Heating Neutral Beam and Electron Cyclotron Power Supplies An overview of the Procurement

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Synopsis

- Overview of the ITER H&CD systems
- Power Supplies procurements sharing amongst ITER Parties
- Neutral Beam (NB) System
- Heating NB Supplies
- Electron Cyclotron (EC) System
- EC Power Supplies
- Time Schedule and Procurement Sharing
- Conclusions

ITER Heating and Current Drive Systems (H&CD) - Hints

The H&CD systems are essential for ITER operation, e.g.:

- to heat of plasma to temperatures required for fusion burn
- to access the H-mode regime
- to achieve steady-state operation (non-inductive current drive)
- stabilisation of Magneto Hydro-Dynamic modes in the plasma
- vessel wall conditioning and plasma start-up assist

Four systems foreseen for ITER: Neutral Beam (NB), Ion Cyclotron (IC), Electron Cyclotron (EC) (Baseline Systems) and Lower Hybrid (LH) (future option)

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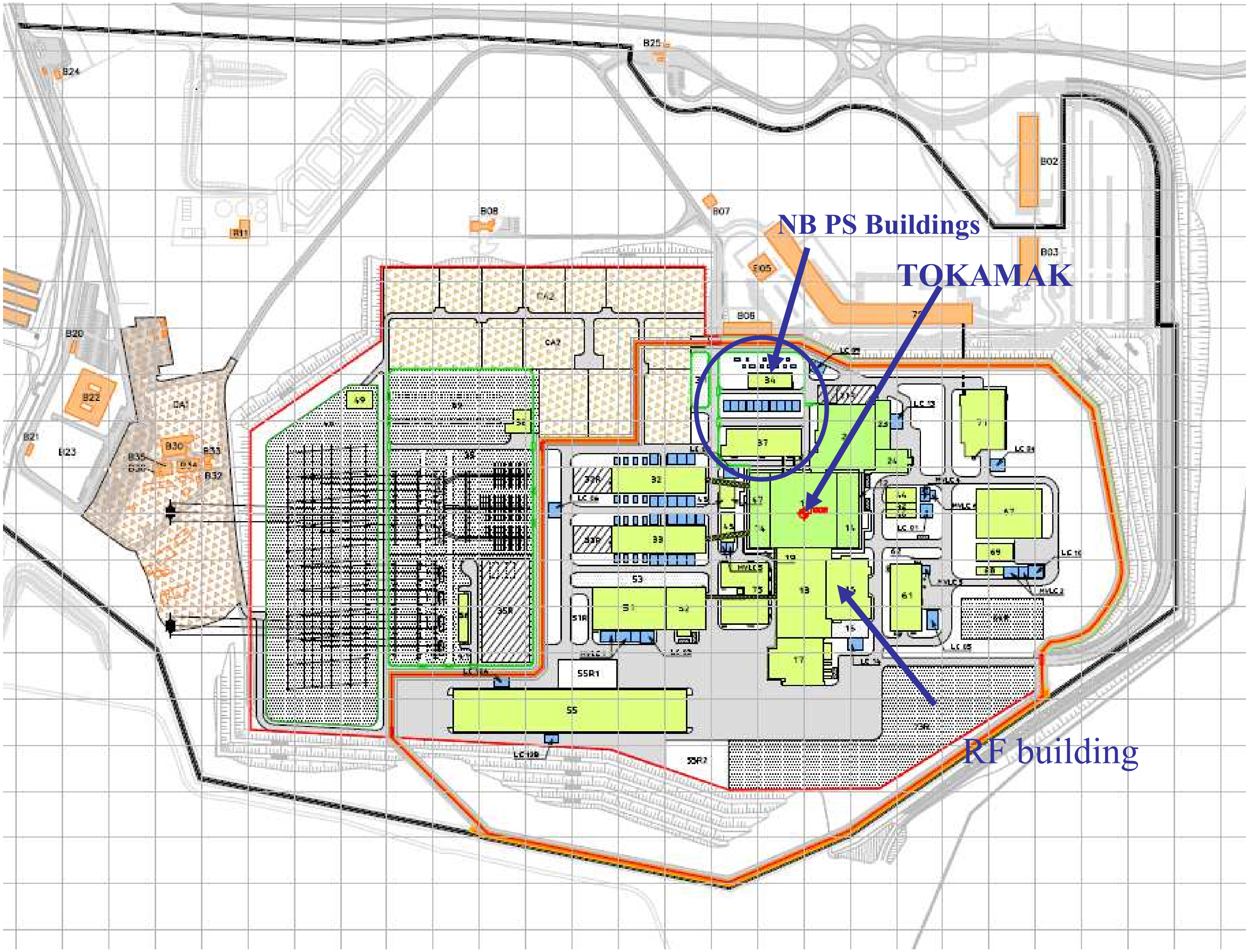
ITER Heating and Current Drive Systems

Power Injected in the Plasma in MW

Heating System	Stage 1 (Day-1)	Possible Upgrade
NBI (1 MVe)	33	16.5
EC H&CD (170 GHz)	20	(20)
IC H&CD (40 – 56 MHz)	20	(20)
LH H&CD (5 GHz)		(20 – 40)
TOTAL	73 →	max 130 (110 simultaneously available) (limited by port availability)
Diagnostic Beam (100 kVe, H^-)	> 2	

ITER site Layout



H&CD Procurement Sharing

%

PP	Description	EU	JA	RF	US	CN	KO	IN	FUND
41.P5	IC Power Supplies							100	
41.P4	EC Power Supplies	92						8	
41.P7	NB H&CD Power Supplies	31	69						

NB H&CD System

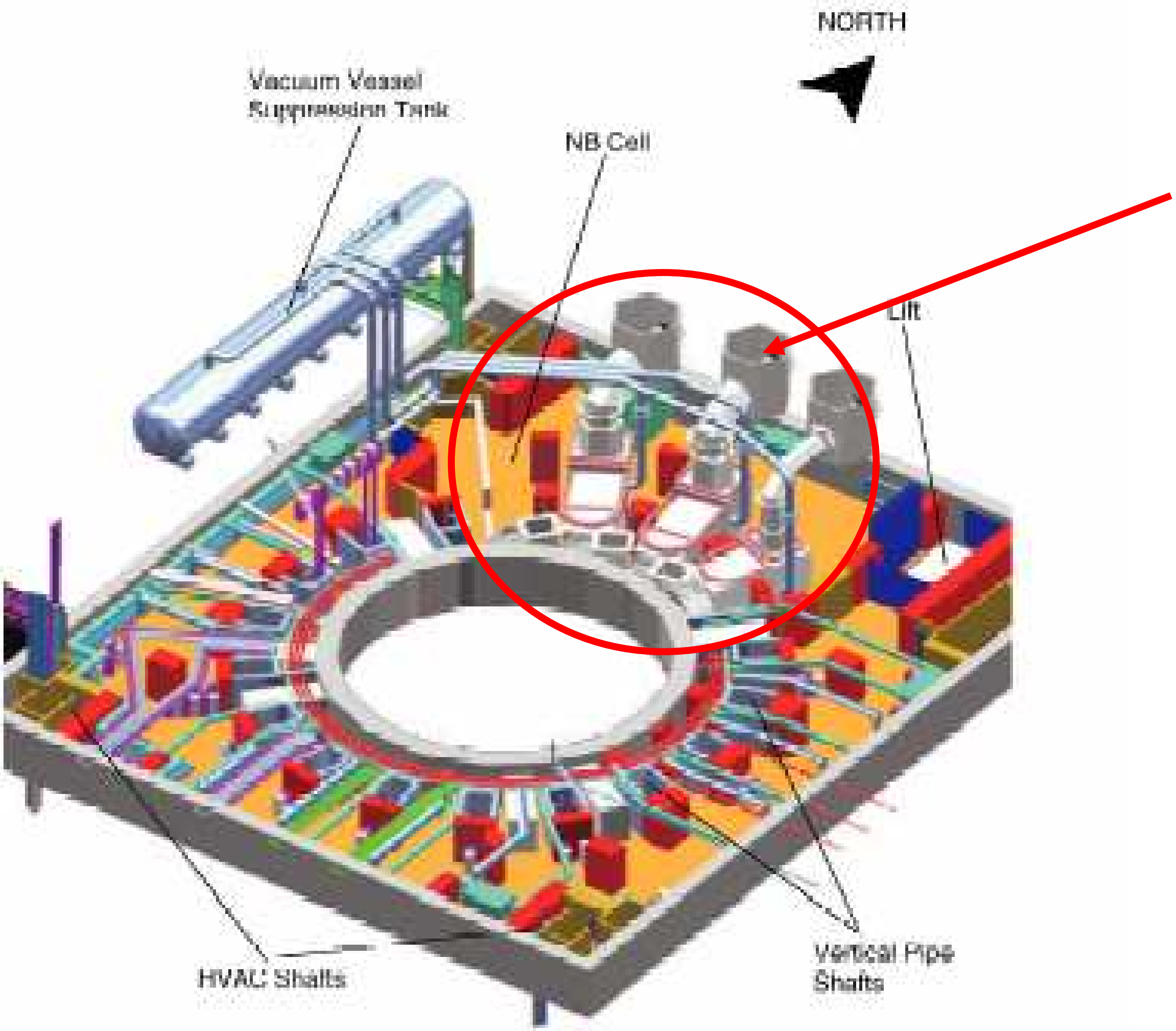
Basic principle: Highly energetic beams of neutralized particles (Deuterium or Hydrogen) are injected into the plasma.

- **Two** heating and current drive injectors (H&CD) (ports #4 - #5)
- **One** diagnostic neutral beam (DNB) injector (shares port #4) for spectroscopy diagnostic
  It shares technology with the H&CD (e.g. same ion source)
- A possible third H&CD injector may be installed later
- Based on acceleration of negative ions

	H&CD NB	DNB
Beam energy	1 MeV (D^-) / 800 keV (H^-)	100 keV (H^-)
Beam current	40 A	60 A
Pulse length	up to 3,600 s	Modulated at 5 Hz for 3 s every 20 s
Current Density	200 A/m^2	300 A/m^2

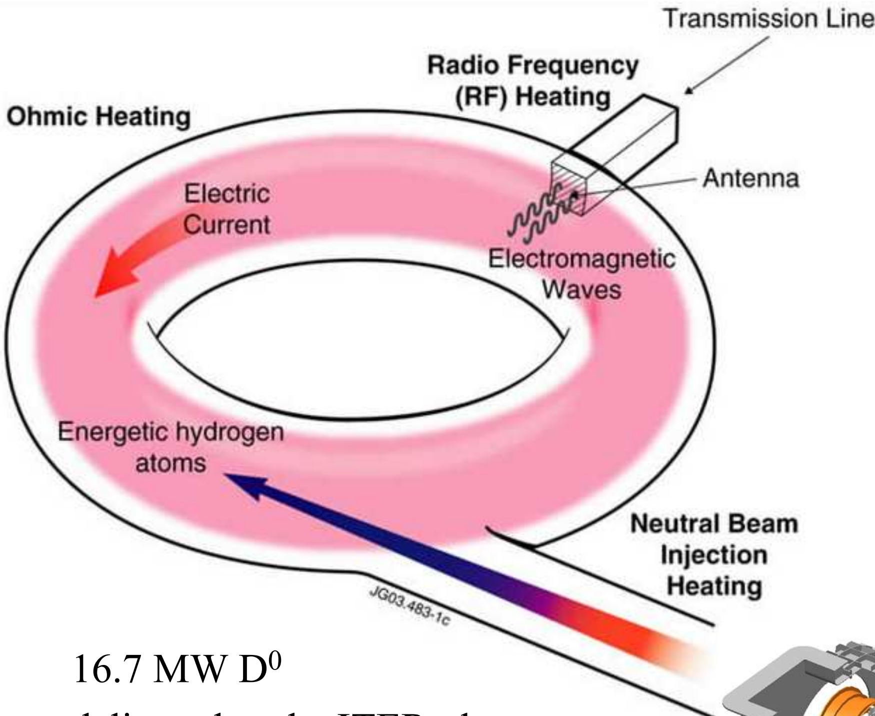
ITER NB System

Lay-out

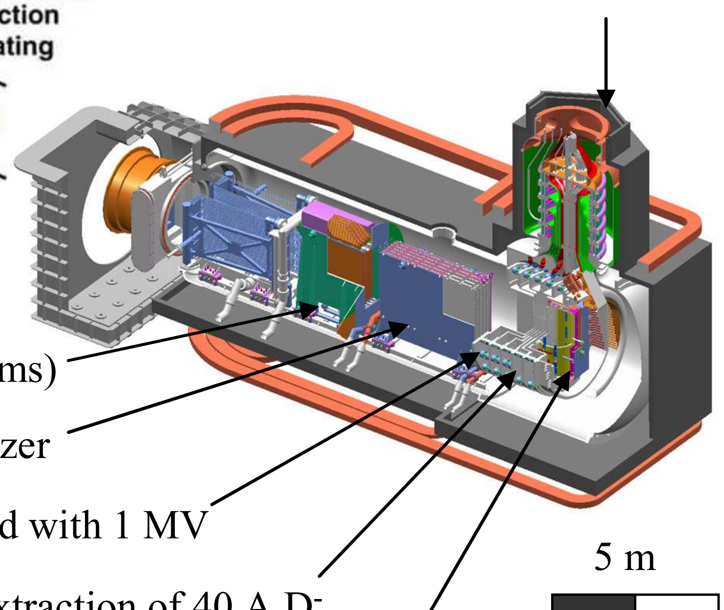


The injectors are extensions of the primary confinement barrier of radioactive materials coming from the vacuum vessel.

Heating NB injector



16.7 MW D^0
delivered to the ITER plasma



Electrostatic RID
(deflection of the residual charged beams)

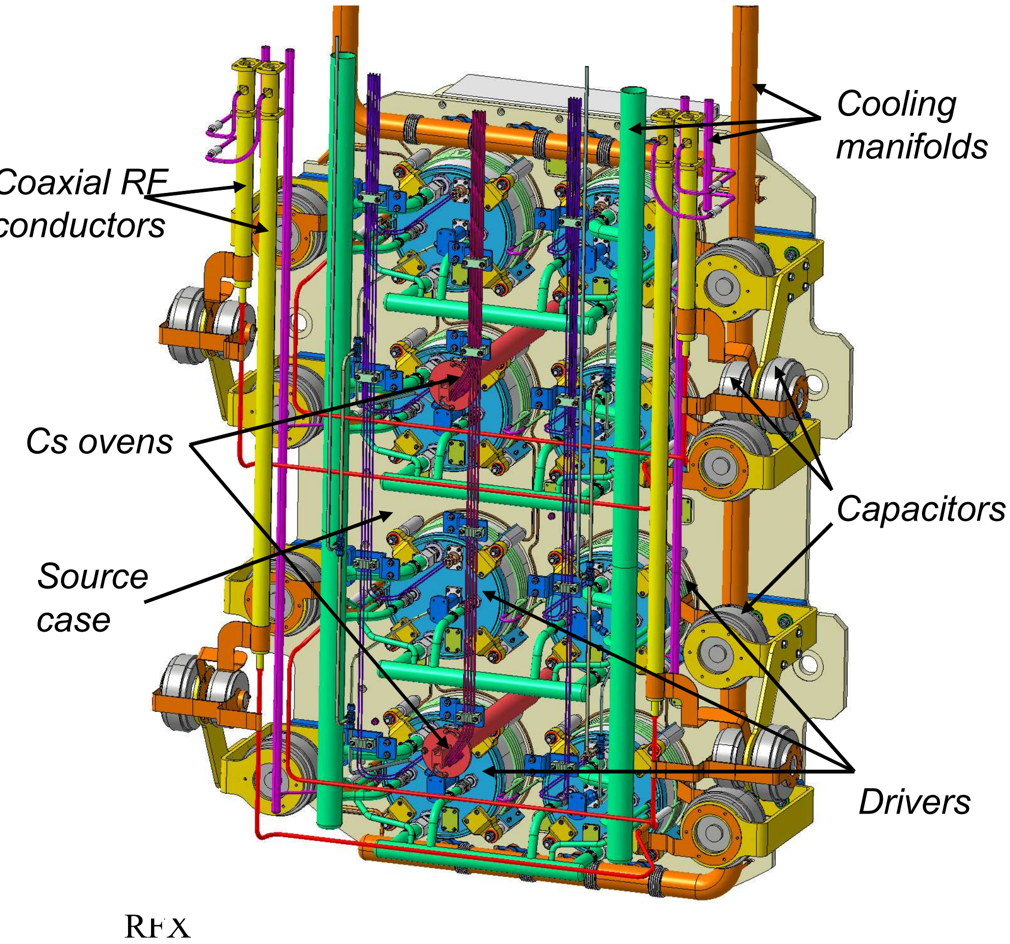
Neutralization to D^0 in the gas neutralizer

D^- ions accelerated with 1 MV

Extraction of 40 A D^-

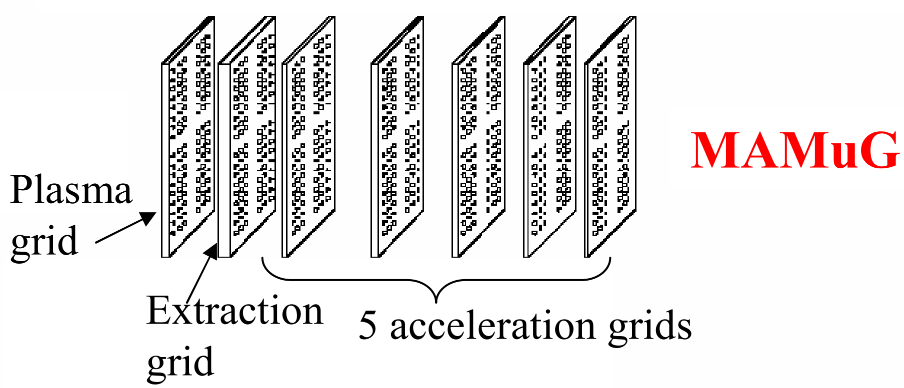
Negative ions D^- are generated in the ion source (required 200 A/m^2 D^-)

Main Electrical Loads of the HNB Power Supplies – Beam Source (AGPS and ISEPS)

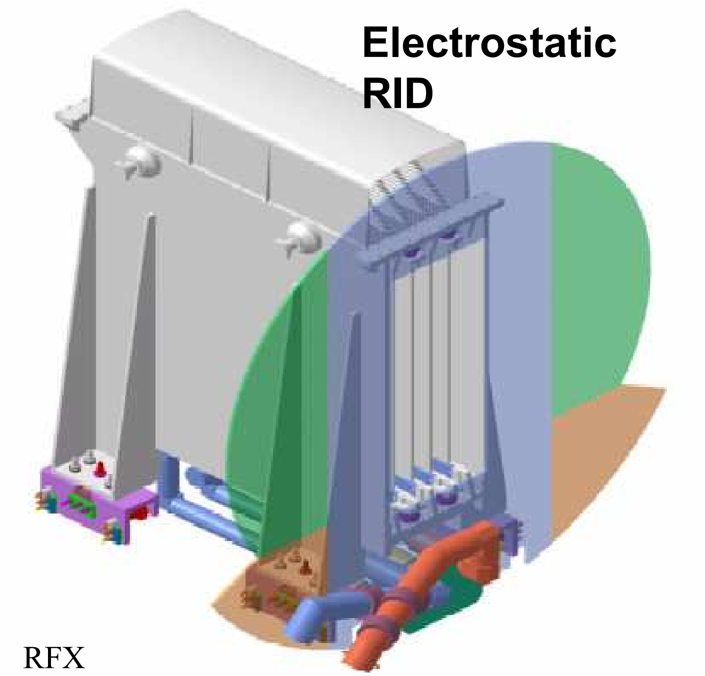


40 A (200 A/m^2) D- beam at 1 MeV (H&CD NB) for 3,600 s pulses

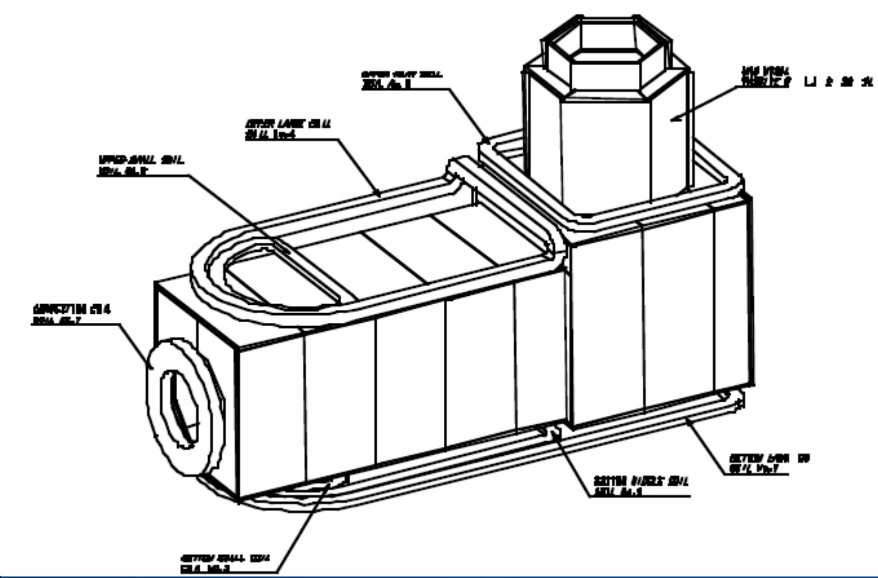
- **ion source** (RF driven)
- the **extractor** and the **accelerator** (Multiple Aperture Multiple Gap, MAMuG)



Main Electrical Loads of the HNB Power Supplies (Ground Related Power Supplies – GRPS)

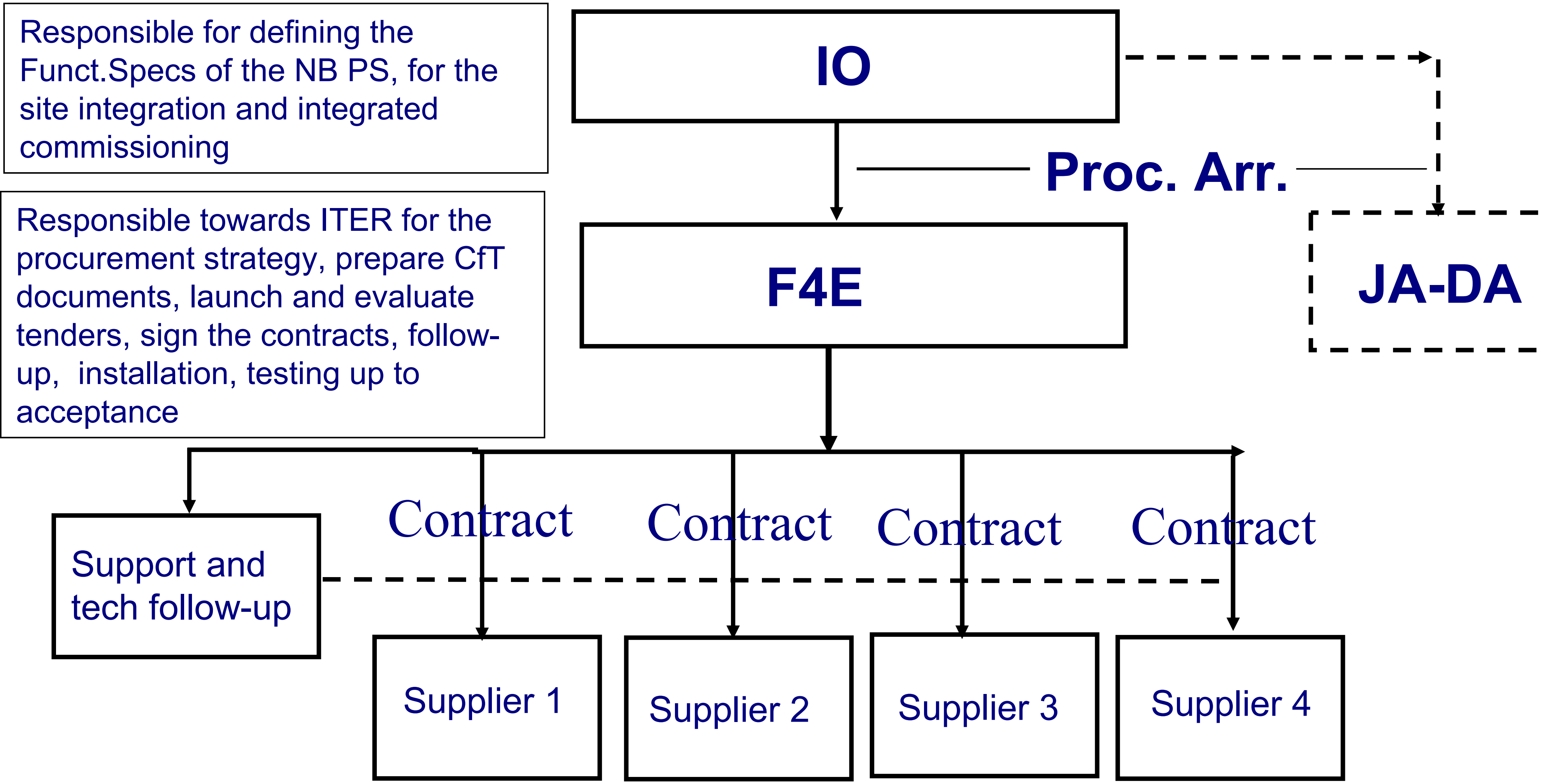


The **residual ion dump (RID) removes t**he charged beams at the exit of the neutraliser An electrical field is applied between the RID panels that are at negative potential (at ~ 20 kV) or are grounded.



Magnetic Field Reduction System (MFRS) – Six copper a coils to reduce the magnetic field inside the injector vessel.

General Organisation of HNB PS Procurement proce



Typical procurement contract includes: design, manufacture, factory testing, transport, installation, site commissioning up to acceptance, for which the Supplier is responsible

General Organisation of HNB PS Procurement process

The Procurement Arrangement (PA) for the HNB PS between ITER and F4E is based on functional technical specification:

F4E has the responsibility to define the actual procurement strategy (e.g. sub-division in more contracts if necessary), and prepare the actual tender and contract specification.

The required performances are specified in detail, possible accompanied b a not binding "reference design", mainly for explicatory reasons.

The Supplier has freedom of choice of design solutions, manufacturing practices, etc. and bears the full responsibility for the fulfillment of the specified performances.

The PA for the NB PS is ready for signature, the functional specification is fully defined. Signature is expected in **July 2009**.

Sharing between Europe and Japan

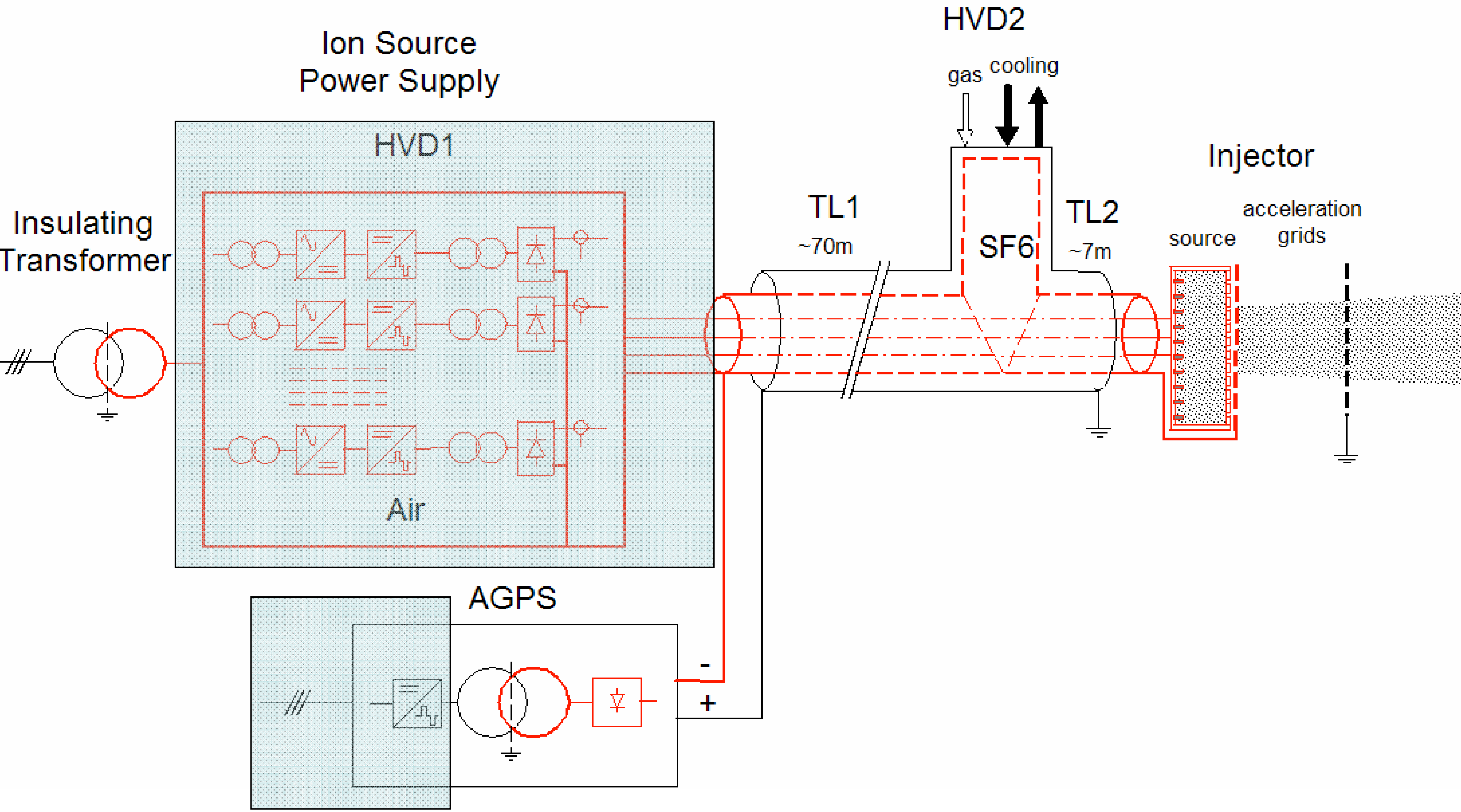
The procurement of the HNB Power Supplies is hared between the EU and JA Domestic Agencies.

In summary:

EU is responsible for the low voltage parts (essentially the conversion system) of the AGPS (up to the cabling to the step-up transformer, of all the ISEPS, including the HV deck where they are located and the HV connection to the SF6 Transmission line, the Ground Related power supplies, the overall control of they power supplies);

JA is responsible for most of the 1 MV components (step-up transformer, rectifiers, filters and SF6 transmission line up to the injectors), including the insulation transformer feeding the ISEPS located in the HV Deck.

The definition and control of interfaces between the two procurements, formally under IO responsibility, is one of the highest element of risk.


Ion Source
Power Supply
HVD1
Air
Insulating
Transformer
AGPS
-
+
TL1
~70m
HVD2
gas
cooling
SF6
TL2
~7m
Injector
source
acceleration
grids

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NB Power Supply System (31%EU, 69% JA)

	PS rating
ted nominal voltage	-1000 kV
ted nominal current ax)	65 A
tage range	20% - 100%
tage control accuracy	± 2%
x voltage ripple	± 3%
sponse time of the load t. system	≤ 200 μs

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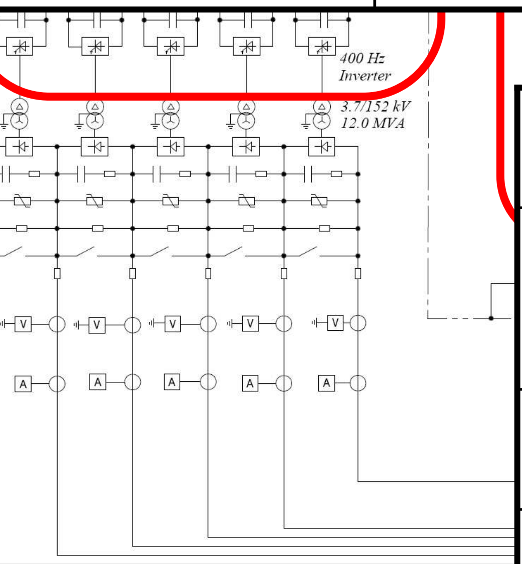
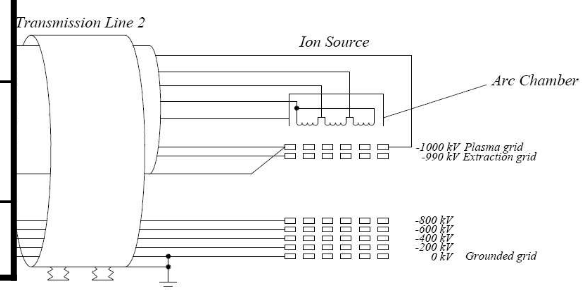
Thyristor converter	Voltage (V)	Current (A)
ACCC converter type a	890	600
ACCC converter type b	400	600
ACCC converter type c	1260	600
Residual Ion Dump	25000	53

Plasma Grid Filter	5 kA	15 V
Rf generators (x4)	200 kW	Typ 1 MHz
Extraction grid	140 A	12 kV
bias	600 A	30 V





NB PS Tentative Procurement Strategy

TER provides the functional technical specifications for the Procurement Arrangement accompanied by the reference designs of the subsystems.

F4E is then responsible for the definition and implementation of the procurement strategy.

The procurements for the PS system under this PA are subdivided in four contracts:

- Ion Source and Extraction Power Supplies (ISEPS) – up to 4 Units needed;
- LV Acceleration Grid Power Supplies + Ground Referenced Power Supplies + NBPS Control and DAQ (NB AGPS + GRPS + NBPS Control & DAQ) – up to 3 Units needed;
- High Voltage Deck 1 (HVD1) and HVD1-TL Bushing; (NB HVD1 + Bushing) – up to 3 Units needed;
- NB System Control and DAQ; (NB Control & DAQ System) – up to 3 Units needed.

Neutral Beam Test Facility

The first two units will be installed in different places!

In fact some R&D is still required to fully develop the ITER injectors

The development programme is centred on the establishment of a Full Scale Test Facility (PRIMA) in RFX, Padua

Two main test beds in Padua:

- For the development of the Ion Source (SPIDER)
- For the full development of the injectors, including acceleration up to 1 MV (MITICA)

The test facility will require, in addition to power supplies identical to the ones of the ITER injectors, also a some specific systems procured under additional contracts.

Procurement Strategy and main Dates (estimates)

CONTRACT 1- NBPS
Ion Source and Extraction Power Supplies (ISEPS);
Quantity: Up to 4 items

1- SPIDER
2- MITICA
3- NBI-1
4- NBI-2

Estimated Call Launch: ***End July 2009***
Estimated Start of the Contract: End March 2010
Contract Duration: 8 years overall – 2 ½ year on average per items

CONTRACT 2
HV Deck and Transmission Line
Quantity: 1 item

Test Facility specific

1 – SPIDER

Estimated Call Launch: **September 2009**
Estimated Start of the Contract: End March 2010
Duration: *24 months*

CONTRACT 3
100 kV AGPS
Quantity: 1 item

Test Facility specific

1 - SPIDER

Estimated Call Launch: **December 2009**
Estimated Start Date of the Contract: August 2010
Duration: 22 months

CONTRACT 4 - AGPS + GRPS + NBPS Control and DAQ
Quantity: 3 items

1 - MITICA
2- NBI-1
3 - NBI-2

Estimated Call Launch: **February 2010**
Estimated Start of the Contract: August 2010
Duration: 8 years overall – 3 ½ year per items

Procurement Strategy and main Dates (estimates)

CONTRACT 4 - AGPS + GRPS + NBPS Control and DAQ
Quantity: 3 items

1 - MITICA
2- NBI-1
3 - NBI-2

Estimated Call Launch: **February 2010**
Estimated Start of the Contract: August 2010
Duration: 8 years overall – 3 ½ year per items

CONTRACT 5
Title:NB HVD1 + Bushing
Quantity: 3 items

1 - MITICA
2 - NBI-1
3 - NBI-2

Estimated Call Launch: **March 2010**
Estimated Start Date of the Contract: December 2010
Duration: 7 years overall - 2 ½ year on average per item

CONTRACT 6
Title: NB System Control and DAQ;
Quantity: 3 items

1 - MITICA
2 - NBI-1
3 - NBI-2

Estimated Call Launch: **October 2011**
Estimated Start of the Contract: May 2012
Duration: 6 years overall - 1 ½ year on average per item

Power Supplies specific for SPIDER

Some contracts will need to be placed by F4E for components specific to the SPIDER:

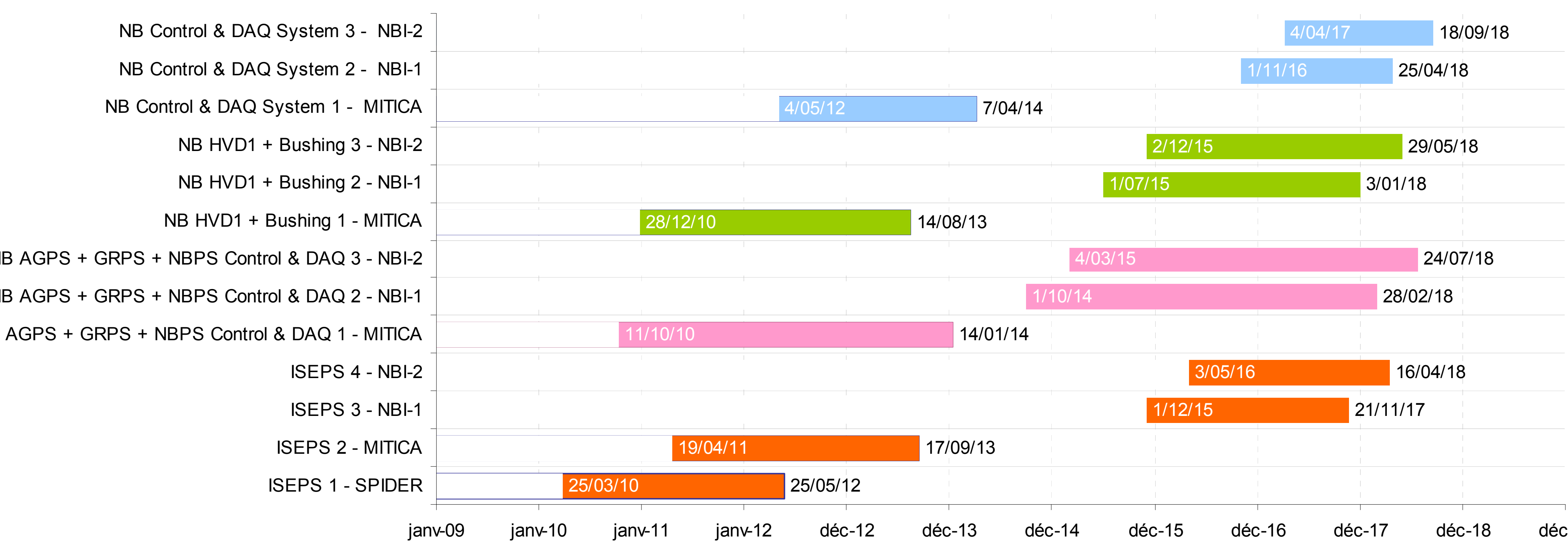
A 100 kV power supply/ 70 A for providing the acceleration of the negative ions extracted from the source

A HV Deck (where the ISEPS is located) and transmission line (air insulated at 100 kV to ground) to connect the ISEPS to the Ion Source.

H&CD NB Power Supplies – Main issues in the European procurement

- General issues related to 1 MV isolation in DC, well above industrial standards
- The HV deck where the ISEPS is installed (MITICA and ITER injectors) must be insulated for a rated voltage of 1 MV DC to ground.
- ISEPS must be connected to the SF6 transmission line (air-to-SF6 connection at 1 MV of many power conductors and RF coax lines) . This connection is a critical part outside the “standard industrial” production.

Tentative Summary Time Schedule for the Procurements



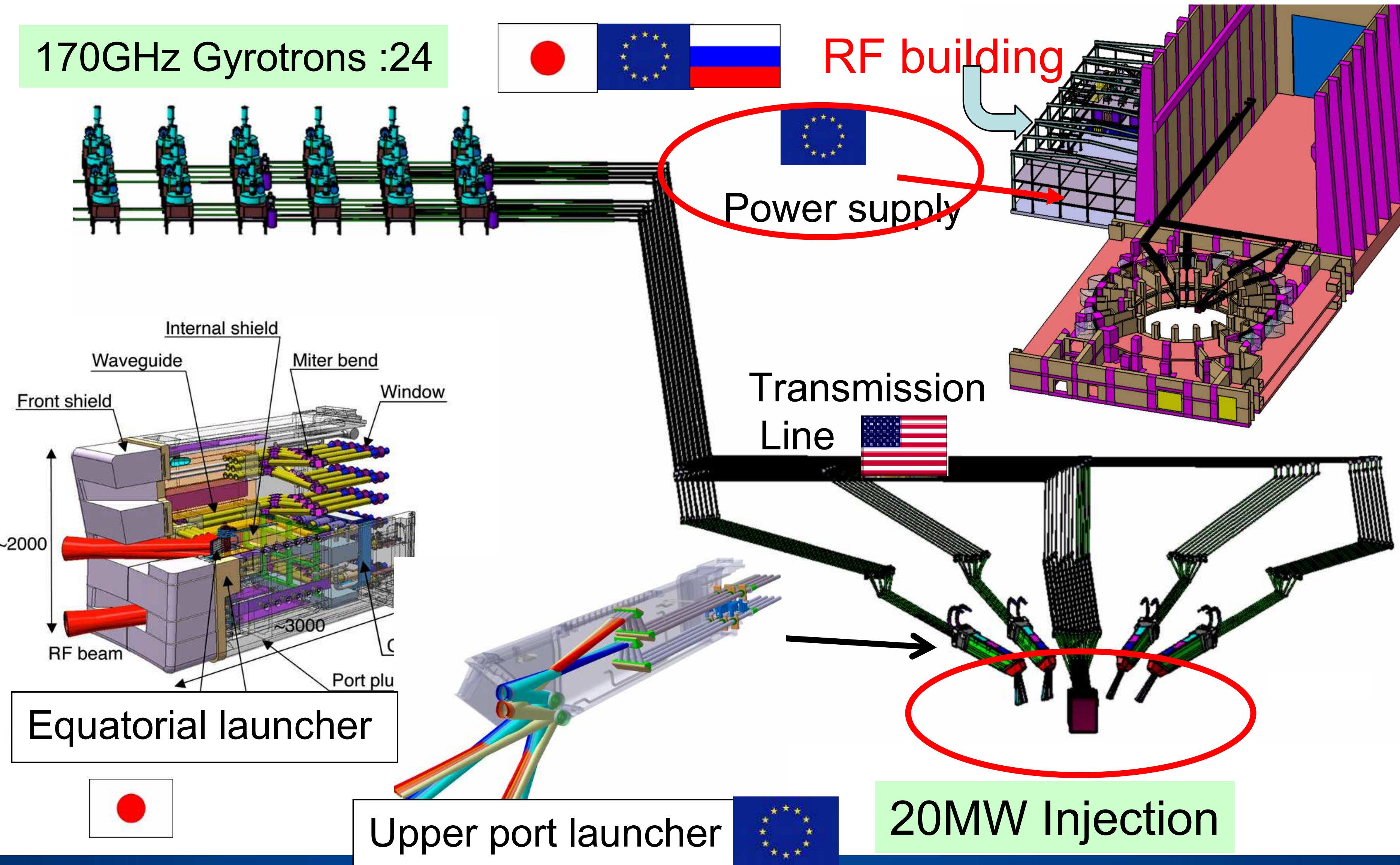
EC H&CD System

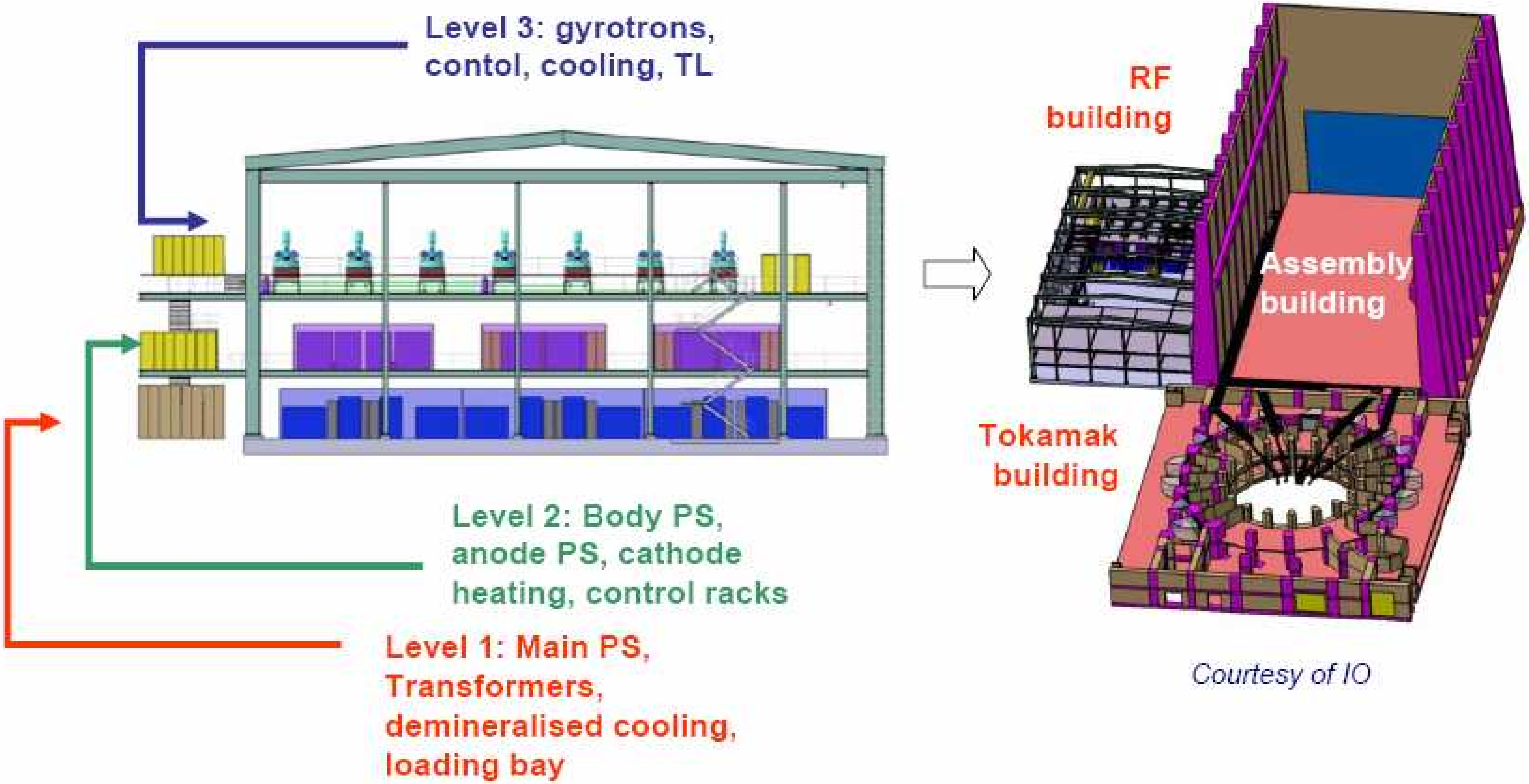
Basic principle: RF power at the millimeter wavelength (electron cyclotron frequency in the ITER magnetic field) is launched into the plasma interacting and directly heating the electrons. The energy is then transferred to the ions by collisions.

	H&CD
Frequency	170 GHZ
EC Power	20 (40) MW

EC H&CD system basic configuration

• 24 gyrotrons of 1 MW, 170 GHZ, CW are needed to inject 20 MW (Note: a 2 MW gyrotron is being developed in Europe)





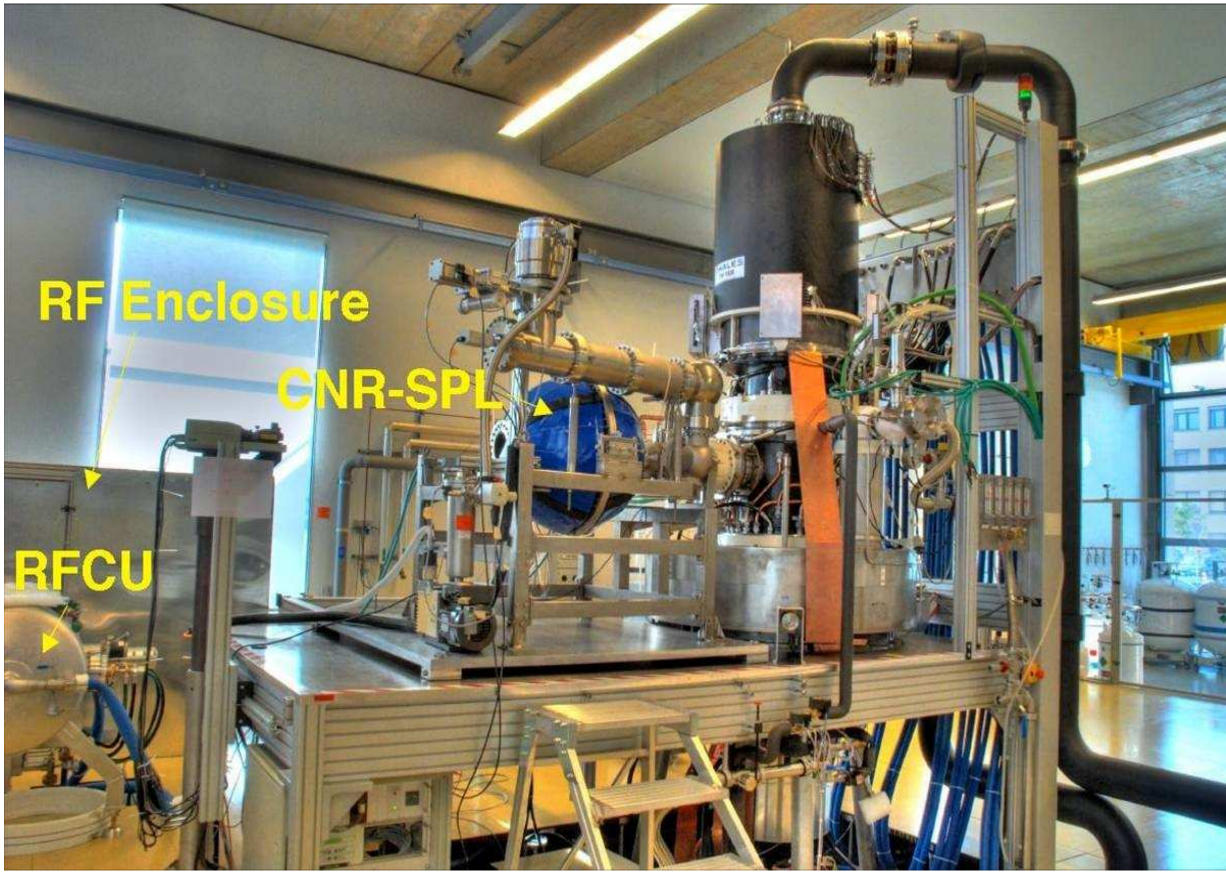
Courtesy of IO

Power Sources (Gyrotrons)

The high power mm-wave is generated by a gyrotron (reference design 1 MW in steady state). An efficiency of ~50 % is possible using a depressed-collector (Collector Potential Depressed – CPD).

As the expected RF power transmission efficiency from a gyrotron is about 80 %, twenty four tubes for 170 GHz are needed to inject 20 MW.

Europe has launched and is carrying out the development of a coaxial cavity 2 MW, 170 GHz gyrotron which will yield some cost reductions in the overall system. Tests of the first prototype are on-going.



EC H&CD Power Supplies

The operation of a CPD gyrotron requires a **main high voltage PS** of about - 60 kV (grounded anode to cathode) and 40 A for (1 MW RF power), while the full acceleration voltage (typically 80 to 90 kV,) is achieved by means of a smaller PS (**Acceleration or Body PS- BPS**, ca 150 mA DC, operating on a mainly capacitive load) also capable of modulating with accuracy its output voltage up to frequencies of, typically, 5 kHz, and therefore capable of providing the current (a few amps peak) on capacitive loads.

Fast switch-off time must be ensured to limit within 10 J the energy deposited in arcs inside the gyrotron

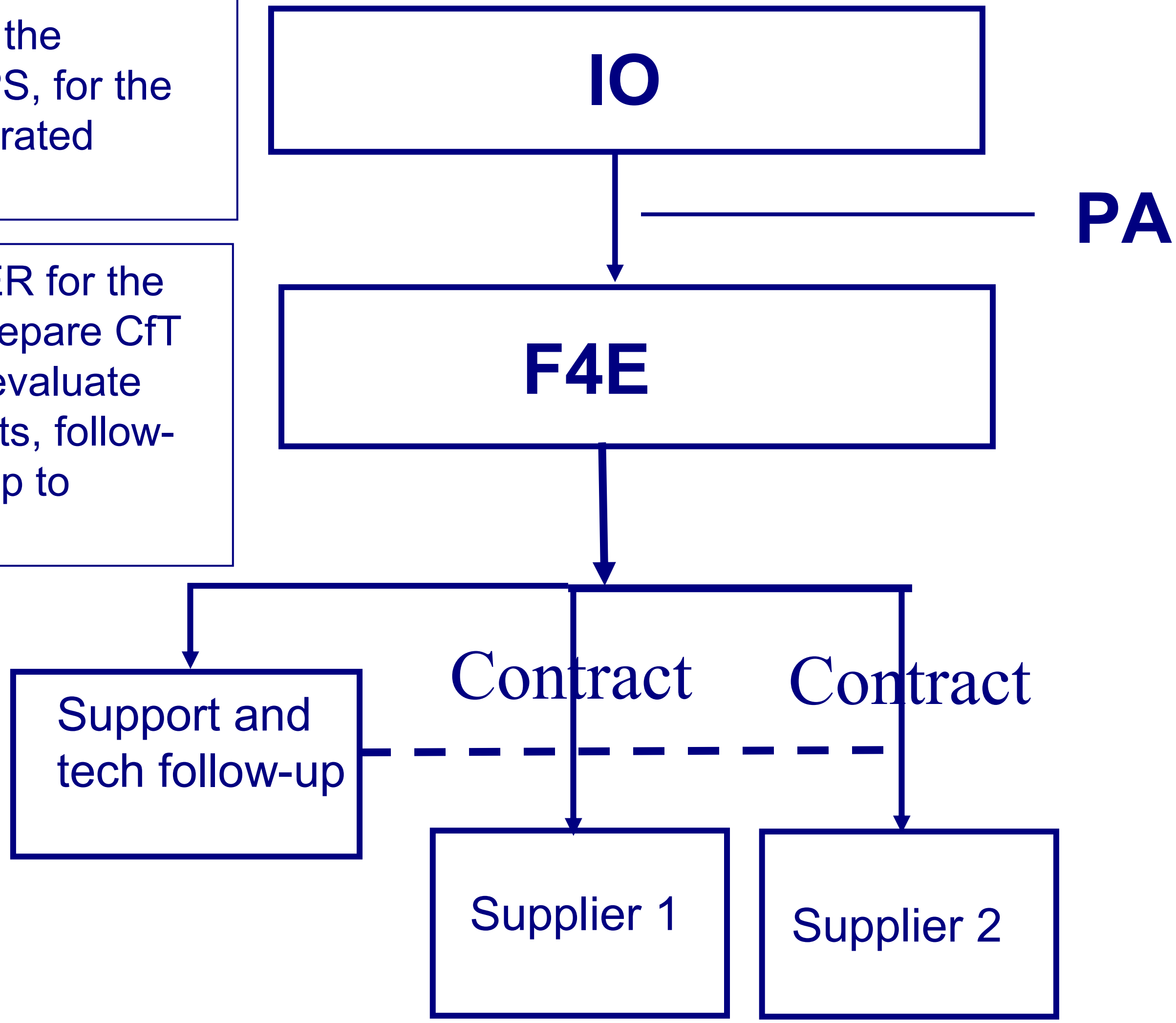
Since the actual procurement specifications for the PS will be "functional" ones, the final PS topology may in fact be subjected to changes.

Europe is responsible for the procurement of all the H&CD EC power supplies

General Organisation of EC PS Procurement process (preliminary)

Responsible for defining the Funct.Specs of the EC PS, for the site integration and integrated commissioning

Responsible towards ITER for the procurement strategy, prepare CfT documents, launch and evaluate tenders, sign the contracts, follow-up, installation, testing up to acceptance



Typical procurement contract includes: design, manufacture, factory testing, transport, installation, site commissioning up to acceptance, for which the Supplier is responsible

Procurement Strategy

The preparation for the procurement of the EC PS is in a more preliminary stage than the one for the NB PS.

On the basis of the ITER project planning, the EC PS Procurement Arrangement is due for signature only in 2011.

The functional specification are being revised by IO in co-operation with F4E.

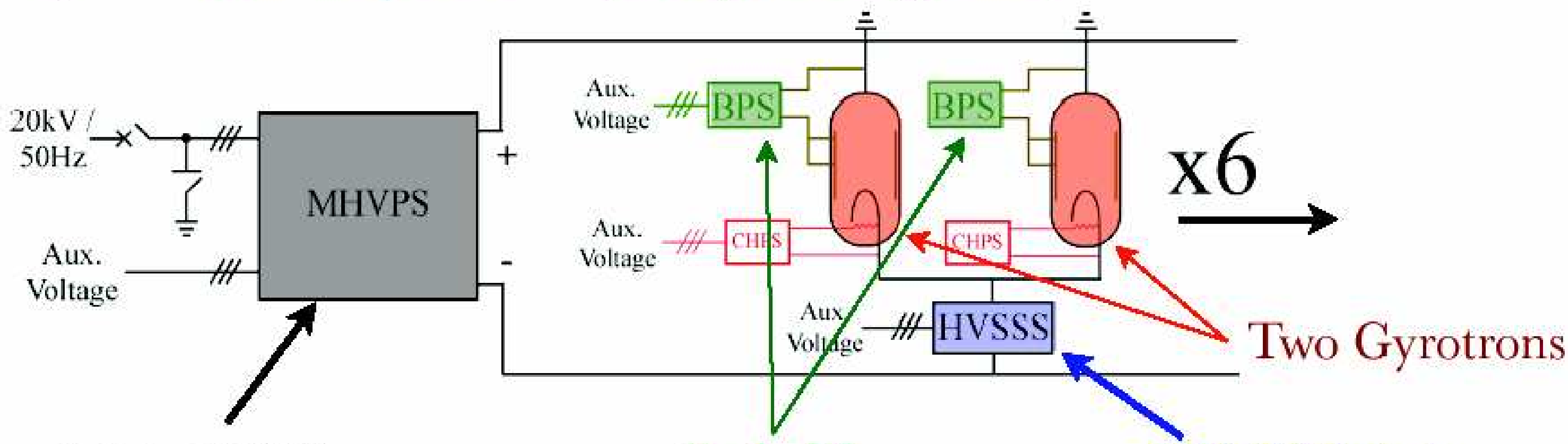
Important issues like modularity and power (to allow for possible enhancements of the gyrotron unit power) are being considered. The final topology can therefore only be defined at a later stage.

The following considerations must therefore be considered as preliminary

H&CD EC PS: ITER Reference Design (2001)

EU provides Power Supplies for the 24 MW H&CD gyrotrons

1) MHVPS: 65 kV, ~500A (1 Main HV PS for 12 gyrotrons)
2) HVSSS: 65kV, ~90A (1 HV SS Switch for 2 gyrotrons)
3) BPS: 40kV, 0.2A (1 Body PS for 1 gyrotron)



Main HVPS
provides main power to gyrotron
thyristor based supplies

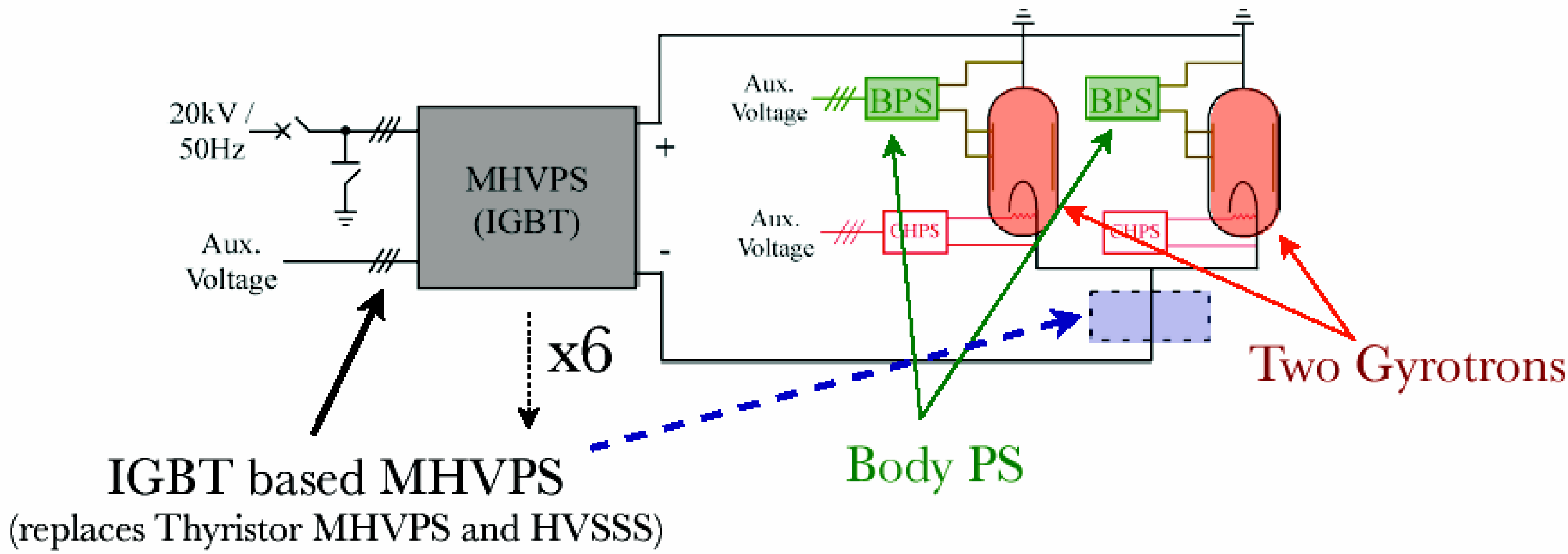
Body PS
de-accelerates electrons
improves efficiency ~50%

HV SS Switch
HV shut down <10μs
P_{RF} modulation

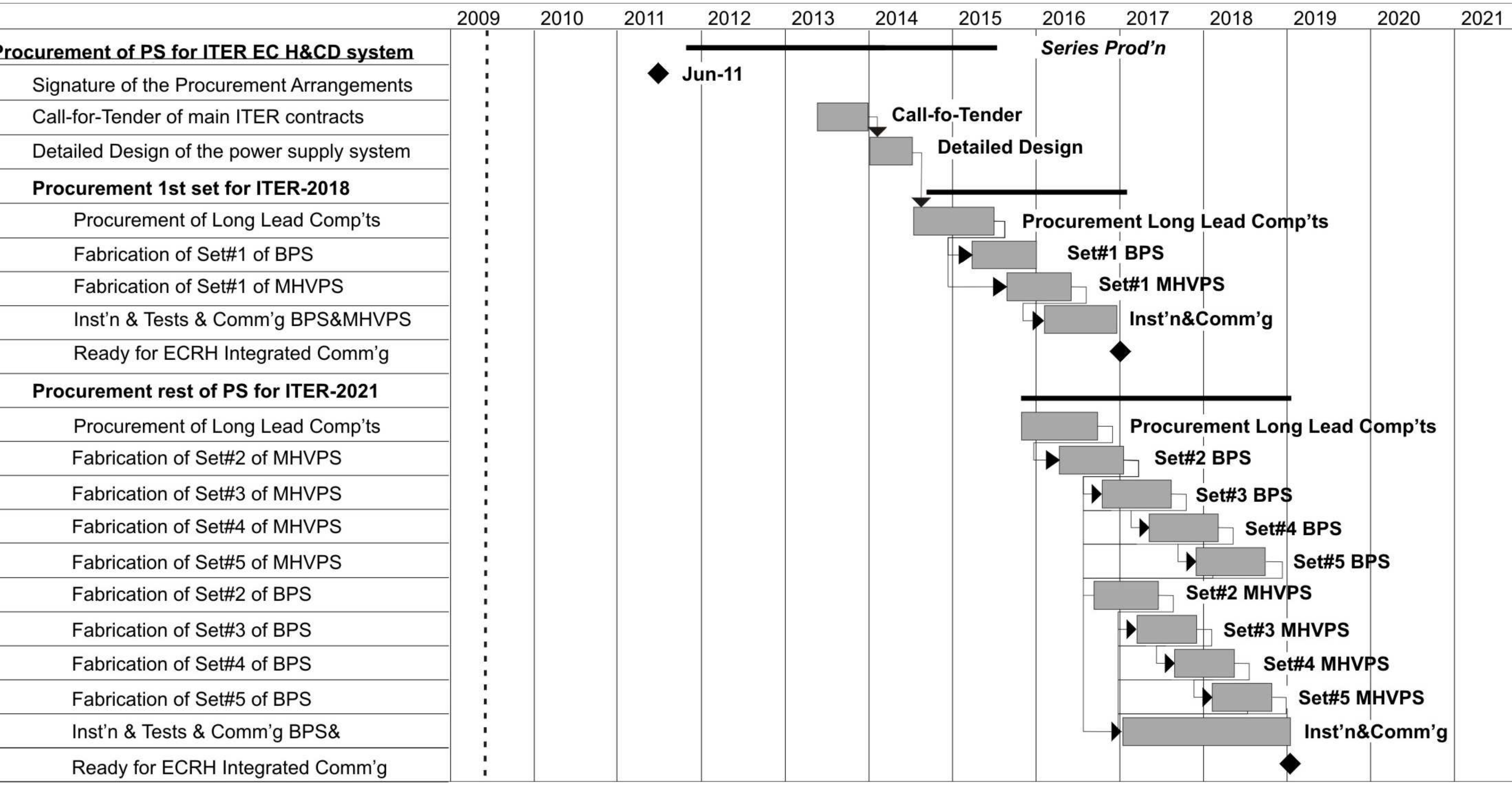
H&CD EC PS: Possible Alternative Scheme – higher modularity and flexibility

EU is studying supplying an IGBT based MHVPS

- Does not require the use of an HVSSS
- Modulation frequency of **~5 kHz** compatible with physics needs
- **Increases capabilities** in modifying **RF power wave form**
- cost aspect under evaluation



H&CD EC PS – Summary Schedule



Conclusions

•The preparation of the first calls for tender of the H&CD NB PS is being completed and the first calls, for units to be installed at the test facilities are expected to be launched before the end of 2009.

•Deliveries are spread over a period of almost ten years

•Components are generally within the EU “standard” capabilities with few identified exceptions for which expertise exist but may require some specific design outside normal practice

•The responsibilities for the fulfilment of the specified performances remain with the industry (Functional specification are issued by F4E).

Good Luck !

THANK YOU