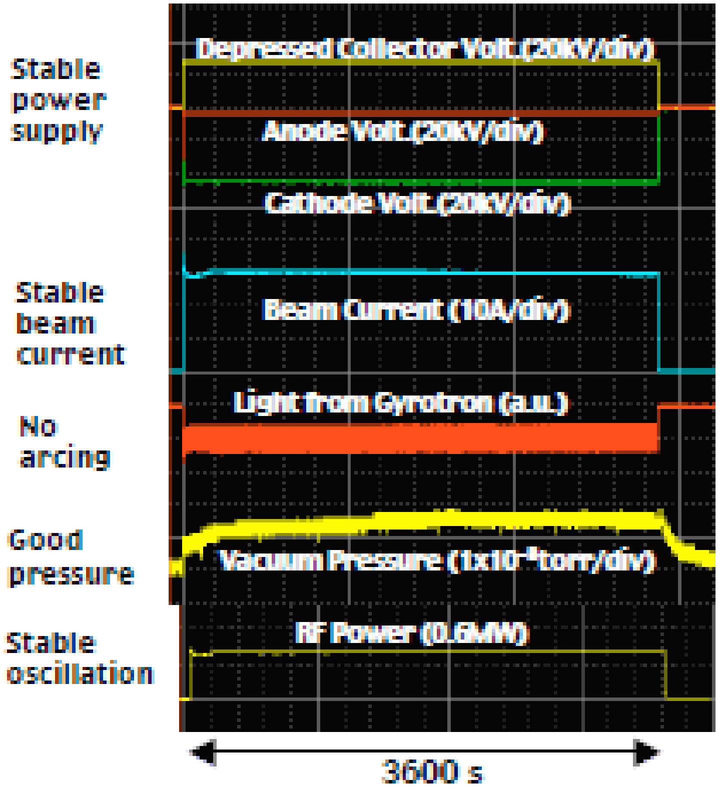
Experimental results of 170 GHz gyrotrons



Status of 170 GHz gyrotron



0.6MW-45%-1hour Operation



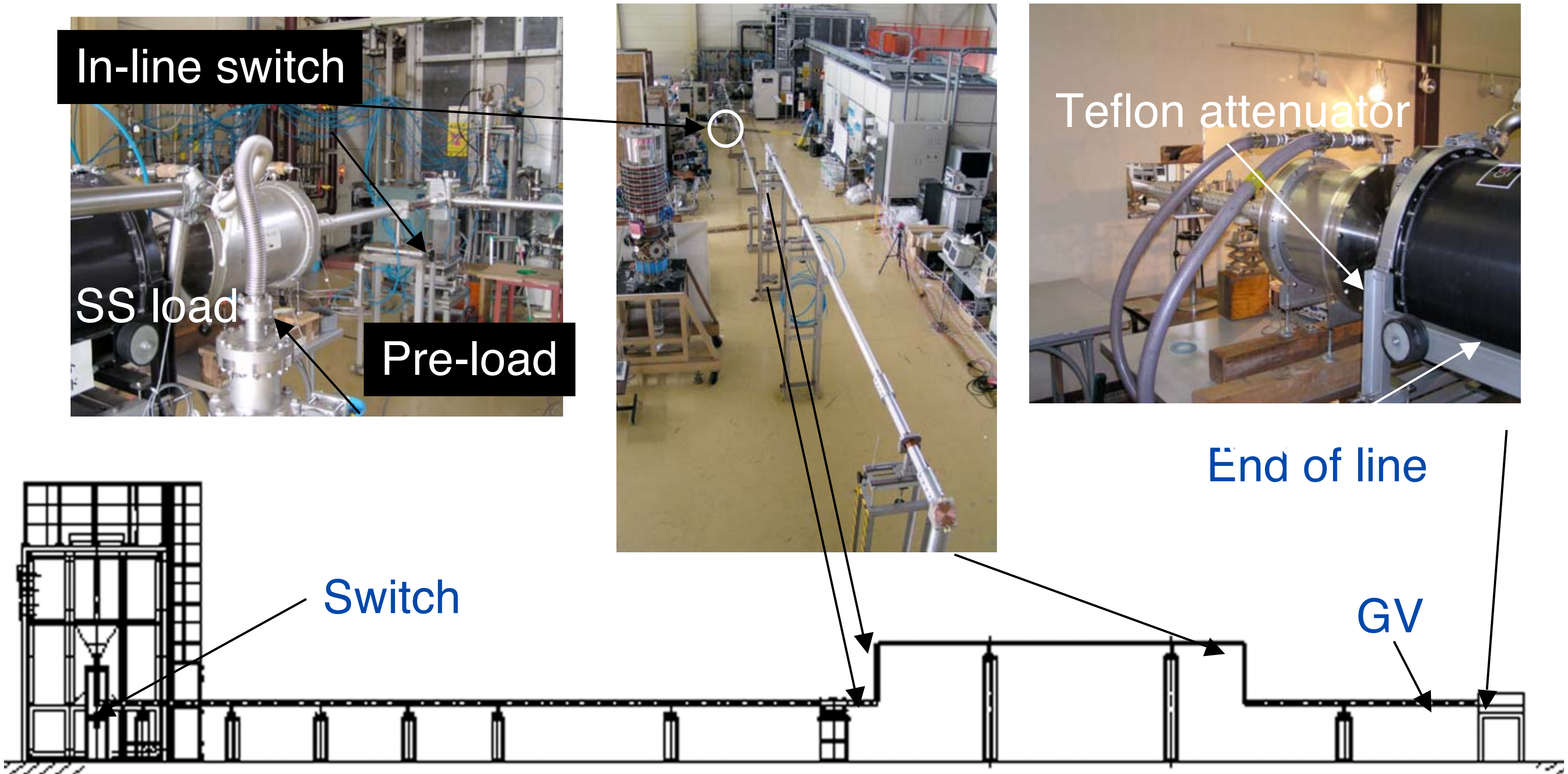
Example of high power long pulse test by JAHT

Issues: Different Gyrotrons, magnets, power supplies & thermal requirements, spares

ITER relevant transmission line (63.5mm)

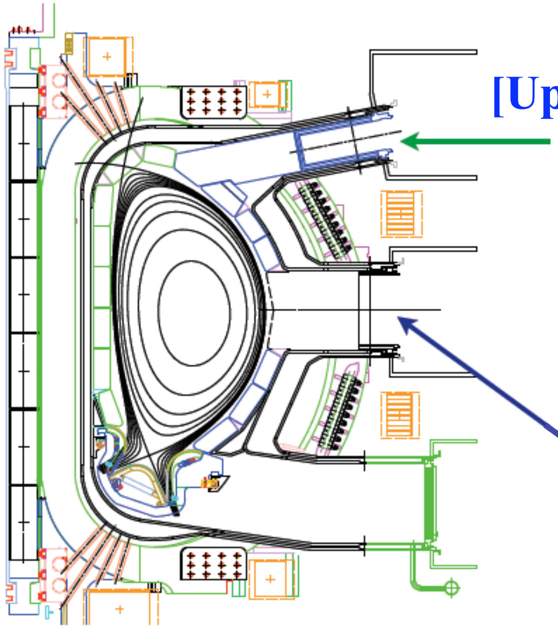
Objectives

- High power rf experiment for the launcher components
- Demonstration of MW-level & CW transmission at 170GHz

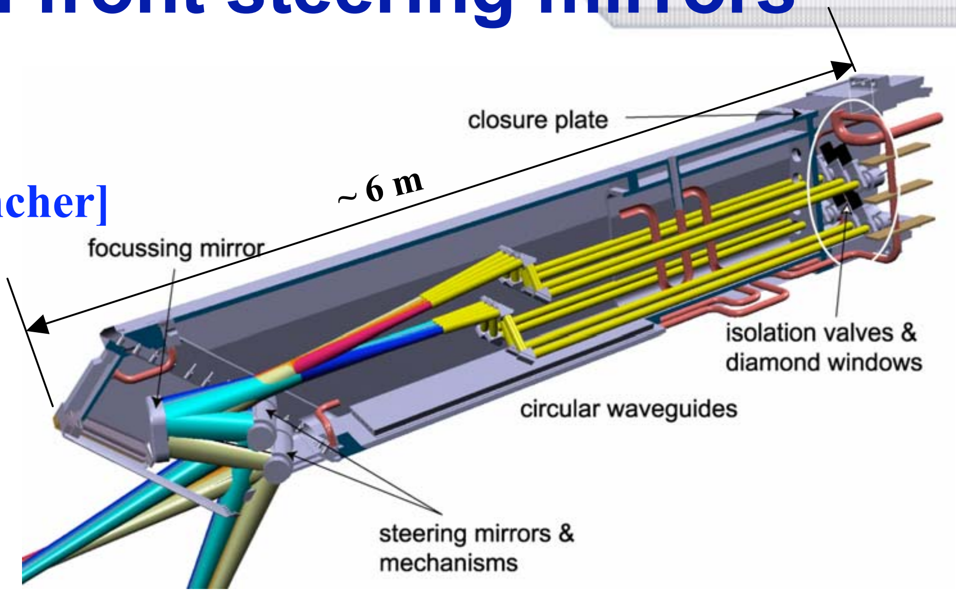


Transmission line (~40m, waveguides, 6bends, 1switch, 2 loads)

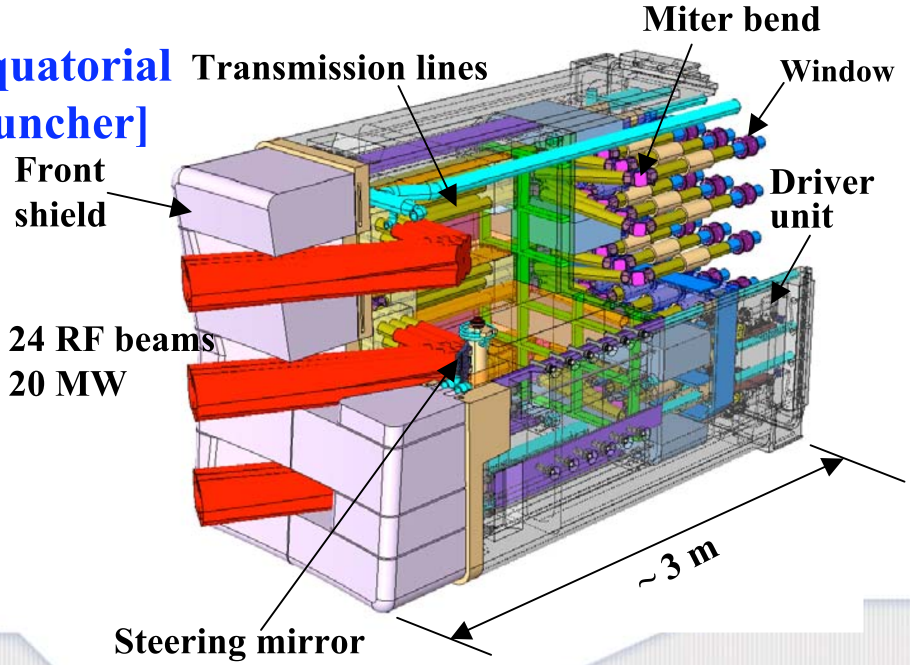
Launchers with front steering mirrors



[Upper Launcher]



[Equatorial Launcher]



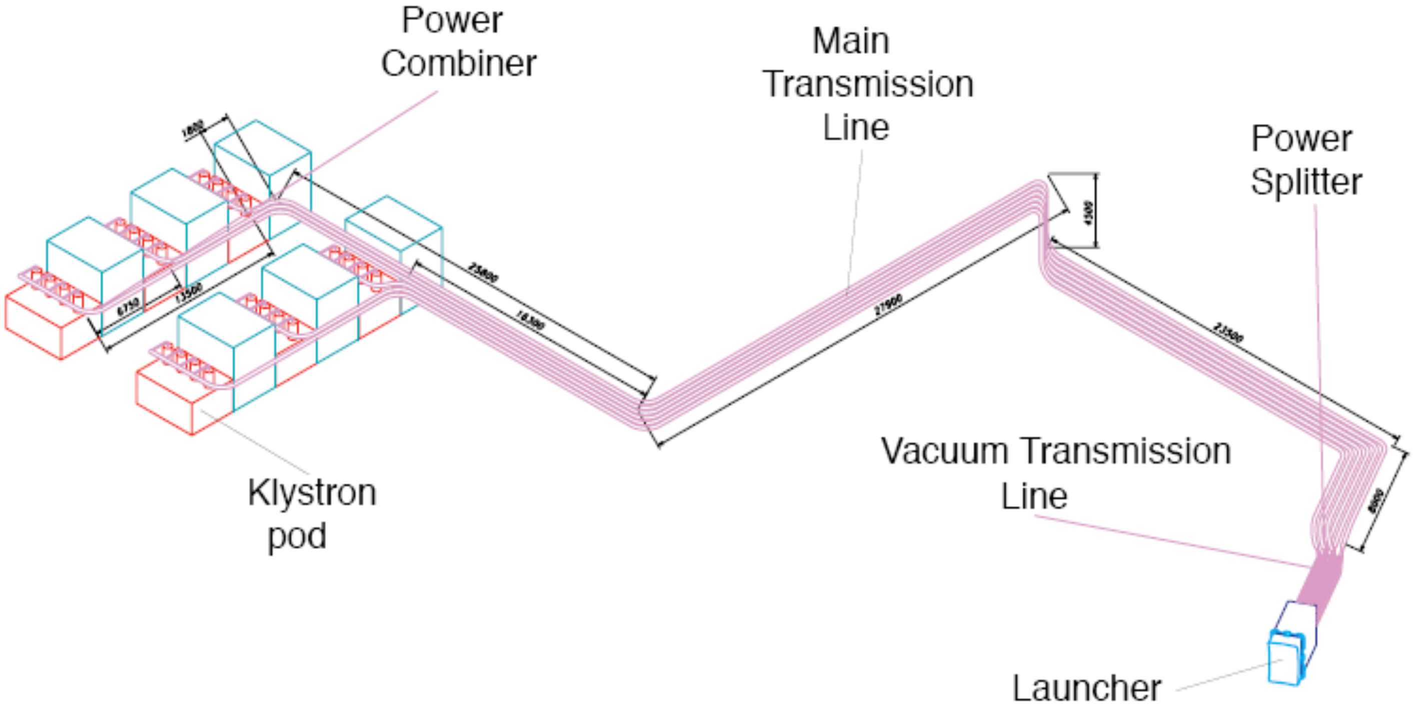
Steering range

Upper launcher: Vertically 53º~69º with 18º inclination for USM
and 39º~61º with the inclination of 20º for LSM.

Equatorial launcher: Horizontally 20˚~45˚

LHCD System

- The Lower Hybrid Heating and Current drive (LH H & CD) system is designed to:
  - **provide steady state off-axis current drive capability for DT, D, H and He plasmas,**
  - **modify current density and q profile.**,
- DDD = one system for 20 MW, Frequency 5 GHz
- Based on 1MW unit power klystrons.



LHCD present concerns

- Confirmation of scenarios :
  - **0 power for start up (procurement package uncredited)**
  - **20 or 40 MW in later configurations**

- Confirm choice of frequency :
  - **5 GHz correspond to low alpha absorption, but high technical difficulties**
  - **3.7 GHz well known, but larger absorption on alphas**;

- R&D program on source (if 5 GHz) and RF window and transmission line technologies.

- Provision of space for generators (assembly hall), power supplies; cooling requirements (in start up configuration)

DIAGNOSTIC SYSTEMS

FUNCTIONAL REQUIREMENTS

The ITER Diagnostic Systems is required to provide measurements of the plasma and first wall needed for

(a) **protection of the machine;** (b) **plasma control** and (c) **key physics studies.**

In total **45 different parameters** need to be measured. About 32 packages with Detail Specifications

Requirements have been worked up in great details mainly through Voluntary works (Physics groups and individuals in the **IT,** the **ITPA Diagnostic Topical Group** and **all the physics groups of the ITPA). O**utput is documented in the PID(Tables 4.22-1 and 2).

Agreed cost sharing table (2004)

Party	Package number	Ports	Lead Diagnostic	Credit value %	Total %	Target %
CN	16	E12	Visible Continuum Array	2.0	3.3	4.0
	25	-	Neutron Flux Monitors (ext)	1.3		
EU	1	U1, U14	Plasma Position Reflectometer	2.7	15.6	15
	2	U3	CXRS (core)	1.2		
	11	E1	Radial Neutron Camera	5.6		
	14	E10	Thomson Scattering (core)	6.0		
	27	-	Thermocouples (div-outer)	0.1		
JA	8	U10	Polarimeter	4.0	14.2	15
	9	U11	Thomson Scattering (edge)	3.6		
	17	L2	Impurity Influx Monitor (div)	5.3		
	24	-	Microfission Chambers	1.2		
	26	-	Thermocouples (div-inner)	0.1		
KO	4	U6	VUV (Main Plasma)	3.3	3.3	4.0
RF	5	U7, U2	H Alpha	2.1	13.6	13
	6	U8	Reflectom (main plas – HFS)	1.2		
	15	E11	NPA	3.3		
	19(1)	L10	Thomson Scattering (X-point)	4.8		
	23	-	Vertical Neutron Camera	1.3		
	29	-	CXRS (edge)	1.0		
US	3	U5	Visible/IR Cameras (upper)	1.8	16.0	15
	10	U17	Reflectom (main plas – LFS)	2.5		
	12	E3	MSE	2.4		
	13(2)	E9	ECE (main plasma)	4.6		
	18	L8	Interferometer (divertor)	2.5		
	28	-	RGA	2.1		
Flex	7	U9	X-ray Crystal Spectrometer	2.0	7.8	5
	21	L16	Bolometers	5.7		
Host	22	-	Magnetics, Thermocouples(in-vess)	2.2	4.4	5.0
	30(3)	-	Diagnostic In-vessel services	2.2		
Fund	20	L14	Reflectometer (divertor)	4.3	21.9	24
	31	-	Ex-Bioshield Elec Equipment	2.3		
	32	-	Window assemblies	4.7		
			Total		100	100
			Standard deviation from target		1%	

Sharing agreed by Negotiators in 2005

EU	25.0%
JA	14.2%
RF	13.5%
CN	3.3%
KO	3.3%
US	16.0%
IN	3.2%
Fund	21.5%

Total = 160.3 kIUA

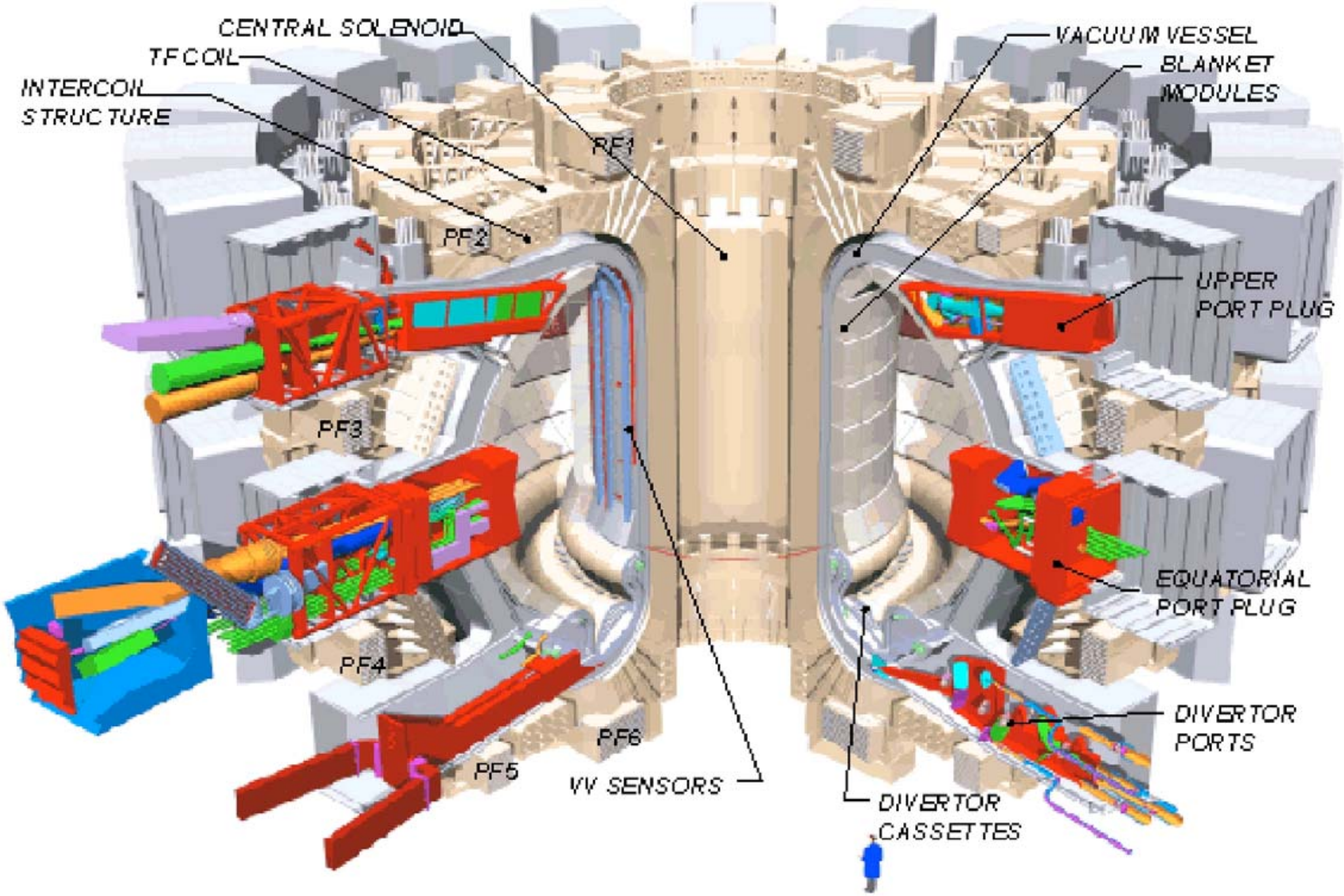
Sharing needs adjustment to accommodate India and any changes coming from Design Review Process.

SELECTED DIAGNOSTICS FOR ITER

Magnetic Diagnostics	**Spectroscopic and NPA Systems**
Vessel Magnetics	CXRS Active Spectr. (based on DNB)
In-Vessel Magnetics	H Alpha Spectroscopy
Divertor Coils	VUV Impurity Monitoring (Main Plasma)
Continuous Rogowski Coils	Visible & UV Impurity Monitoring (Div)
Diamagnetic Loop	X-Ray Crystal Spectrometers
Halo Current Sensors	Visible Continuum Array
Neutron Diagnostics	Soft X-Ray Array
Radial Neutron Camera	Neutral Particle Analysers
Vertical Neutron Camera	Laser Induced Fluorescence (N/C)
Microfission Chambers (In-Vessel) (N/C)	MSE based on heating beam
Neutron Flux Monitors (Ex-Vessel)	**Microwave Diagnostics**
Gamma-Ray Spectrometers	ECE Diagnostics for Main Plasma
Neutron Activation System	Reflectometers for Main Plasma
Lost Alpha Detectors (N/C)	Reflectometers for Plasma Position
Knock-on Tail Neutron Spectrom. (N/C)	Reflectometers for Divertor Plasma
Optical Systems	Fast Wave Reflectometry (N/C)
Thomson Scattering (Core)	**Plasma-Facing Comps and Operational Diag**
Thomson Scattering (Edge)	IR Cameras, visible/IR TV
Thomson Scattering (Divertor region)	Thermocouples
Toroidal Interferom./Polarimetric System	Pressure Gauges
Polarimetric System (Pol. Field Meas)	Residual Gas Analyzers
Collective Scattering System	IR Thermography Divertor
Bolometric System	Langmuir Probes
Bolometric Array For Main Plasma	**Diagnostic Neutral Beam**
Bolometric Array For Divertor	

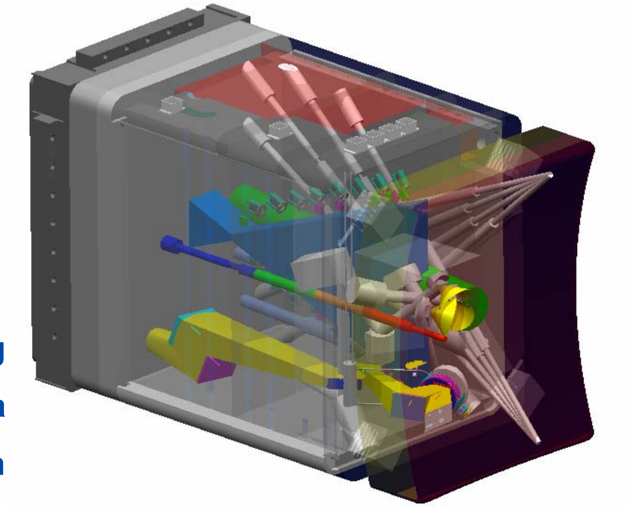
ITER Diagnostics

Diagnostic components are installed in multiple locations: in upper and equatorial ports, in the divertor ports



Procurement Strategy

- Diagnostics will be procured using port-based procurement.
- A typical package consists of a lead diagnostic plus components from one or two other diagnostics and all the port engineering structures.



Eq#01: Vis/IR viewing

Rad Neutron Camera

MSE, Div Imp Mon

- The party that supplies the lead diagnostic also supplies the engineering structures and carries out the integration.
- Interfaces with the tokamak (largely generic) and between diagnostics and port structures. These interfaces have been identified (about 100).
- There are also about 10 distributed systems/packages (e.g. magnetics)

Difficulty in communicating with individuals and various labs in the absence of DAs;

Port Integration Task Force formed to interface with various systems (1 at managerial level + 1 at working level from each party with the IO members).

ITER ENVIRONMENT

•Relative to existing machines, on ITER the diagnostic components will be subject to (relative to JET)

- High neutron and gamma fluxes (up to x 10), Neuutron heating (1 MW/m^3) (essentially zero)
- High fluxes of energetic neutral particles (up to x5), High neutron fluence (> 105 !)
- Long pulse lengths (up to x 100)

New territory for diagnostics

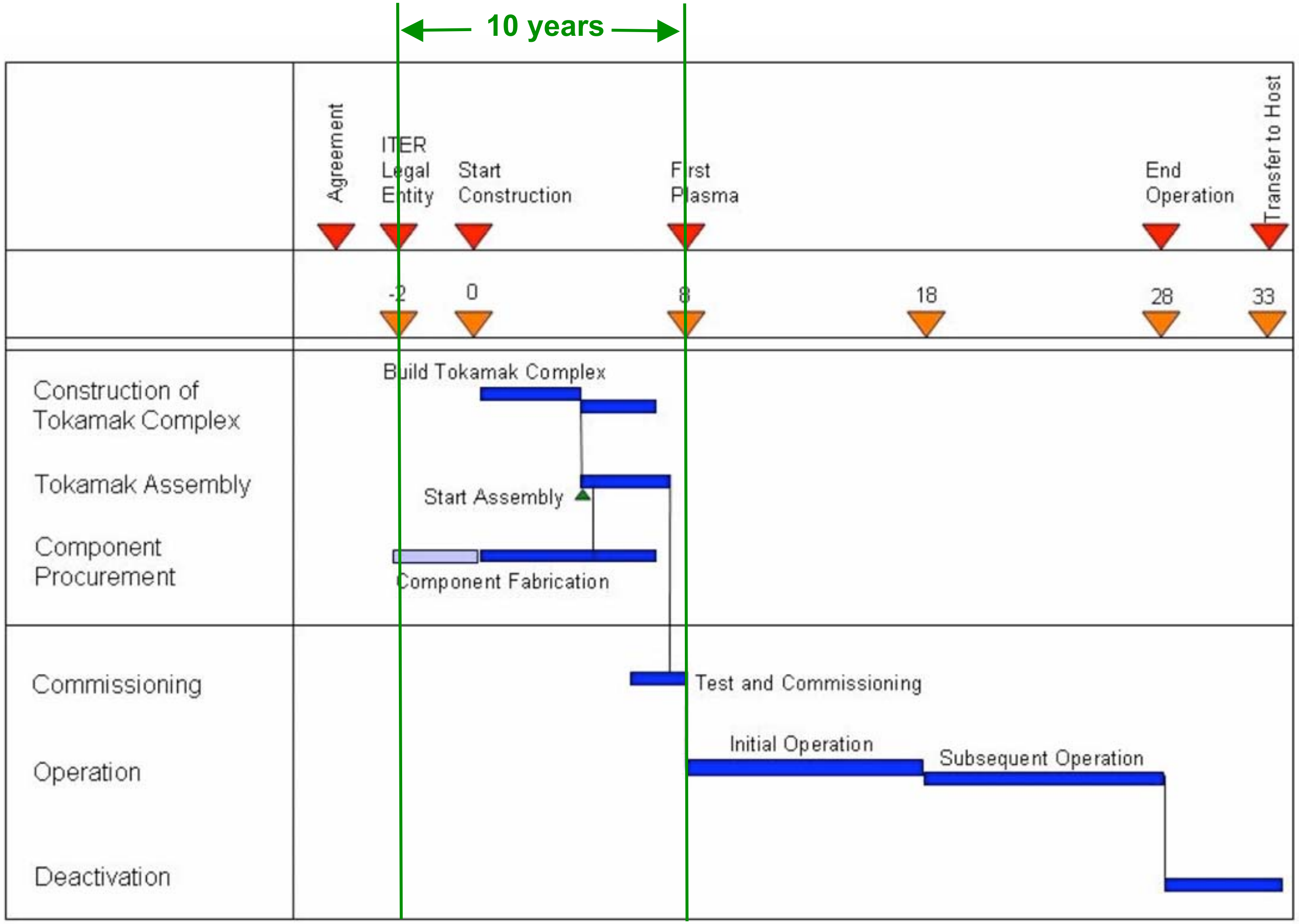
A range of phenomena have to be considered that are new to diagnostic design and calls for R&D effort in

- Radiation-induced effects like conductivity (RIC), (RIED), (RIEMF), absorption
- Erosion, dust and deposition on mirrors
- Radioluminescence
- Heating
- Change in other properties such as activation, transmutation and swelling

The **nuclear** environment sets **stringent** demands on
neutron shielding, Tritium containment, vacuum integrity, RH compatibility etc.

Until now efforts have been mainly voluntary by various individuals, labs & other organizations; present effort is to make INTERACTION more effective through IO R&D tasks

Top Level Schedule



Presented at the First Interim ITER Council meeting (IIC-1(M))

Summary

- Issue of majority of Procurement packages by 2008
- R & D in specific areas of H&CD to meet Day 1 requirements

  NBTF for NB issues

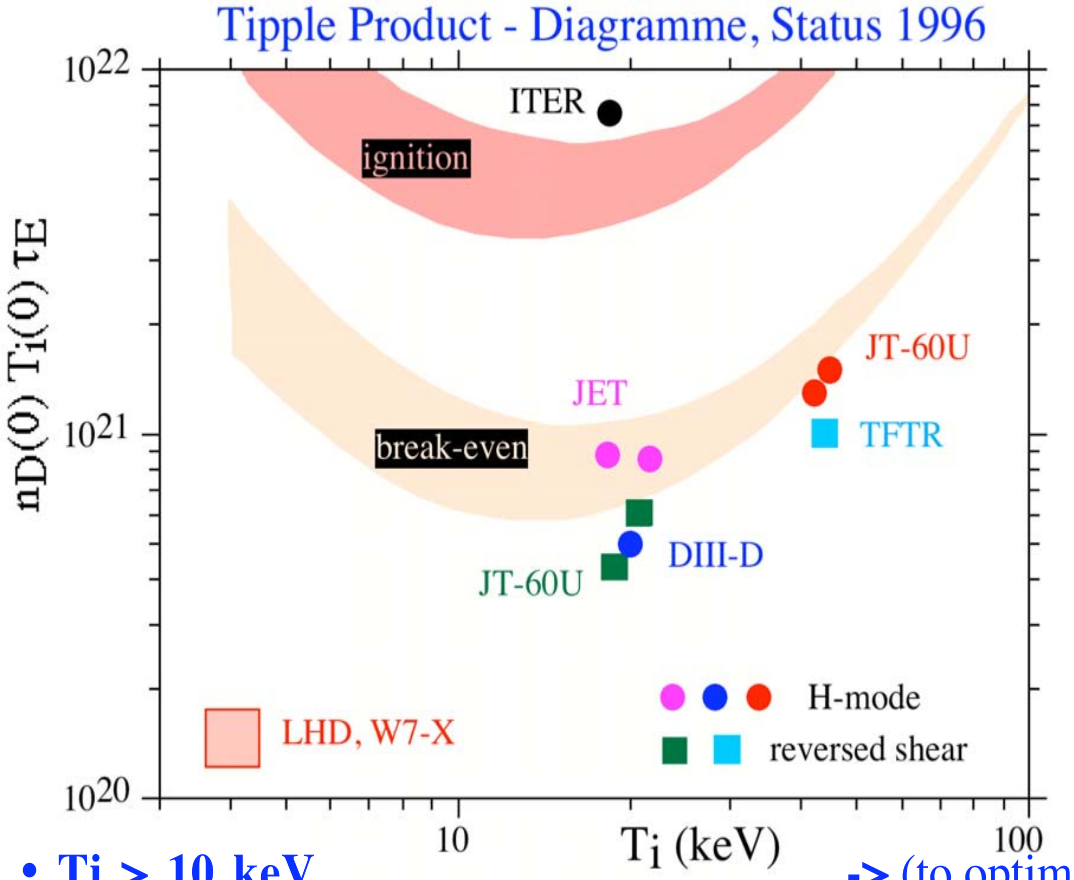
  HP CW Gyrotron development

  HP MW Windows & other components

  MW Level IC Launcher, combiner
- R&D in Diagnostics in component level (to withstand harsh environment) and measurement methods (e.g.Dust)
- Insourcing of resources & outsourcing of work

Thank you

How do we size a Reactor class Fusion machine (1)

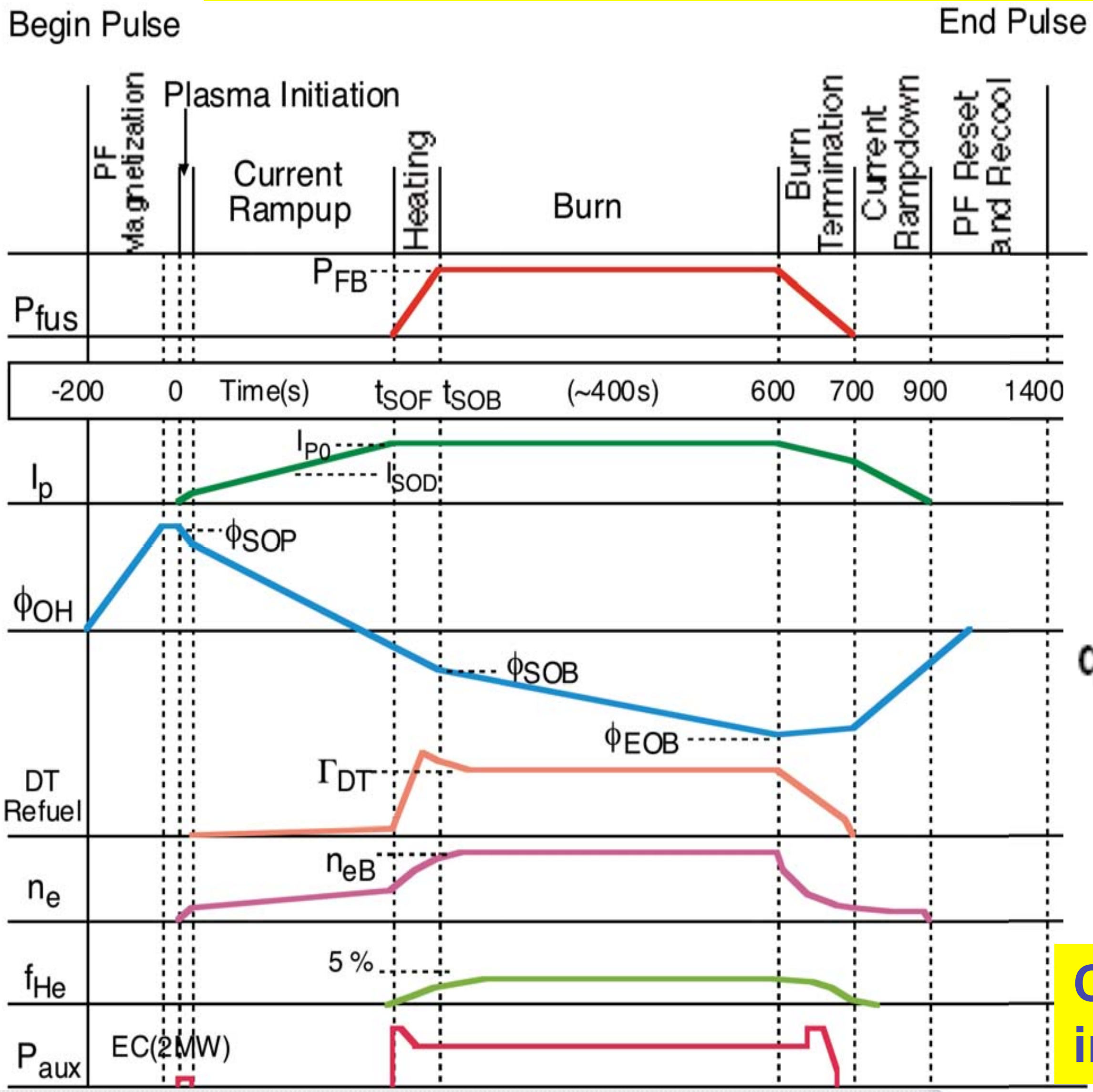


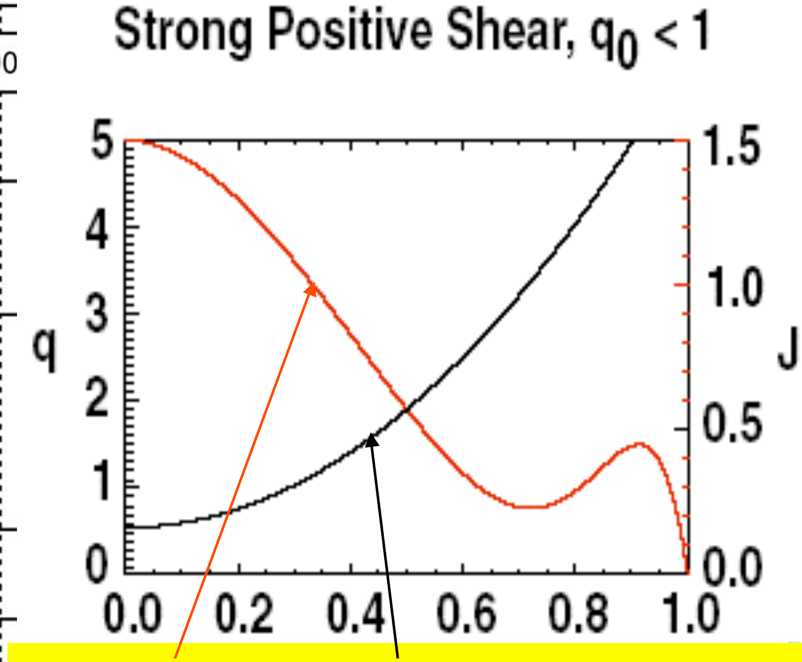
- **Ti > 10 keV** -> (to optimise D-T reaction rate)
  - => $n_e \times \tau_E \sim 6.0\ 10^{20}\ m^{-3}s$
  - => $n_e \sim 1.0\ 10^{20}\ m^{-3}$ -> (close to Density Limit: $n_L \sim I/a^2\pi$)
  - => $\tau_E \sim 6.0\ s$ -> (defines more or less machine size)

H-mode Confinement Scaling Relation:

$$\tau_{E,th}^{ELMy} = 0.0562 \times I^{0.93} B^{0.15} P^{-0.69} n_{e,19}^{0.41} M^{0.19} R^{1.97} \varepsilon^{0.58} \kappa^{0.78}$$

Typical Example of an Inductive Tokamak Pulse (ITER)

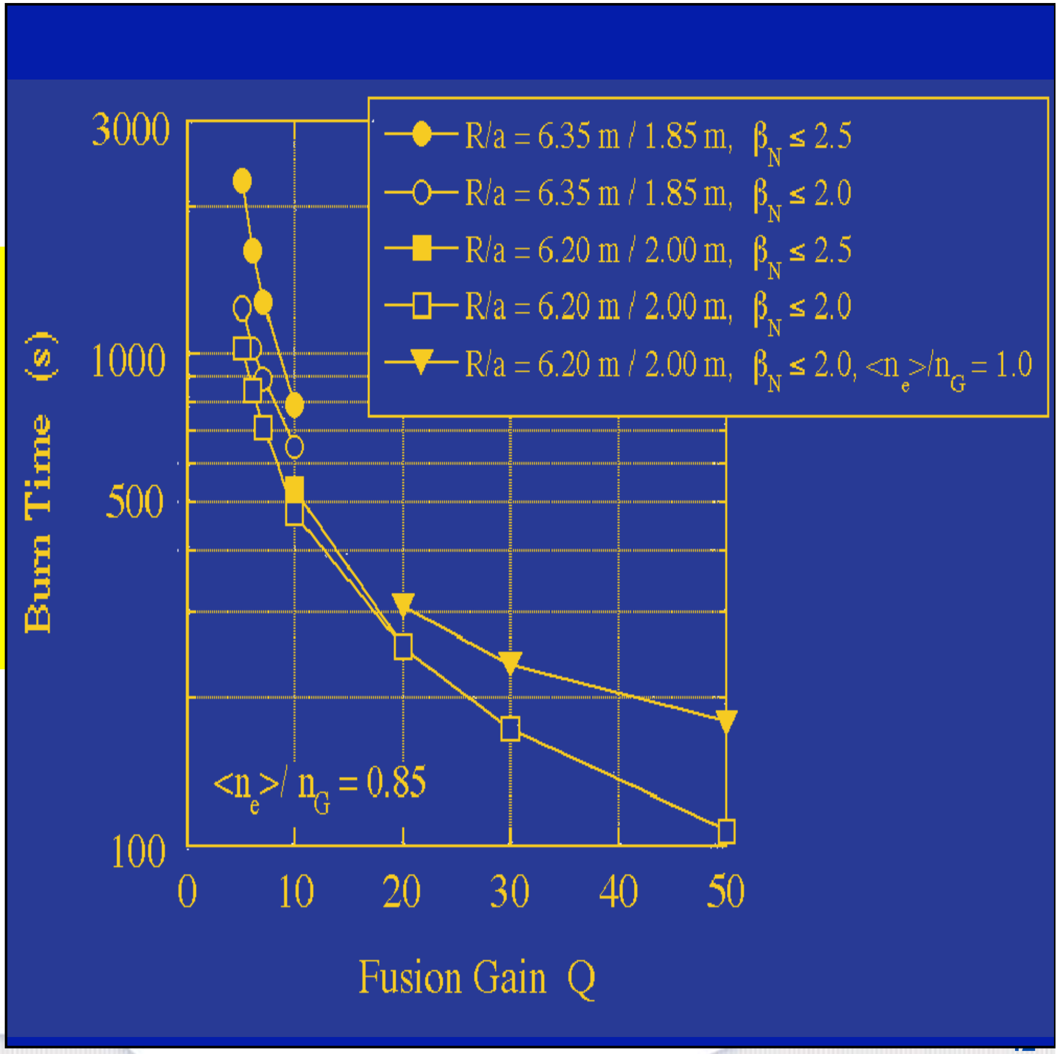




Current and "q" profile for an inductive Tokamak pulse

ITER - Mission

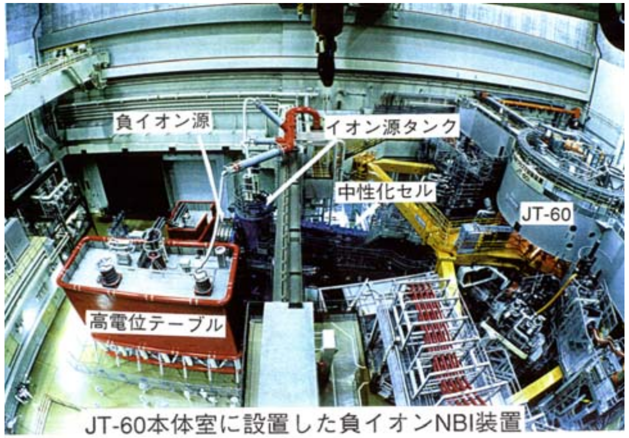
Expected long Pulse and Steady State Performance in ITER



Technical

- **Aim at steady state with Q>5**

Existing systems: JT 60U and LHD



In JT-60U
1.6MW, 360 keV for pulses lasting 20 s.

Y. Ikeda, et al., Nucl. Fusion 46 (2006) S211

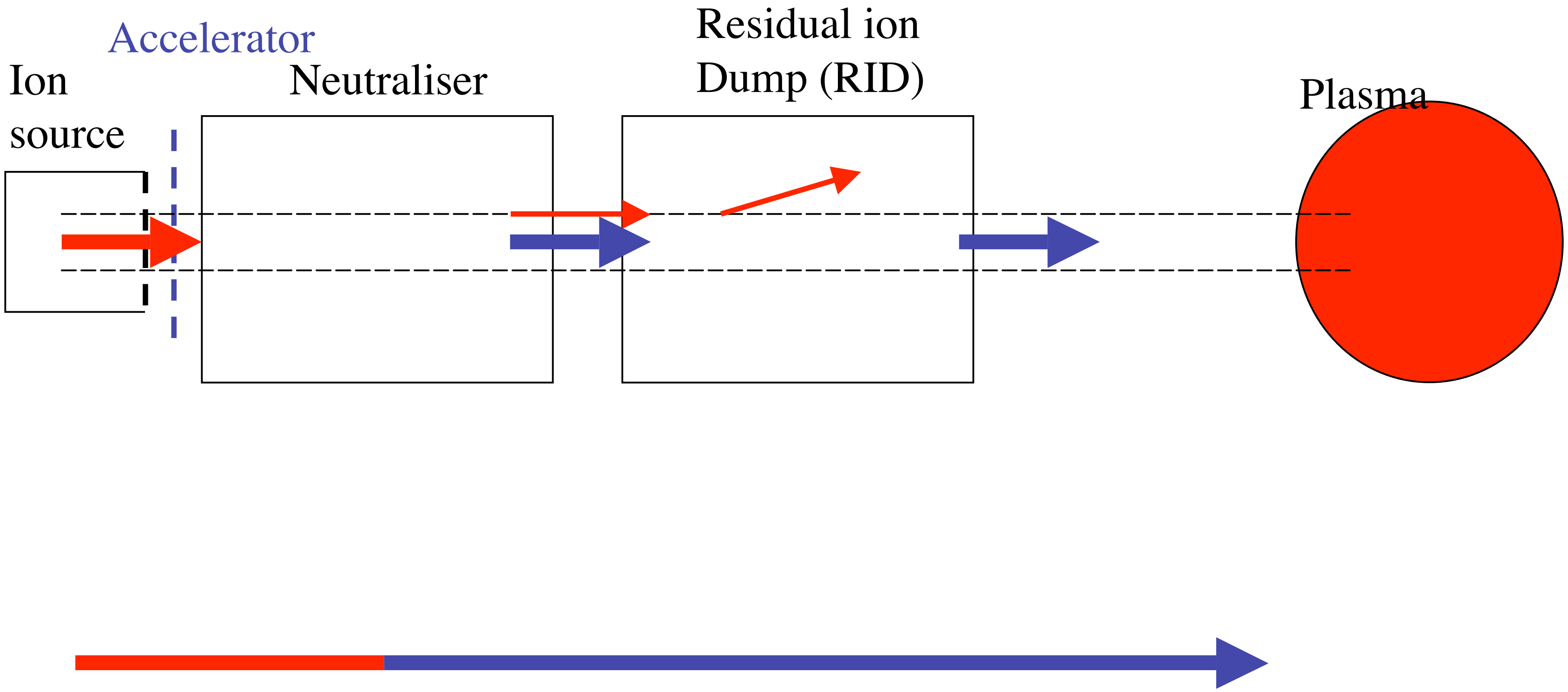
Upgrade up to 100s foreseen in next future.

Y. Ikeda, et al., P3-B-336

In Large Helical Device (LHD)
5.7MW , 184 keV.
Steady operation up to 120 s at 0.2–0.3MW.

Y. Takeiri, et al., Nucl. Fusion 46 (2006) S199

Neutral beam injection: principles



ITER NBI requirements

Neutral beam injection is required since the beginning of ITER operation

The NBI system consists of **2 (+1) beams** for **Auxiliary Heating** and **Current Drive**

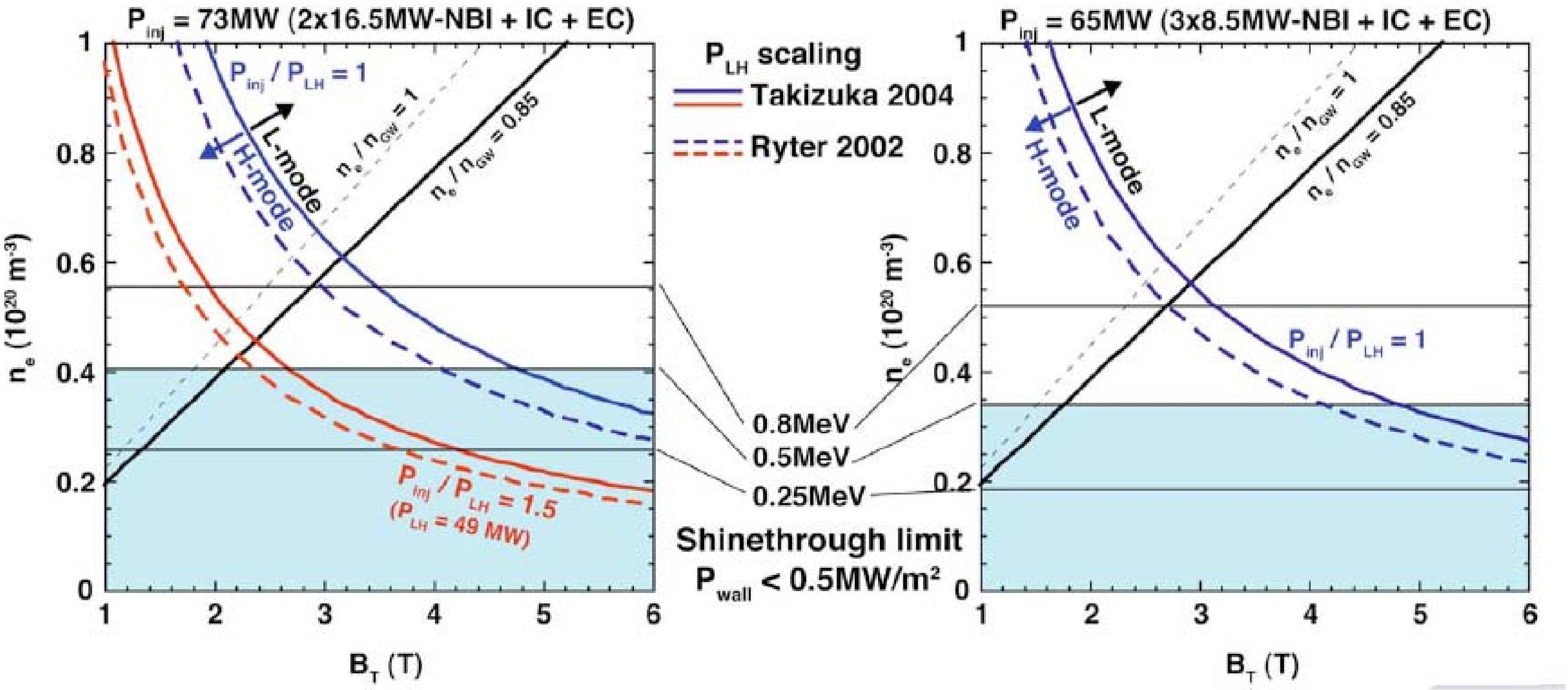
Beam parameters:

P=16.5MW
I=40A
V=1MV (to heat the core plasma)
t pulse=3600s

1MeV neutrals implies negative ions for efficient neutralisation (60%)

H-mode accessibility in H plasmas

- **Shine through limits EB < 0.5MeV for H-mode.**
- **Either with two 16.5MW-inejctors or three 8.5MW-injectors, H-mode space is narrow and the operation point needs to be carefully chosen with available heating powers.**

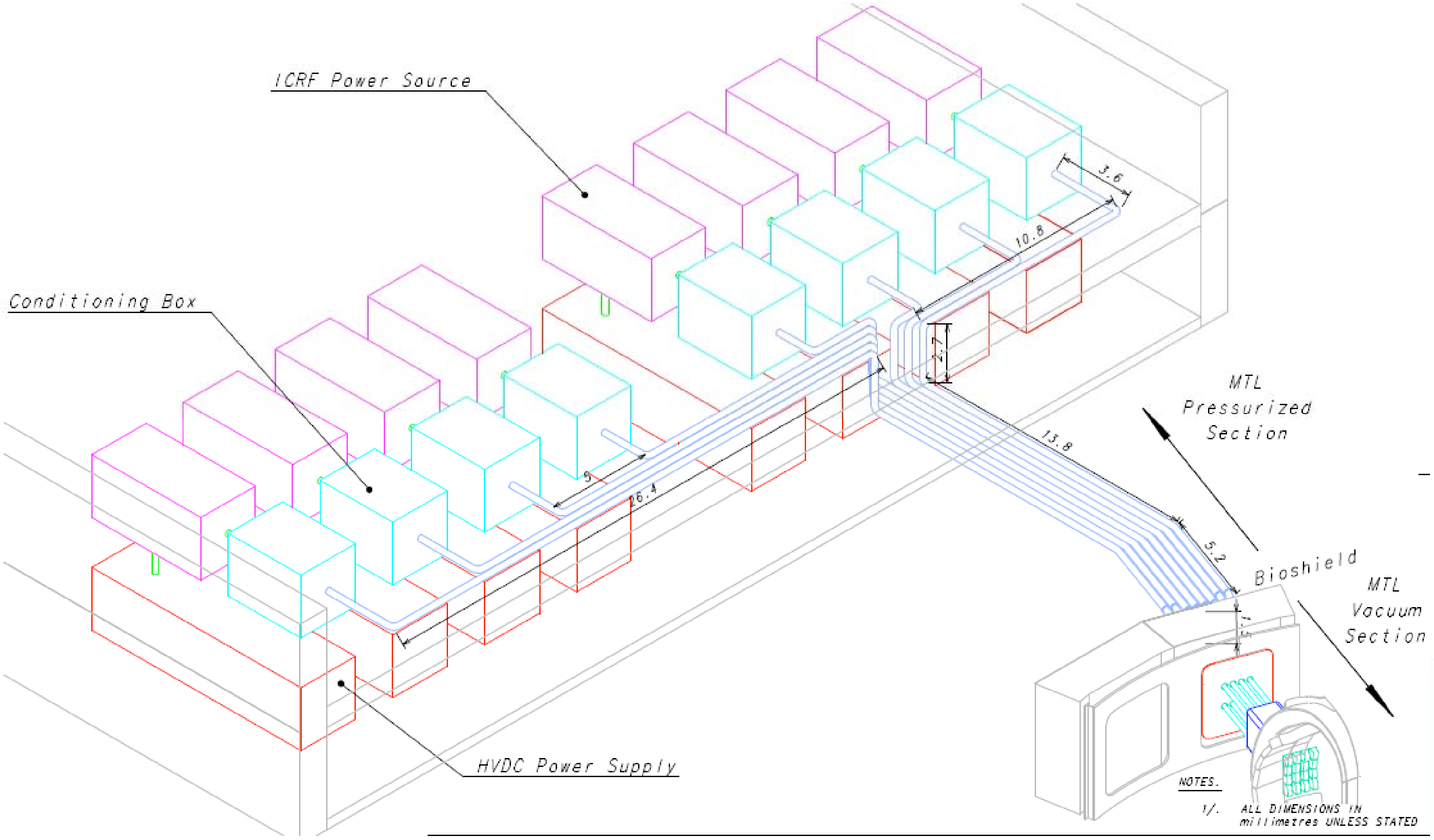


T. Oikkawa ITPA May 07

Milestones

1. Start tendering Jan 2008
2. Shipping of High Voltage JA PS to test facility Jan 2012
3. Common testing of the HNB & DNB Ion source with complete optimization for DNB Aug 2010 to 2013
4. Test of DNB start 2012 end 2015
5. Start HV tests Feb 2013 end 2017
6. Delivery schedule: DNB components to Cadarache Jan 2016 and H&CD injector in End 2017.
7. The second injector will be assembled directly in Cadarache by 2016.
8. Then NBTF to continue for further tests of various components.

ICH & CD


ICRF Power Source
Conditioning Box
HVDC Power Supply
MTL Pressurized Section
Bioshield
MTL Vacuum Section
3.6
10.8
2.7
13.8
5.2
5
26.4
NOTES.
1/. ALL DIMENSIONS IN millimetres UNLESS STATED

ICH&CD procurement

- EU will procure the antenna from fabrication drawings:
  - Detailed design phase with participation from partners to provide built to print drawings
  - R&D supporting detailed design phase (windows, faraday shield, fabrication techniques, etc…).
- US provides TL from functional specifications and perform the necessary prototyping and R&D.
- IN provides HVPS and RF sources, control and perform the necessary prototyping and R&D.
- Installation, commissioning is under responsibility of IO

Budget and resources for NBTF

- Manpower 150 pmy for 5 years for detail design (EU-JA-IN 2007-2011) and 20-40 professionals for operations (EU+PTs TBN)
- Building and services 31MEuros EU+Host
- ITER procurement: 1 complete set of PS, HV lines, bushing, ion sources, one set of internal components Transportation re-commissioning at Cadarache (TBN).
- Organization to be defined among ITER and DAs (EU-JA-IN) open to other interested parties.
- 8.8 kIUA of R&D ITER budget.

Issues related to the interfaces of the NB systems

- **NB cell**: The NB injectors are located in the NB cell. Most of the north side of the **Tokamak building**.

  1. Dose rates are such that manned access is very limited
  2. RH necessary for top maintenance and installation of beam line components
  3. Top diagnostic ports (4,5,6,7) have reduced capability
  4. Due to high radiation doses installation of the vessel and of the compensation coils of 3rd injector has to be done before operations.

- **Interface with the vessel and PFC:**

  1. Routing of the VVPSS pipe and maintenance of the VVPSS bursting disc
  2. Overheating of the NB ducts in the port extensions
  3. Maintenance of NB ducts in the port extensions.

- **Other interfaces** (electrical, cooling water etc.)

ITER 2007 design basis for ICRH antenna

- The design to focus on
  - Emphasis on simplicity and robustness to ensure reliability.
  - Windows/ceramics to be separately maintainable
  - Simplification of the equipment in the equatorial port inter-space to facilitate access to the plug
- This implies no moving parts inside port plug and minimise number of components within torus vacuum and port inter-space.
- These objectives best achieved with 24 straps connected in triplets in the front part of the plug.
- 8 input TL and reduces component number inside bioshield.
- ELM resilience is performed outside the biological shield.

ICRF community has agreed to complete a single integrated design fulfilling above guidelines

ICH&CD system

- Conceptual design in progress with important contributions from EU, IN and US on the ICH system components.
- Antenna concept guidelines chosen in **May-June**, and will allow to specify the generators and transmission lines.
- Procurement packages for Transmission lines (US) and generators (IN) will be defined for **October 2007**.
- Detailed design phase for antenna port plug and port cell matching units will start **this summer for 3 years,** in parallel with corresponding R&D

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KEY STEPS BEFORE PROCUREMENT

- Completion of design of a few outstanding systems at the functional spec level (e.g. lower vertical neutron camera)

- Completion of the detail design of a few systems, especially the in-vessel magnetic sensors

- Completion of the detailed design of the port plugs (ITAs coordinated through the **Port Engineering Task Force)**

- Decisions regarding the uncredited systems

- Some items of R&D

Ports and systems will take 5 years to construct and integrate. They will need to be on site 2-3 years before vessel closure for testing and installation. Hence need to launch port based pps in early 2008.

POSSIBLE CHANGES in THE BASELINE

- Changes to the system selection, design and ports coming from DCRs in the pipeline, especially DCR 49 which will disturb diagnostics in upper ports 5, 6 and 7.
- Changes coming from the diagnostic system design.
- Unexpected problems coming from the supporting R&D.
- Integration of some of the uncredited systems.
- Changes coming from the ITER design review process.

WORK PLAN FOR 2007/8

- **Review** choice of selected diagnostics, port allocation, and prioritization in the light of ITER measurement requirements and any changes coming from the ITER design review process. Include an assessment of measurement capability relative to requirements. Full party involvement will be sought for this.

- **Finalize** proposed procurement packaging

- Develop detailed procurement plan for all packages. Initiate preparation of procurement packages

- **Develop detailed design** of port plugs

A detailed plan that deals with these points in time to launch the first diagnostic procurement packages in the 1st Q of 2008 has been developed (ITER_D_258JV9).

PROCUREMENT PLANS

- Diagnostics will be procured using port-based procurement.

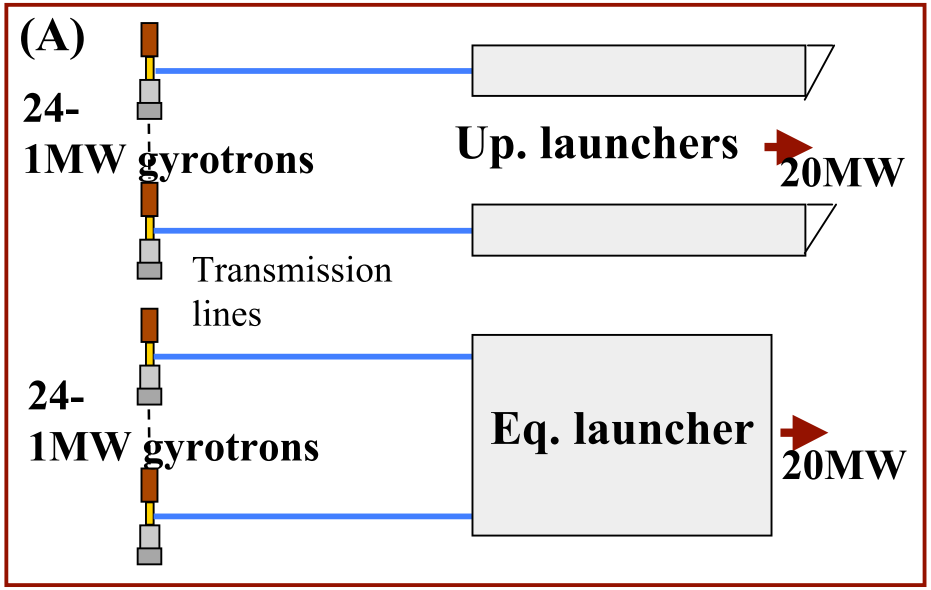
- A typical package consists of a lead diagnostic plus components from one or two other diagnostics and all the port engineering structures.

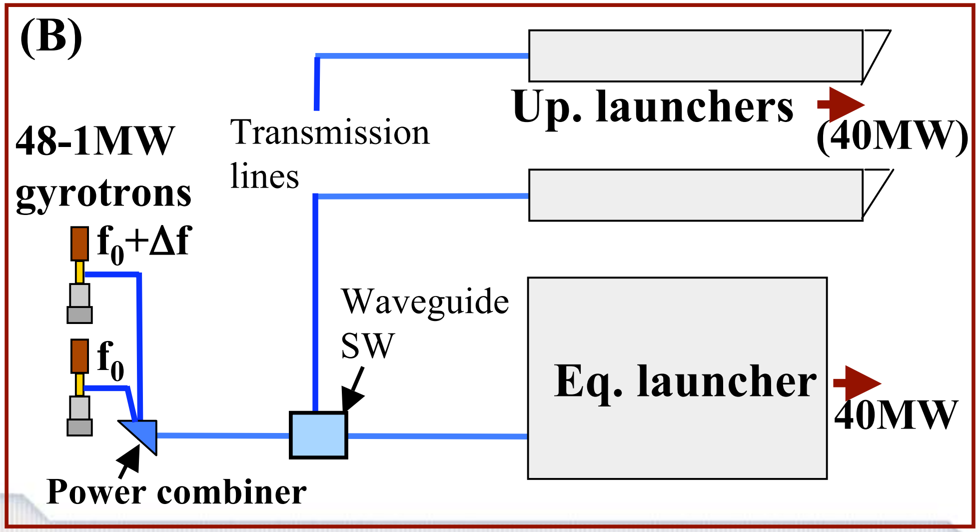
- The party that supplies the lead diagnostic also supplies the engineering structures and carries out the integration.

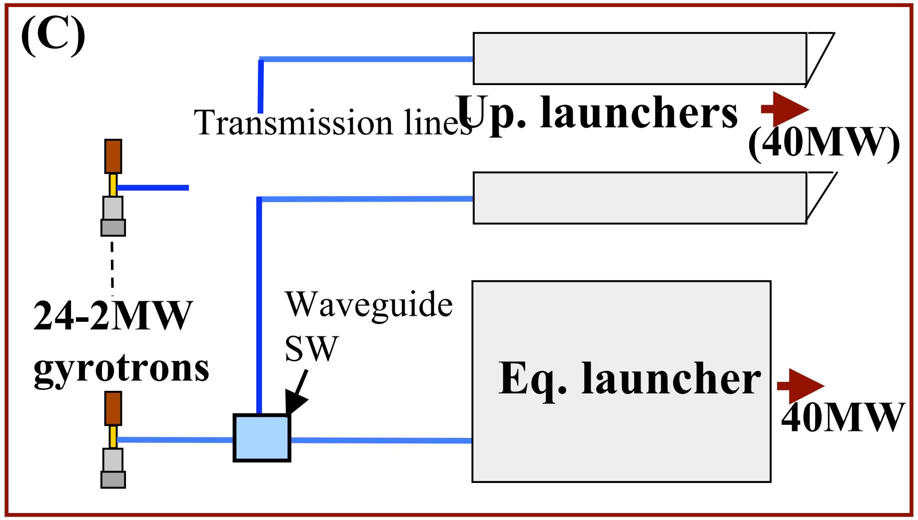
- Interfaces with the tokamak (largely generic) and between diagnostics and port structures. These interfaces have been identified (about 100).

- There are also about 10 distributed systems/packages (eg magnetics).

EC 40 MW Upgrade Plan

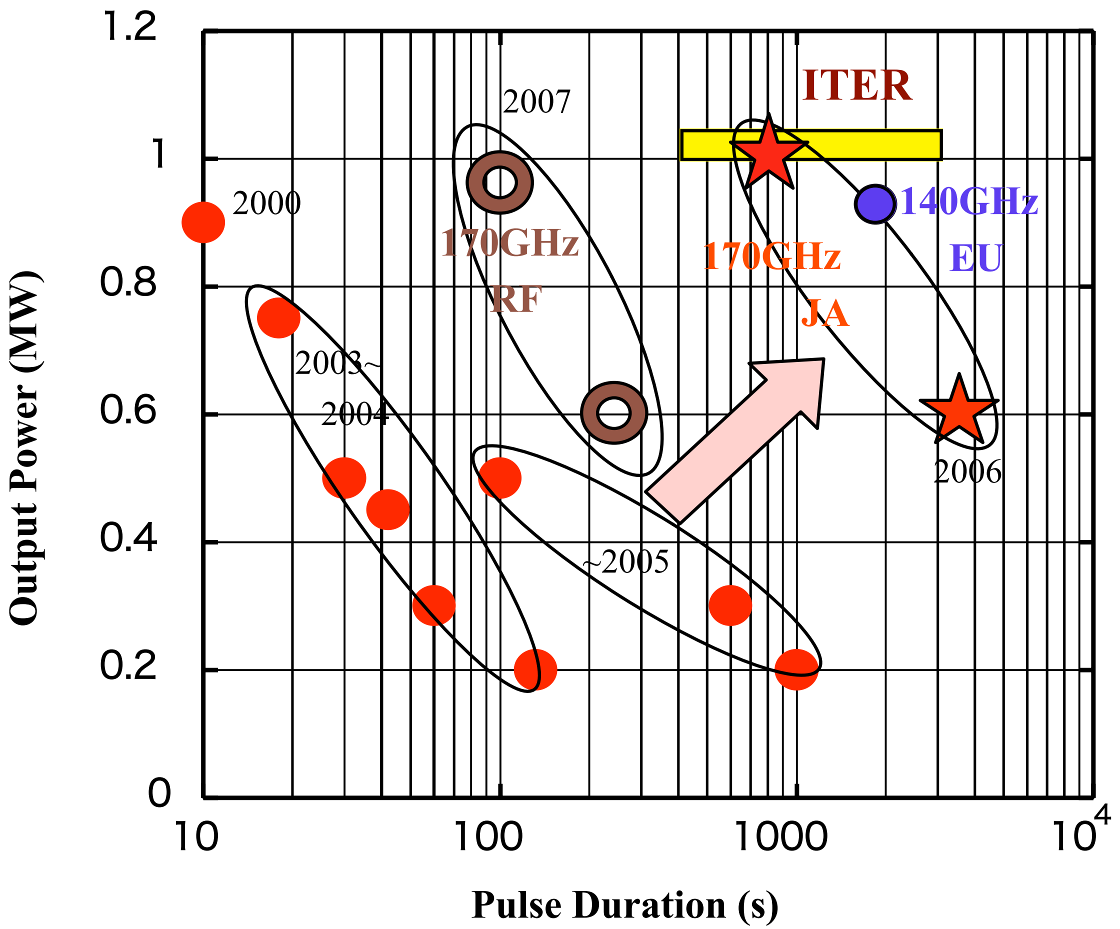






	feature	Key issue
A	No RF route change	Twice T-lines in RF building
B	Present T-line configuration	R&D of High power combiner
C	Present T-line configuration	R&D of 2MW gyrotron

Experimental results of 170 GHz gyrotrons



DCR-90 Use of spare IC antenna

The IC antenna procurement package contains one antenna plus one spare antenna. It is proposed to install both antennas in the machine right from the beginning. The benefit is to couple power with increased reliability in excess of up to 25 MW. It allows upgrade at a later stage by increasing the source power.

Use a blank port # 15 reserved for RF power upgrade

Uses foreseen TL but requires extra matching components (~3kIUA)

Saves a blank plug (~0.5 kIUA)

Doubles the operating range and increases power when limited by V_{max} on antenna

Provides additional power ~ 5 MW due to lower VSWR

Later power upgrade done entirely in the RF hall

DCR-80
ICRF Discharge cleaning

- *The PID Version 3 states in section 4.18.2 that IC discharge cleaning is at present a "Desirable Capability" of the IC system.*
- *WG-1 recommends that this capability should be changed back to the "Functional Requirements" as in FDR-2001 in view of the high uncertainties and risk of other wall cleaning methods (GDC, ECRH)*

- Used routinely in EAST between shots with field on
- High efficiency also demonstrated in Textor, JET, Tore Supra
- About ~ 1MW required
- Resources: no cost to ITER; Work programme in existing machines to establish operating range

DCR-89:
RF building space and schedule

- *The installation and commissioning of the IC/LH/EC systems requires an estimated 2.5 years. The construction of the RF building can only take place in the assembly hall from the beginning of 2014, or possibly 2016 if the space is still required for assembly.*

- *Additionally any unforeseen maintenance of the Tokamak will be in conflict with the installation of the RF equipment, or worse requires the dismantling of the RF building (i. e. coil repair)*

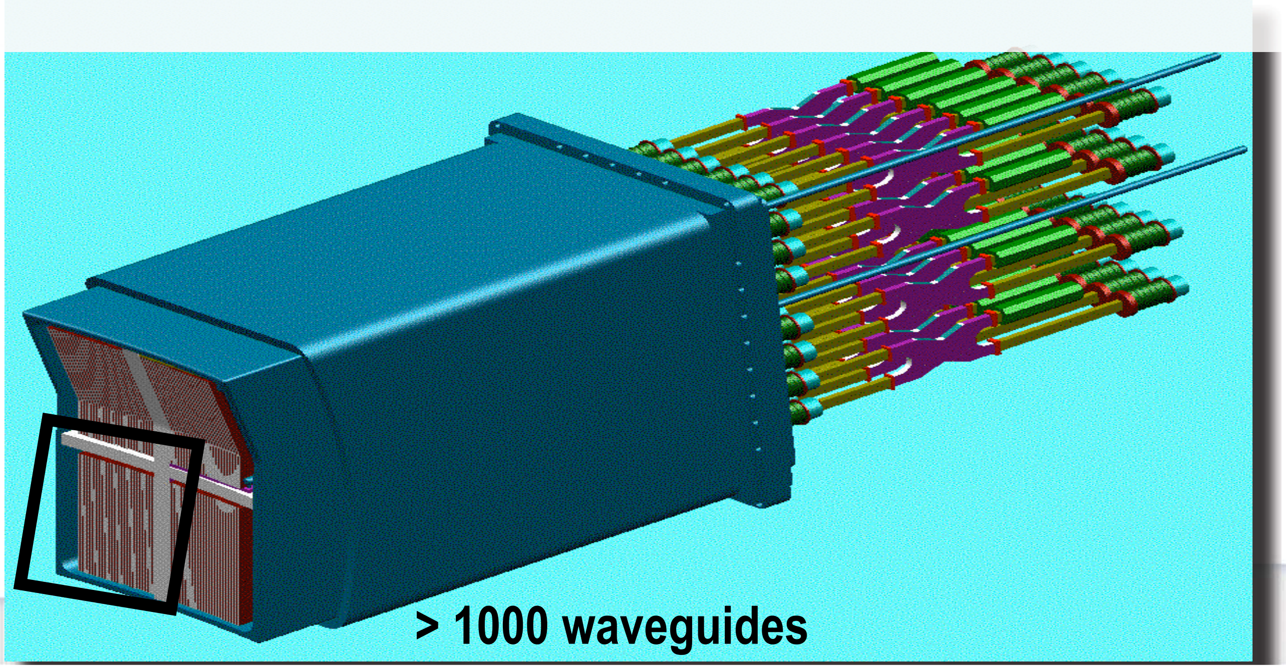
- *The construction of an RF building will allow for timely and efficient installation of the components, testing and greatly reduce the risks for the ITER programme, in case of need of major dismantling. The WG6 recommends the construction of a devoted building on the east side of the assembly hall. Such a building will be 2 floors, without heavy crane and a simple frame.*

Shorter cooling pipes and connections and simplified gyrotron frame nearly bbalance cost of the shell (3.6 M€-2.8M€)

DCR-73

LH R&D work plan

- *In order to prepare the successful implementation of LHCD on ITER (needed for scenarios 1 & 2), a two-step modular approach is recommended by the design review working group WG-6.*
- *The first step (so-called "day1") consists in procuring one fourth of the basic 20MW system, through the installation of one fourth of the source power (twelve 500kW/CW klystrons) connected to a quarter antenna (Mark-I). Mark-I would be in place for the first plasma of ITER and be commissioned during the non active phase.*



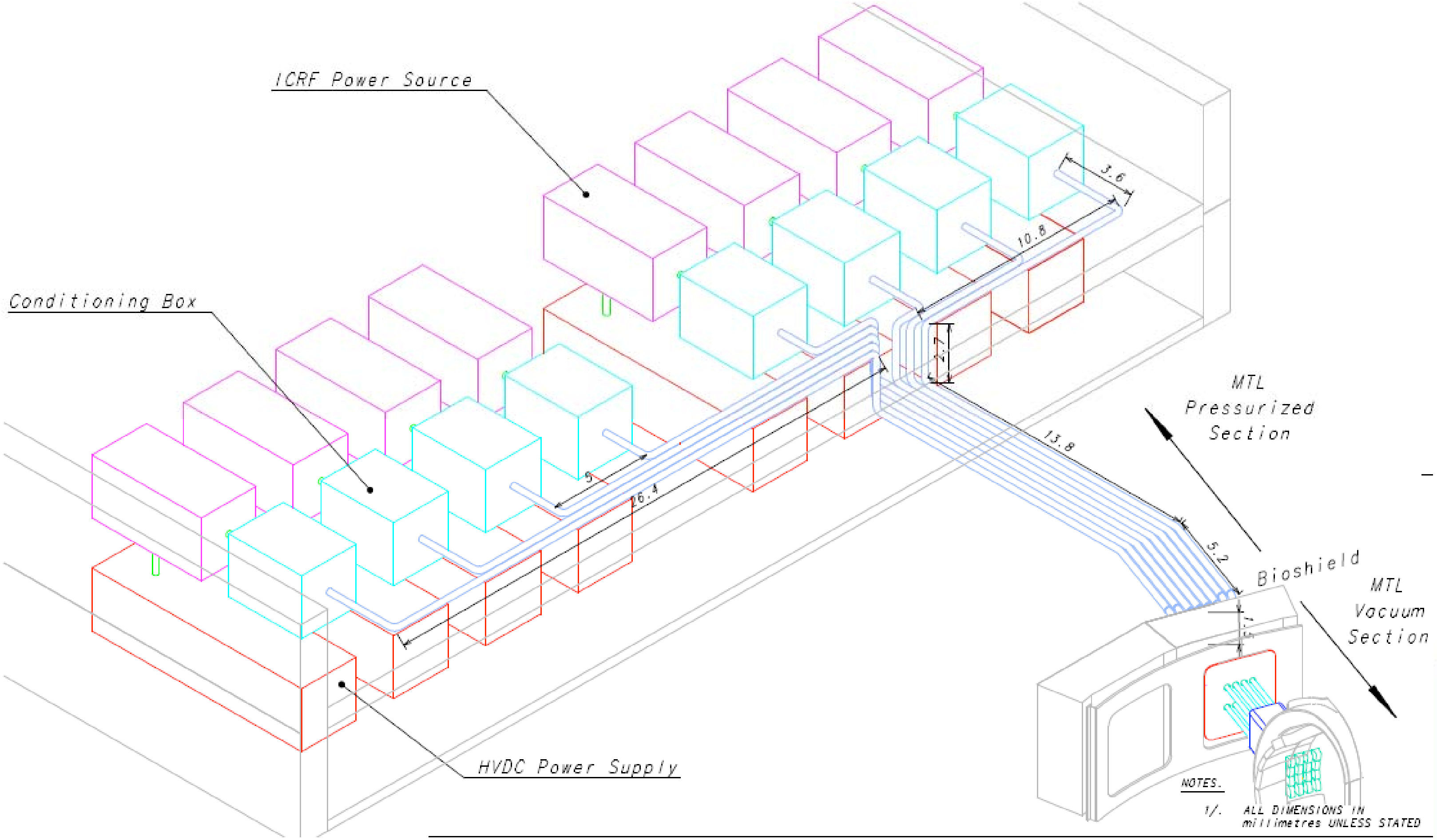
> 1000 waveguides

ICH Requirements

- Basic requirements
  - Deliver 20 MW *to H-mode ELMy plasma*
  - 40-55 MHz operating frequency range
  - ~140 mm avg. distance between antenna and separatrix
    - Typical dist. is 50 – 80 mm in most present-day machines
- Heating and current drive
  - Provide ion and electron heating in 50-50 DT plasma and during early non-activated H operation
  - Drive current up to 1 MA of current near plasma center
- Other
  - Assist in plasma startup
  - Use for wall conditioning with H and other gases, with and without full field (may use dedicated system)

–Constraints : coupling is dependant on plasma configuration (geometry, density, shape, composition,ELMs, etc…)

ICH & CD


ICRF Power Source
Conditioning Box
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3.6
10.8
2.7
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5.2
9
26.4
NOTES.
1/. ALL DIMENSIONS IN millimetres UNLESS STATED

ICH & CD system

- Upgrade possible by doubling the equipment to 40 MW
- System is composed of:

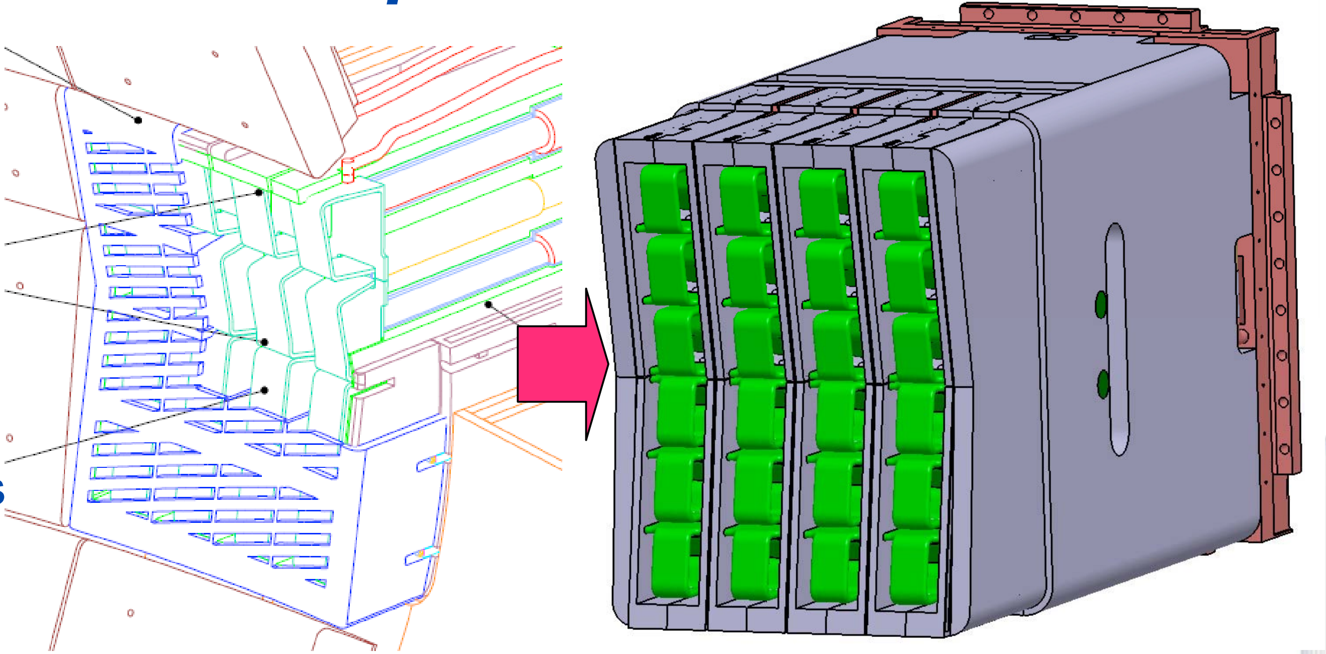
– AC/DC power supply system,	IN	(no R&D)
– DC/RF converters system, control system	IN	(little R&D)
– Transmission line system,	US	(little R&D)
– Antenna system	EU	(lot of R&D)
+ interface with Tokamak		IO

IC Antenna Design

IC antenna conceptual studies have shown that the DDD version needs to be updated.

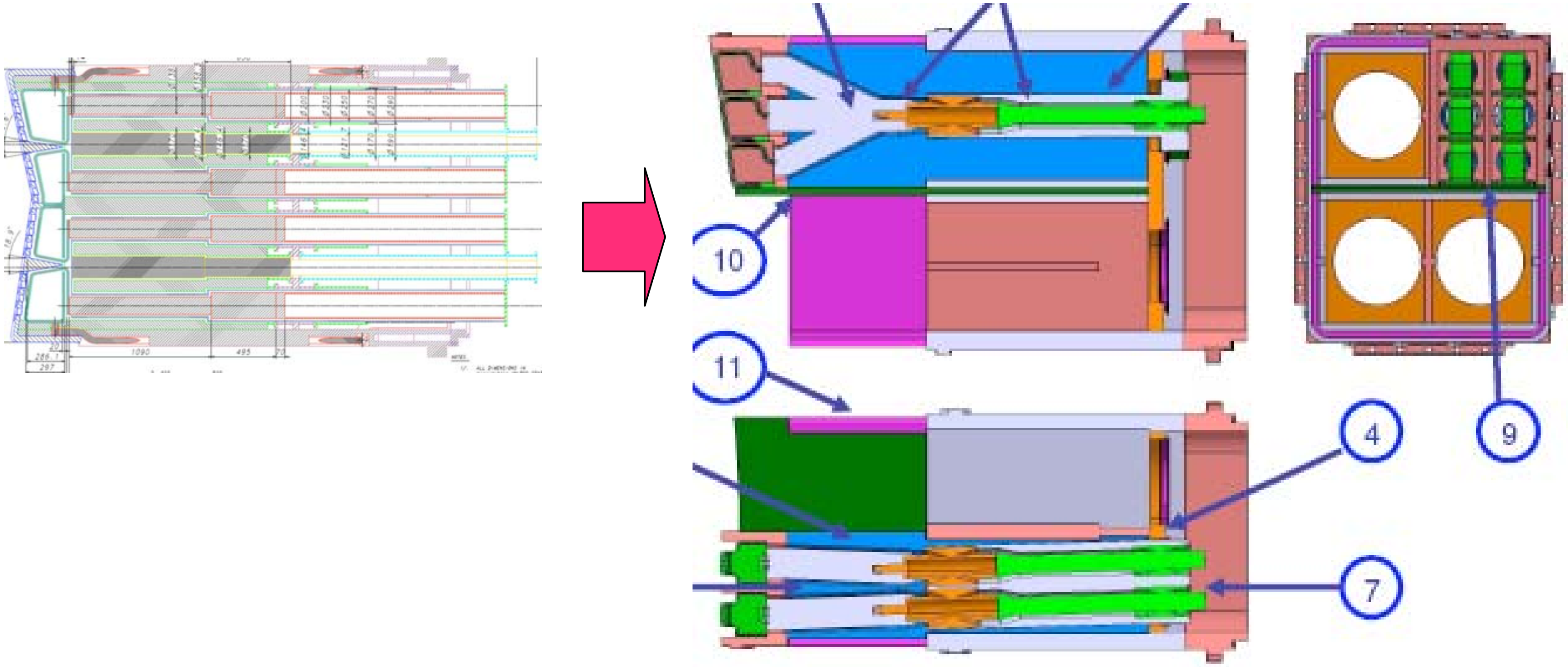
Now, antenna will be an array of 24 straps radiating to the plasma, and the tuning and matching components have been moved out of the plug and the interspace.

- 24 straps maximizes the power coupled at given voltage(16 in DDD)
- No moving parts in antenna plug
- Modularity
- Removable feedthroughs



IC Antenna Design Update

- **DDD:** port plug incorporates all-metal matching system with many movable elements (sliding contacts), 8 input transmission lines for 16 straps
- **Update:** matching moved out of port plug, modular plug elements, no moving parts, (private) vacuum transmission lines with ceramic supports separately removable, 8 input transmission lines for 24 straps

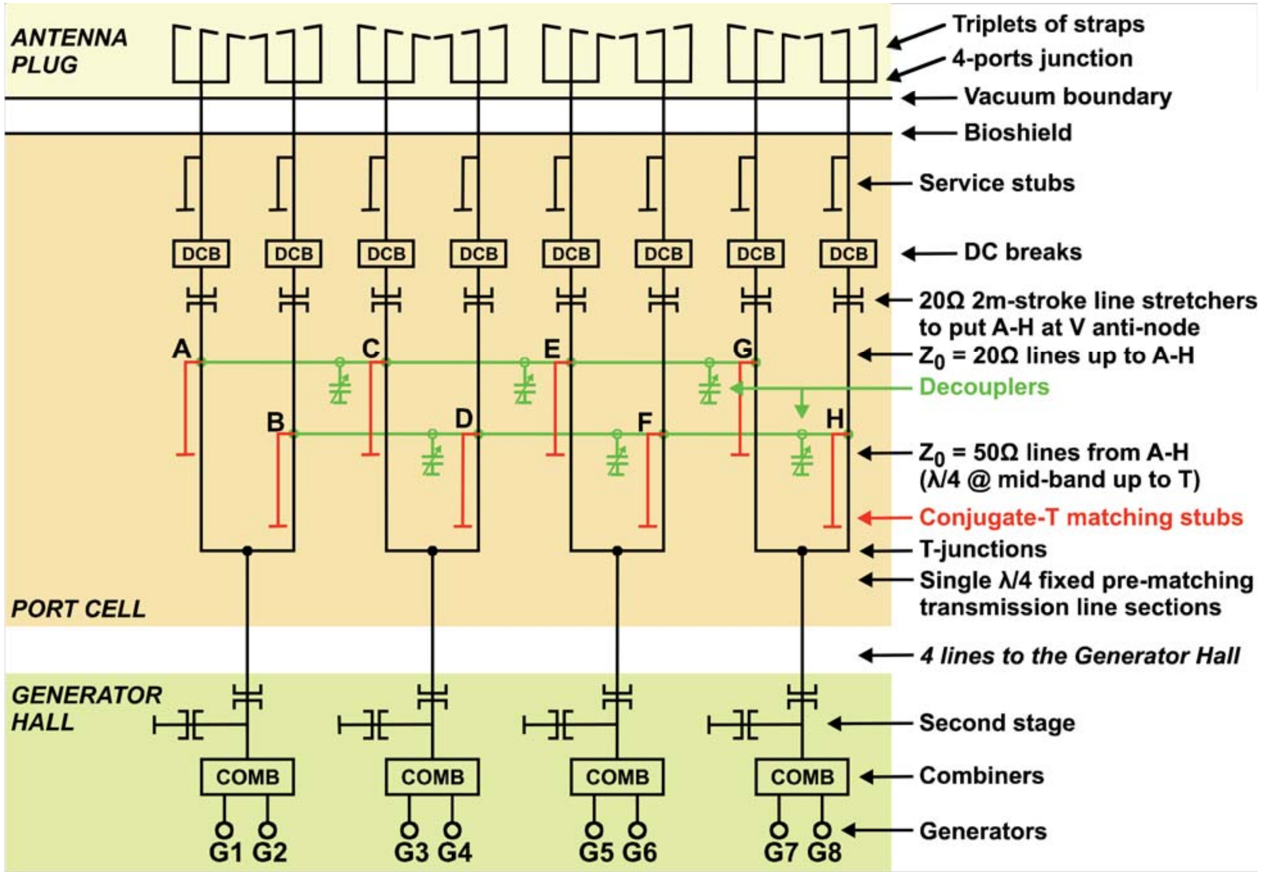


Concept simpler and more robust

IC Antenna Design Update

Matching principle: ELM-resilient conjugate-T

- Kept from DDD but all tuners moved outside port-plug



Triplets of straps

4-ports junction

Vacuum boundary

Bioshield

Service stubs

DC breaks

20Ω 2m-stroke line stretchers to put A-H at V anti-node

Z_0 = 20Ω lines up to A-H

Decouplers

Z_0 = 50Ω lines from A-H (λ/4 @ mid-band up to T)

Conjugate-T matching stubs

T-junctions

Single λ/4 fixed pre-matching transmission line sections

4 lines to the Generator Hall

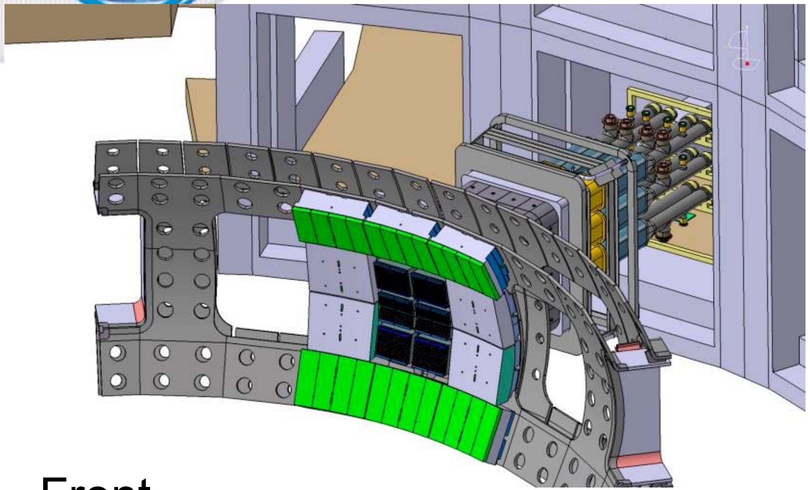
Second stage

Combiners

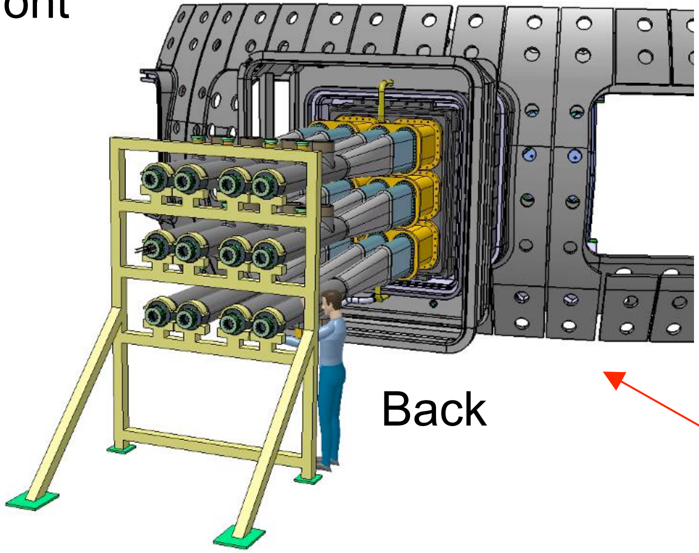
Generators

More flexible, allows alternative matching schemes, like ELM-dump if 8 TL's installed

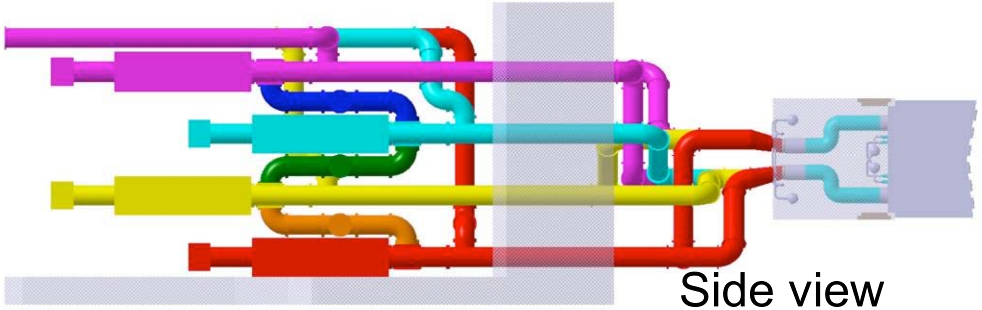
Example of 2 antenna configurations



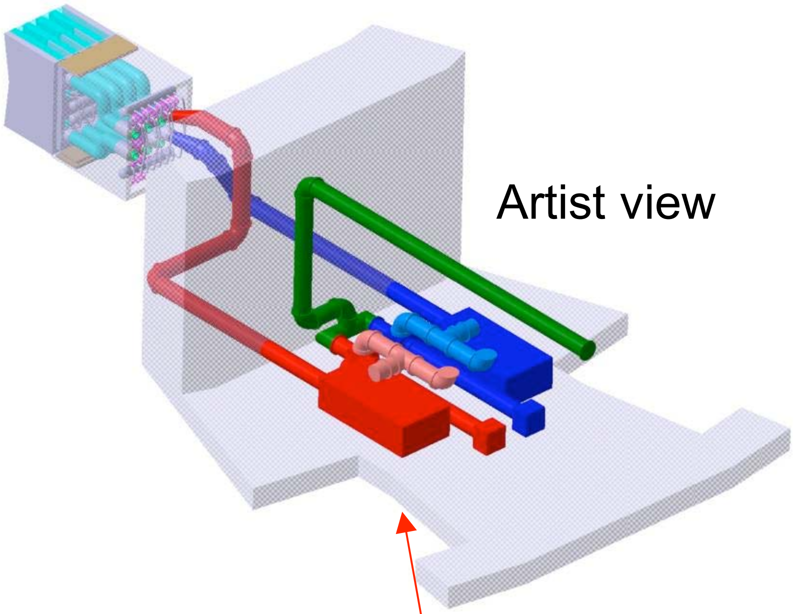
Front



Back



Side view



Artist view

- Matching units in interspace or port cell

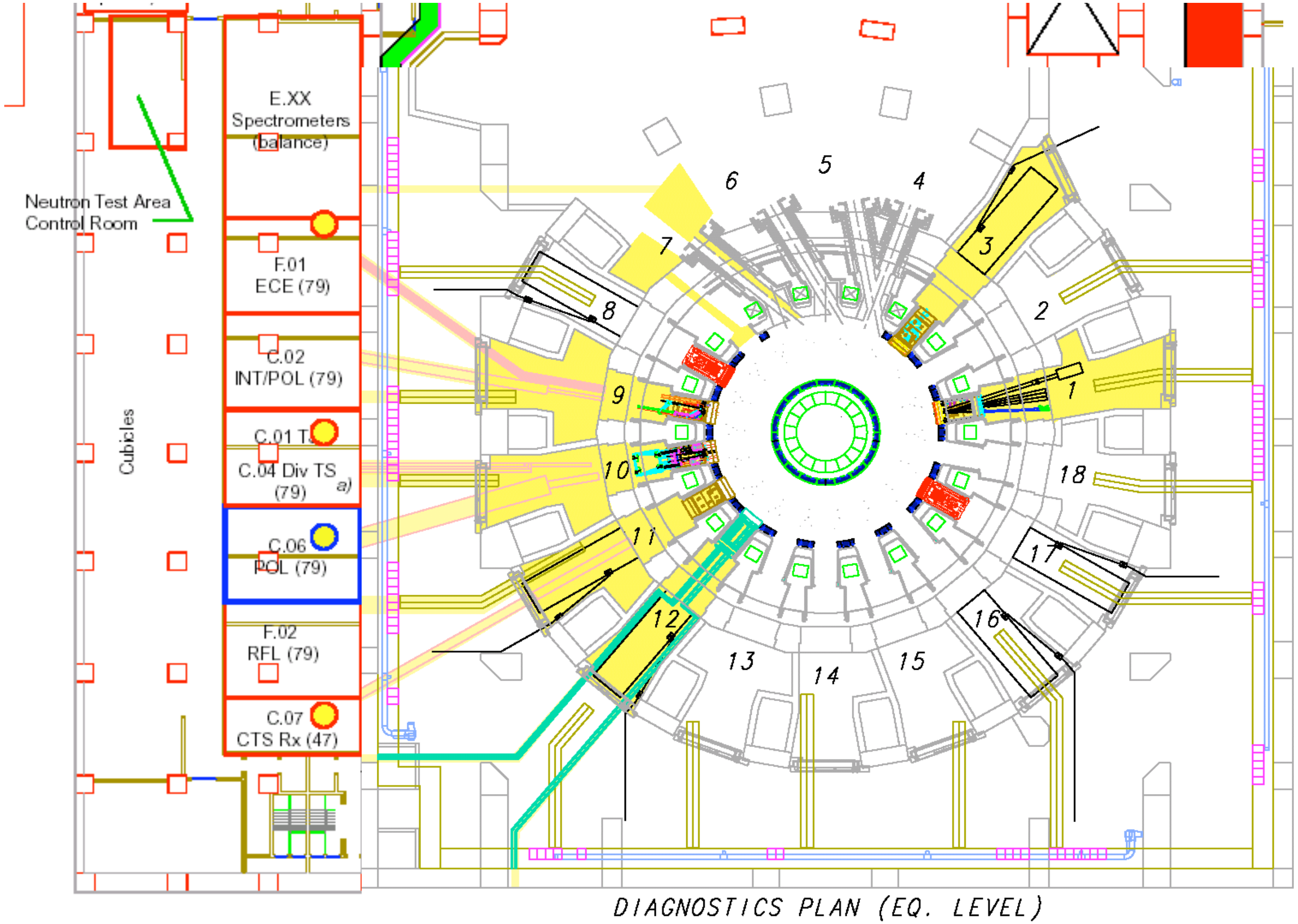
Backup and Supplementary Measurements

Location	On vessel inner skin behind blanket									In divertor		Within vessel structure				Ex-vessel	
System Measurement	Tangential Coils	Normal Coils	Equilibrium Saddles (partial flux loops)	continuous flux loops	Toroidal coils	HF coils	Dedicated MHD saddles	Diamagentic loop sensors	Halo sensors	Equilibrium coils	Toroidal coils	Tangential Coils	Normal Coils	Steady state sensors (tangential)	Steady state sensors (normal)	External flux loops	External rogowski
Plasma Current	●			⊕		★						⊕		⊕		⊕	⊕
Plasma Position and Shape	●	●	●	●		★	★			●		⊕	★	⊕	★	⊕	⊕
Loop Voltage				●												⊕	
Plasma Energy					⊕			●			⊕				⊕		
Locked modes		⊕	⊕				●										
Low (m,n) MHD Modes, Sawteeth, Disruption Precursors	⊕	⊕	⊕			⊕	●					⊕	⊕	⊕	⊕		
Halo Currents					⊕			⊕	●		⊕						
Toroidal Magnetic Field					⊕			●			⊕						
High Frequency macro instabilities (Fishbones, TAE Modes)	⊕					●											

●: Main, ★: Backup, ⊕: Supplementary

Diagnostic Building

Transmission lines pass through the galleries to lasers, detectors, spectrometers etc in the diagnostic building



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