Neutral Beam Power Supplies for ITER:
Calls for Tender planned in 2009, 2010 and beyond

Muriel Simon, H&CD Group, ITER Department

Heating and Current Drive Power Supplies for ITER
Information day 27 May 2009 – Barcelona

Background

Neutral Beam Power Supplies are needed:

- For the ITER experiment in Cadarache, France
- For the Neutral Beam Test Facility in Padua (SPIDER, MITICA)

ITER Site

Padua test Site

In total, it is planned to distribute the overall procurement of the Neutral Beam Power Supplies over 6 procurement contracts:

4 are for procurements covering both the NB Test Facility and ITER injectors

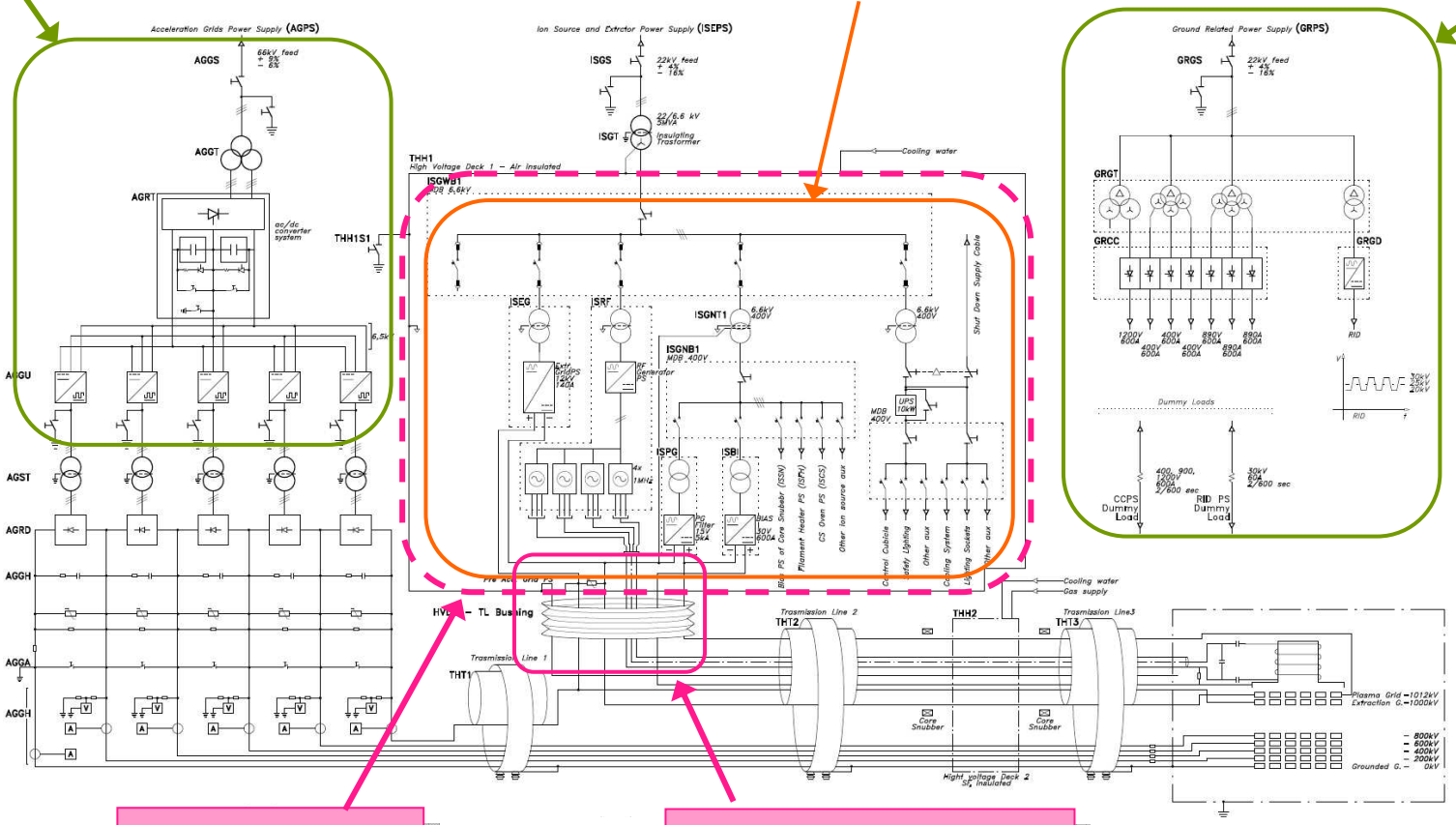
2 are for procurements specific to the NB Test Facility in Padua (SPIDER)

Layout for the 1MV NB Injector

2. Acceleration Grid PS

1. Ion Source and Extraction Power Supplies

2. Ground Related PS

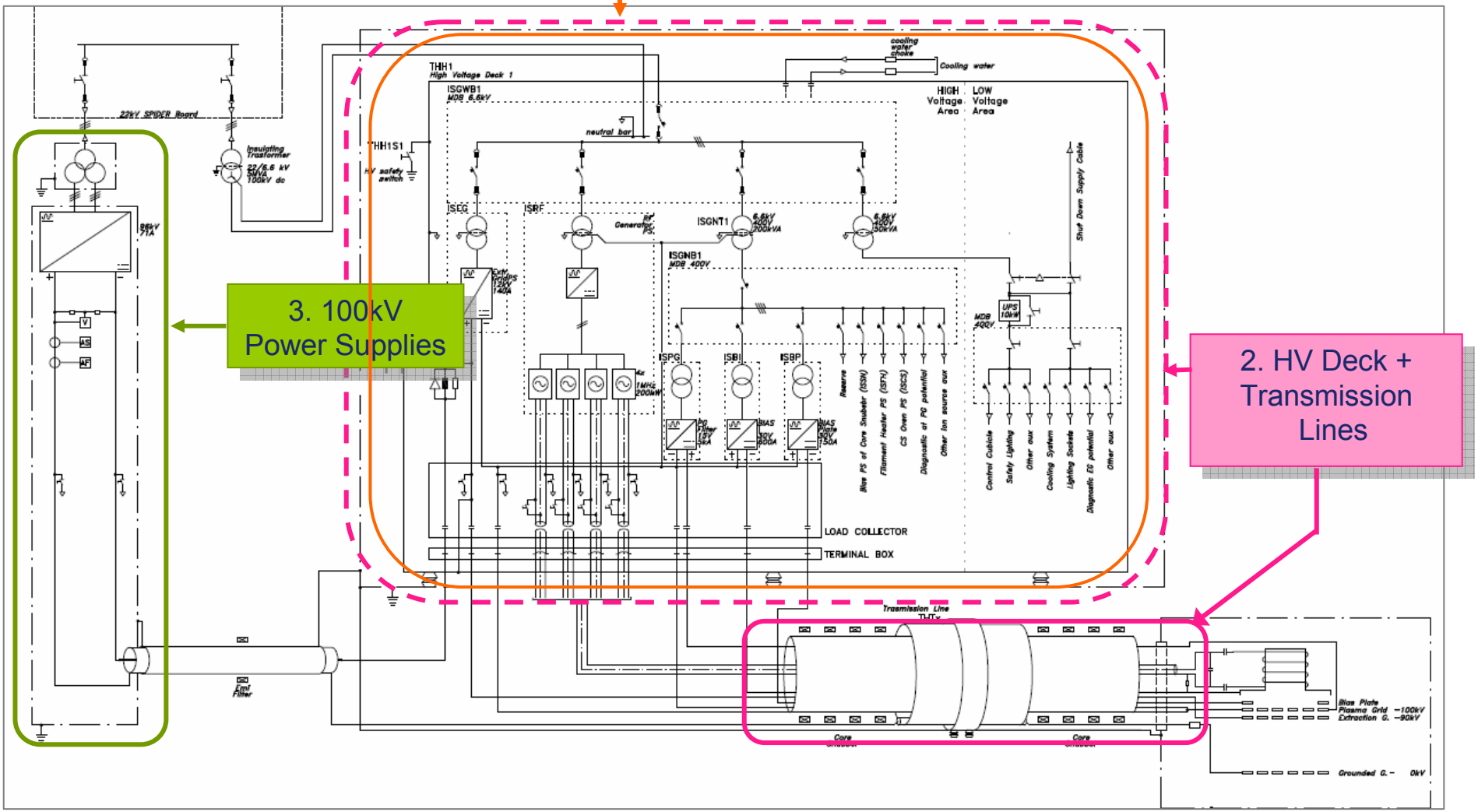


3. HV Deck

3. HVD1-TL Bushing

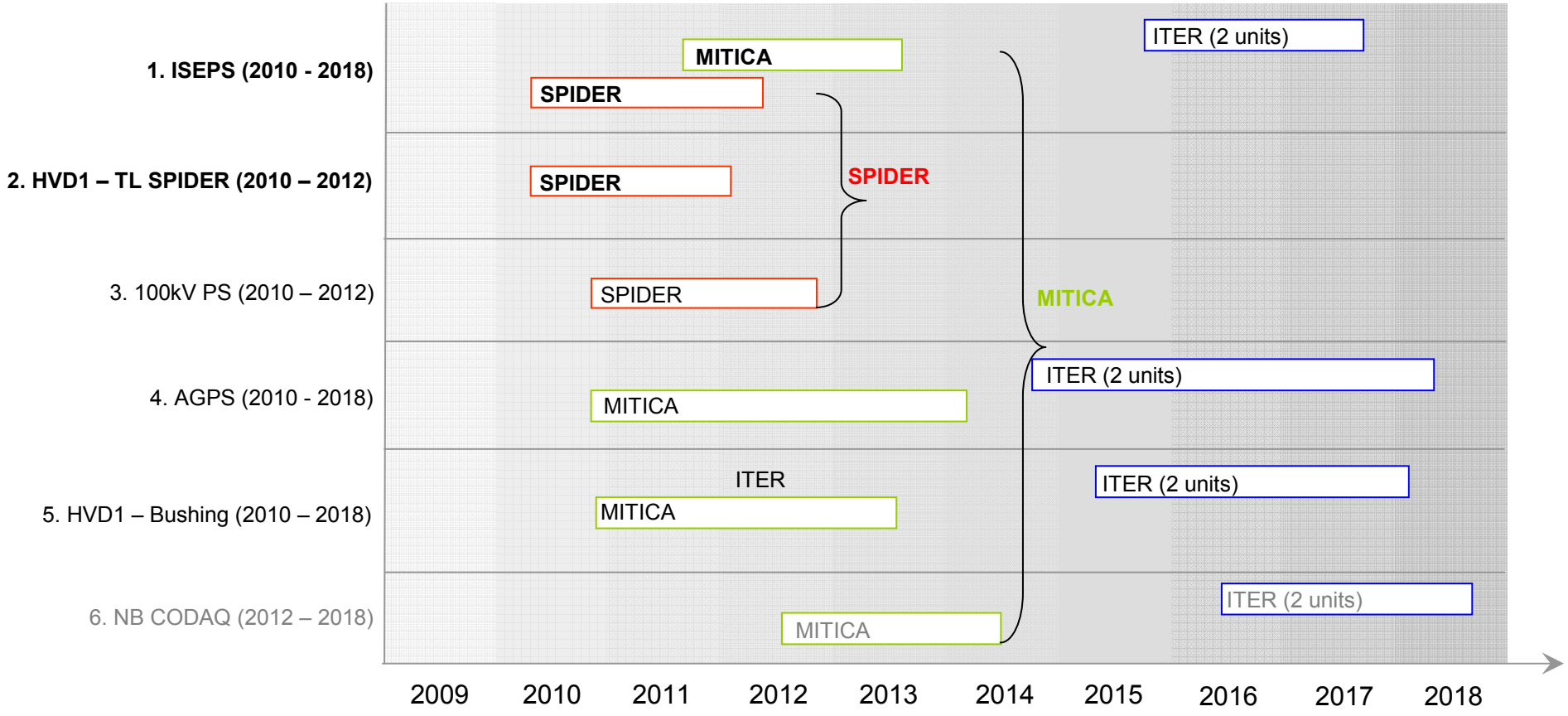
Layout for the 100kV Ion Source

1. Ion **Source and Extraction Power Supplies (// ITER)**



Draft Procurement schedule

One contract per component,
covering both NBTF and ITER sites



⇒ This presentation:

First Calls, mid 2009:

- **Ion Source PS**
- **(100kV HV Deck+TL)**

End 2009, 2010:

- 100kV PS
- (1MV PS + GRPS+ PS Control)
- (1MV HV Deck + Bushing),

Beyond 2010: NB Control

Scope of supply for all PS procurements

1. Detailed Design, up to manufacturing drawings
2. Fabrication
3. Factory testing
4. Transport
5. Installation
6. On-site commissioning and acceptance testing
7. Documentation and Training

FUSION FOR ENERGY

Short-term

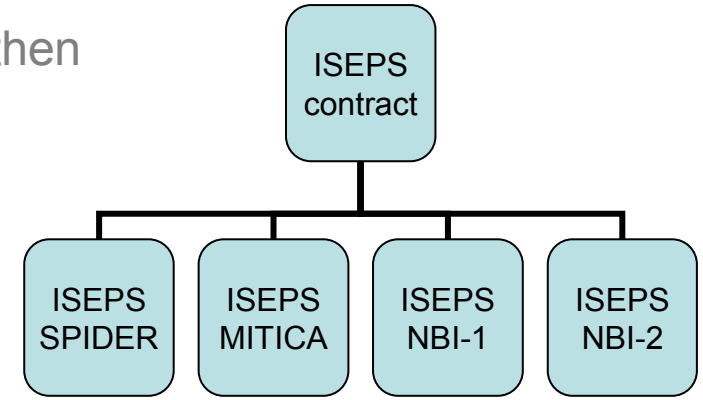
Procurement 1: Ion Source Power Supplies – ISEPS

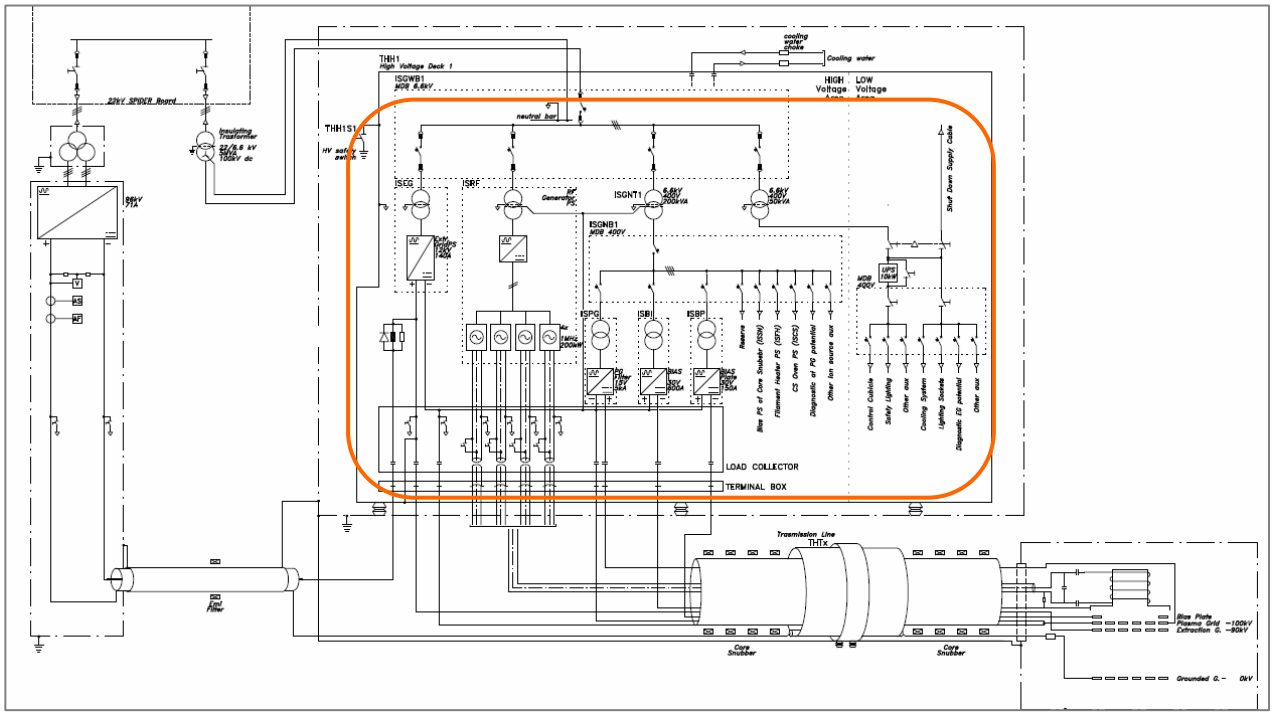
Call for Tender planned Q3 2009

Ion Source and Extraction Power Supplies - ISEPS

First units are for the Test Facility in Padua (SPIDER, then MITICA)

- Additional units needed later for ITER Site in France (NBI-1, NBI-2)
- In total, 4 units needed





ISEPS operating conditions

	SPIDER	MITICA	ITER HNB
Maximum pulse duration	3600 s	=	=
Duty cycle	1 shot/10 min for pulse duration <150 s 25% for pulse duration >150 s	=	=
Modulation required	Yes (5Hz for 3 sec every 20 sec)	No	No

Pulse duty

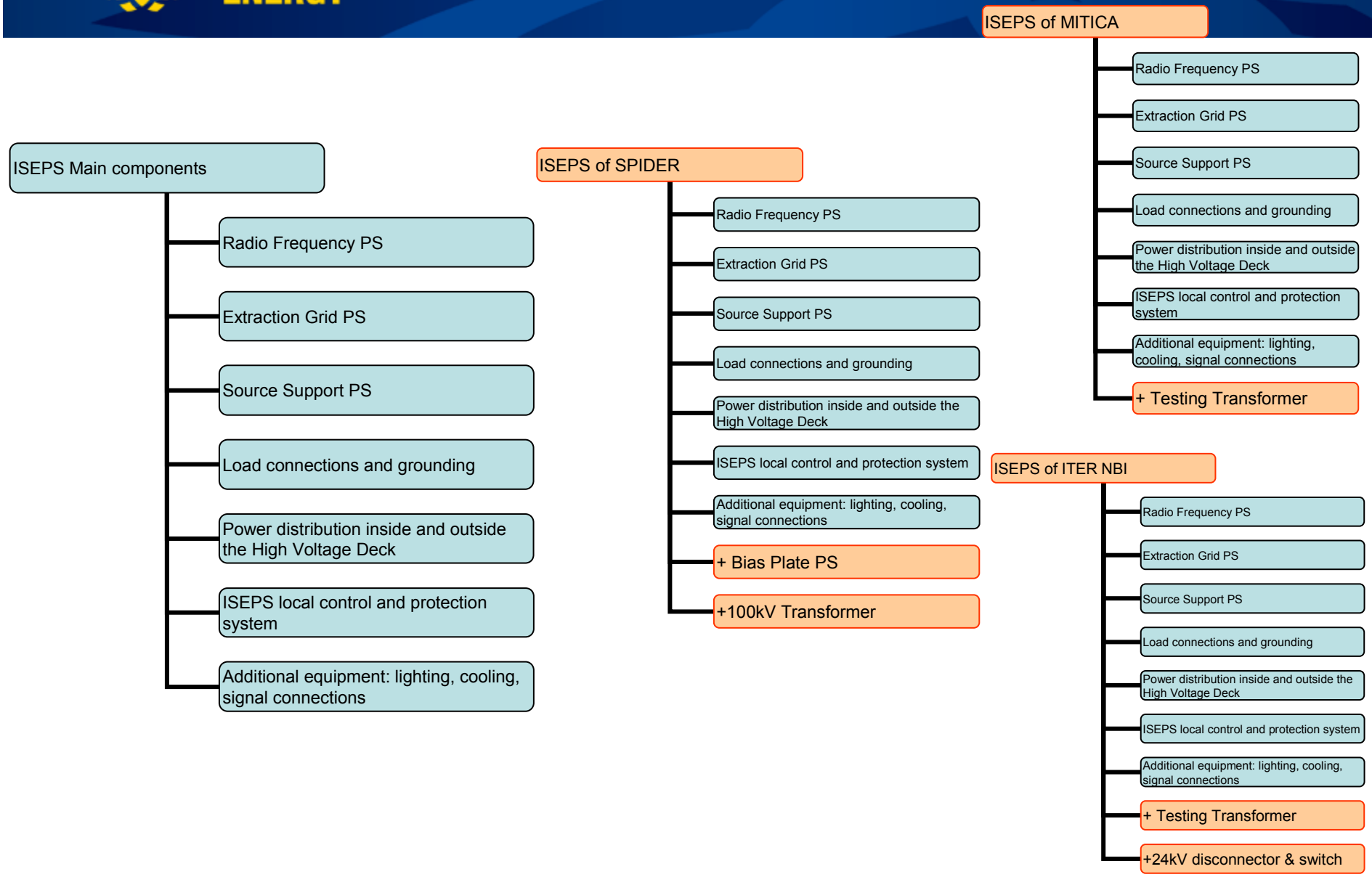
Total number of pulses	50,000
Total beam on time	1.98×10^7s
Total number of breakdowns	450,000

ITER Operational life

Parameter	*Value*
Maximum detection time	50 μs
Maximum switch-off time	100 μs
Time to be ready for restart after a BD	20 ms
Maximum number of BD for a single pulse	200 total (in 1 hour) 50 consecutive

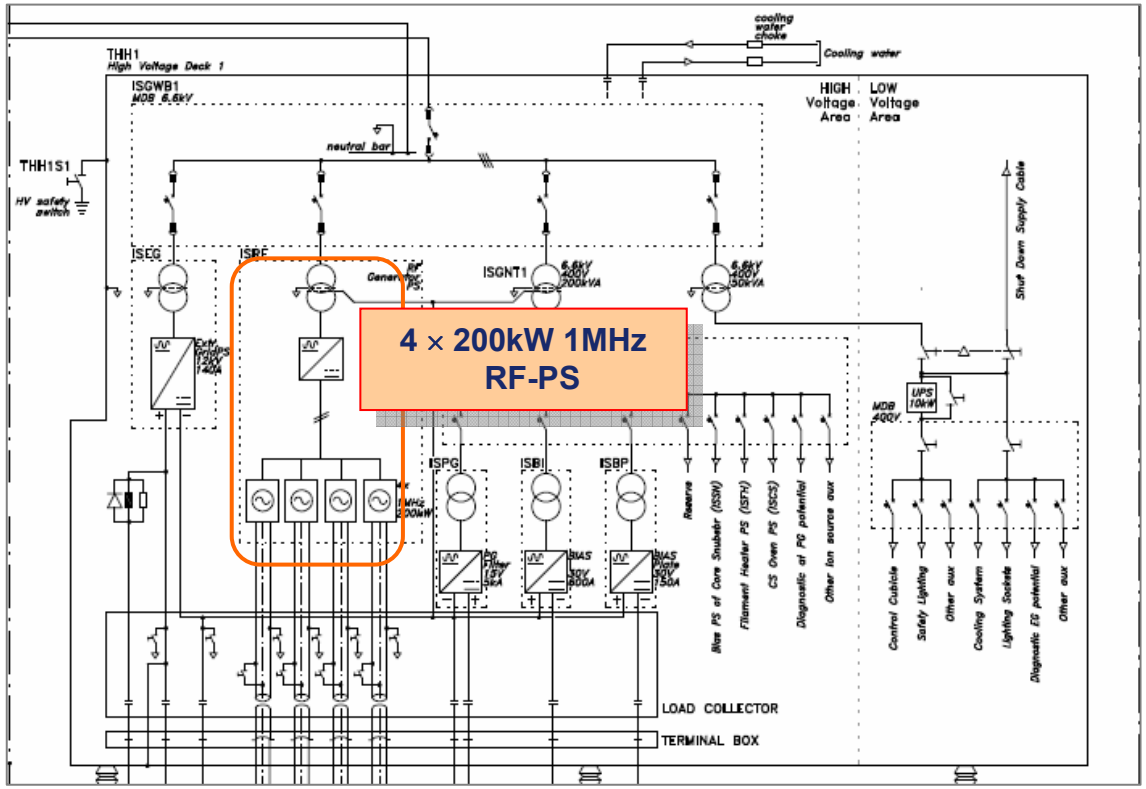
Grid breakdowns

ISEPS – Main components

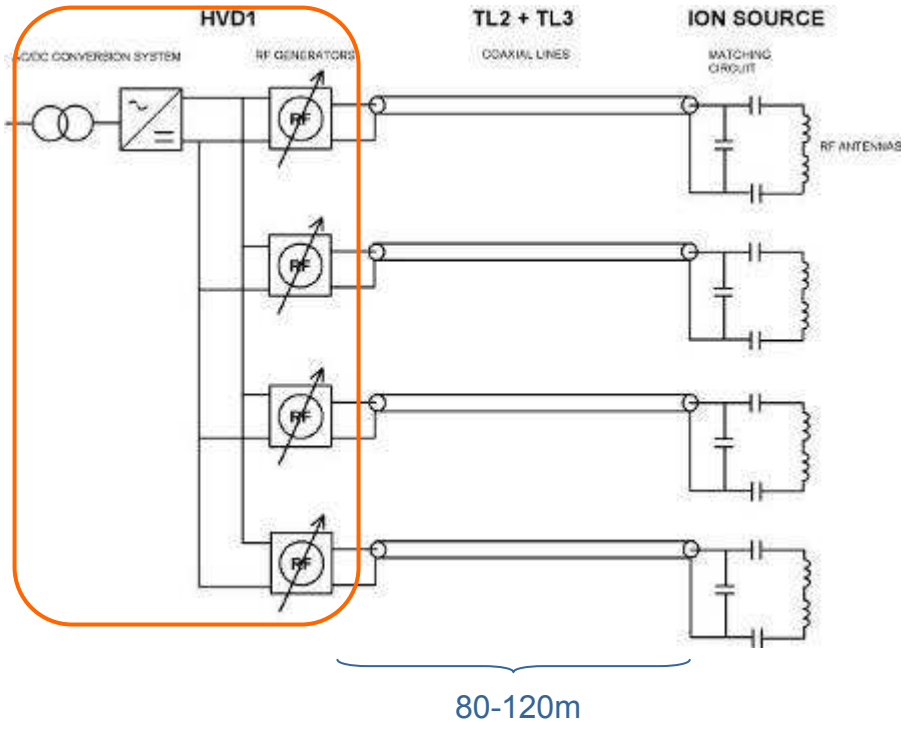


ISEPS – Main components

- ISEPS Main components
  - **Radio Frequency PS**
  - Extraction Grid PS
  - Source Support PS
  - Load connections and grounding
  - Power distribution inside and outside the High Voltage Deck
  - ISEPS local control and protection system
  - Additional equipment: lighting, cooling, signal connections



Radio Frequency PS



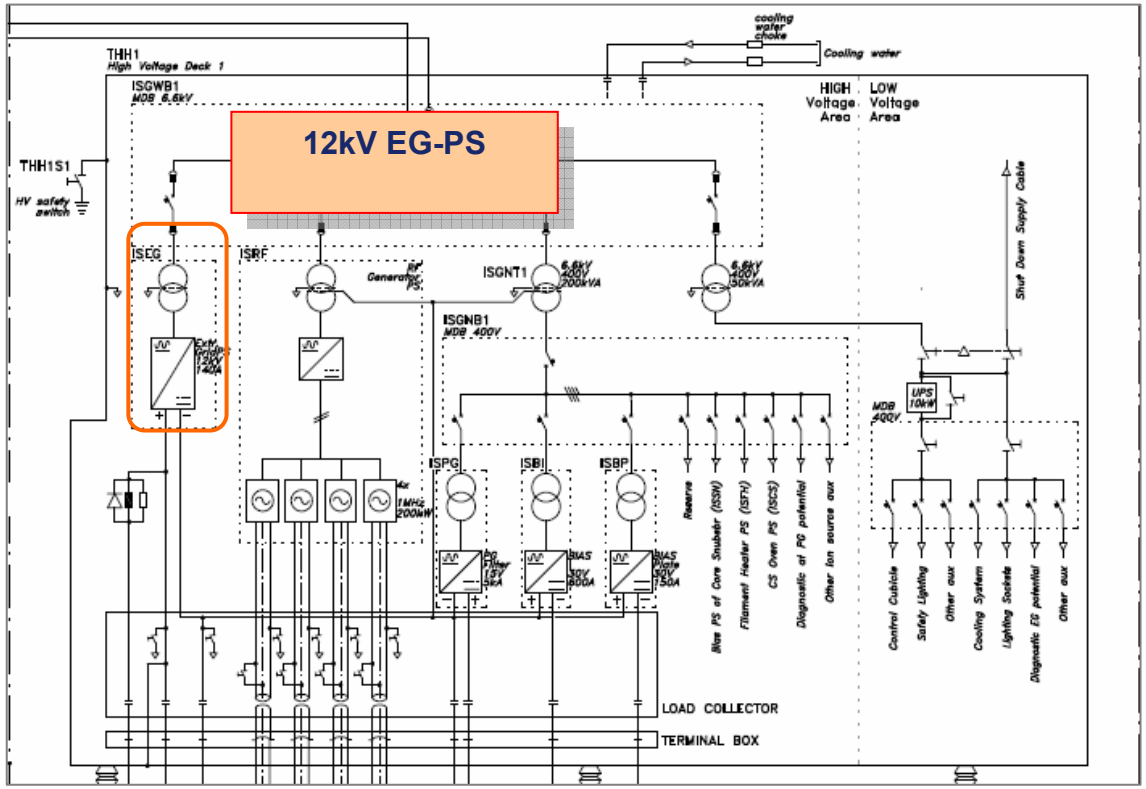
Number of generators	4
Active power to the load	200 kW (50 Ω load impedance)
Output Power Range	10 – 100 %
Working frequency	(1 ± 0.1) MHz
Frequency accuracy	± 1 kHz
Rise Time to rated power	< 0.3 ms
Decay time from rated power to notch value	< 0.3 ms
Efficiency at full power	> 50 %
Type of duty	Cw
Quantity to be controlled	Output Power
Total harmonic distortion of RF output	< 1% at full power on 50 Ω load

Two different technological solutions identified for the RF generators:

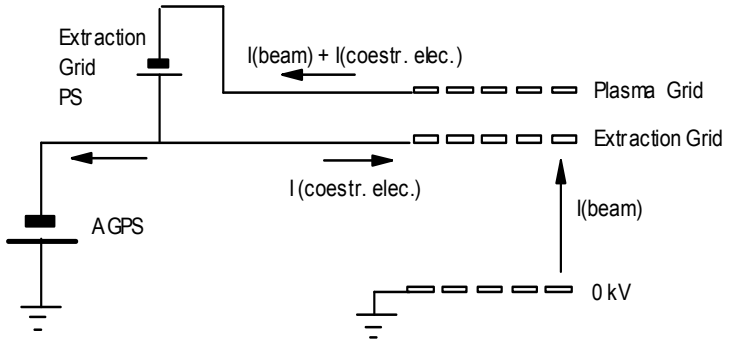
- Oscillator (tetrodes)
- Solid state amplifier (MOSFETs)

ISEPS – Main components

- ISEPS Main components
  - Radio Frequency PS
  - **Extraction Grid PS**
  - Source Support PS
  - Load connections and grounding
  - Power distribution inside and outside the High Voltage Deck
  - ISEPS local control and protection system
  - Additional equipment: lighting, cooling, signal connections



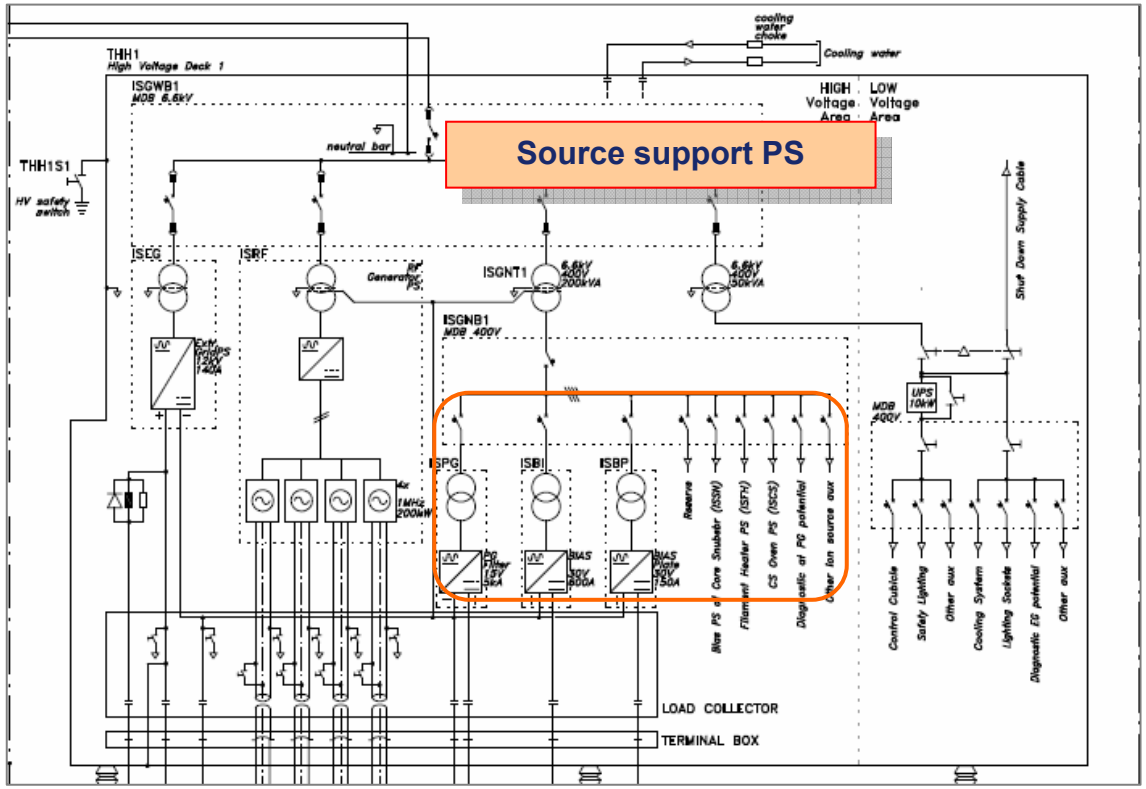
ISEPS main specifications - EGPS



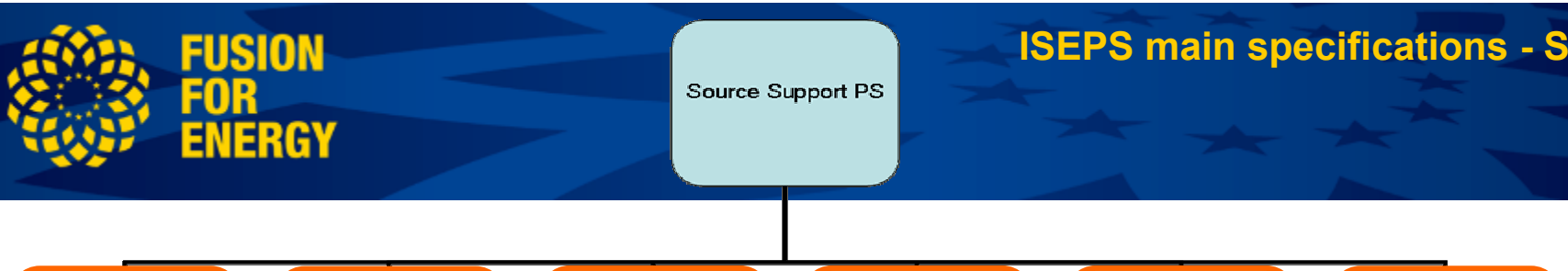
	Ratings
Output voltage	-12 kV dc
Output voltage range	0 – 100%
Output voltage resolution	100 V
Rated output current	140 A
Maximum switch-off time	100 μs
Energy onto breakdown	10J
Time to be ready after a BD	20 ms
Quantity to be controlled	Voltage
Efficiency at full power	> 80%

ISEPS – Main components

- ISEPS Main components
  - Radio Frequency PS
  - Extraction Grid PS
  - **Source Support PS**
  - Load connections and grounding
  - Power distribution inside and outside the High Voltage Deck
  - ISEPS local control and protection system
  - Additional equipment: lighting, cooling, signal connections



ISEPS main specifications - SSPS



	Ratings required at the power supply
Rated output power	75 kW
Output voltage	15 V
Output current	5 kA
Output current range	0 – 100%
Current accuracy	1%

	Ratings required at the power supply
Output voltage	0 - 30 V
Output voltage resolution	0.1 V
Rated output current	150 A
Voltage accuracy	5 %
Quantity to be controlled	Voltage / Current

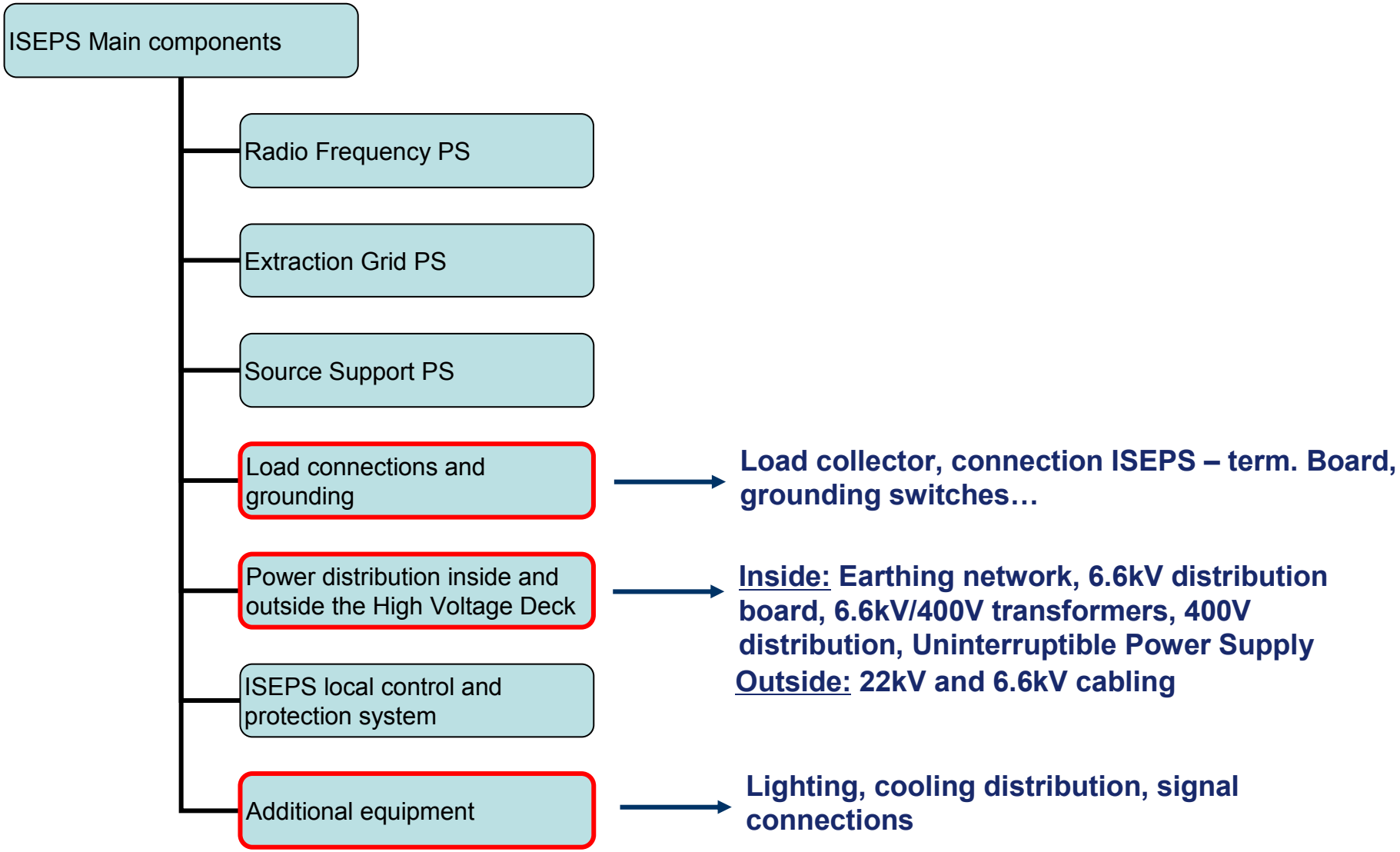
	Ratings required at the power supply
Number of units	3
Total Power	3 x 400 W
Type of supply	220 - 240V ac 50Hz

	Ratings required at the power supply
Rated output power	18 kW
Output voltage	0 - 30 V
Output current	0 - 600 A
Voltage accuracy	1 %
Current accuracy	1 %
Quantity to be controlled	Voltage / Current

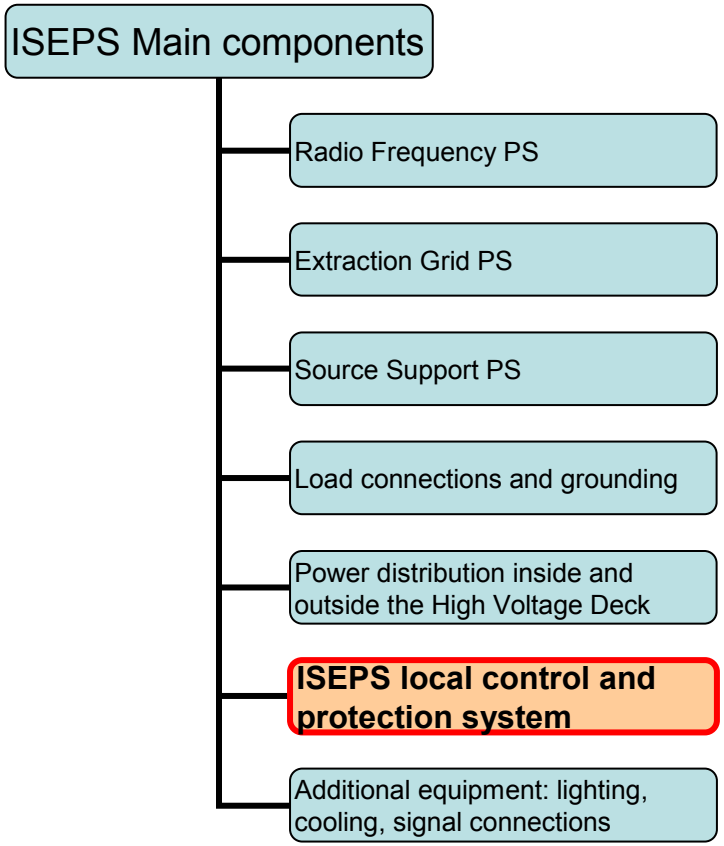
Number of filaments 8	Ratings required at the power supply
Power	1200 W
Type of output	ac 50Hz
Output voltage	20 V
Output current	60 A

	Ratings required at the power supply
Number of units	2
Output Current	140 A
Output Voltage	50 V
Quantity to be controlled	current
Current accuracy	1 %
Max peak to peak current ripple	1 %

ISEPS – Main components



ISEPS – Main components

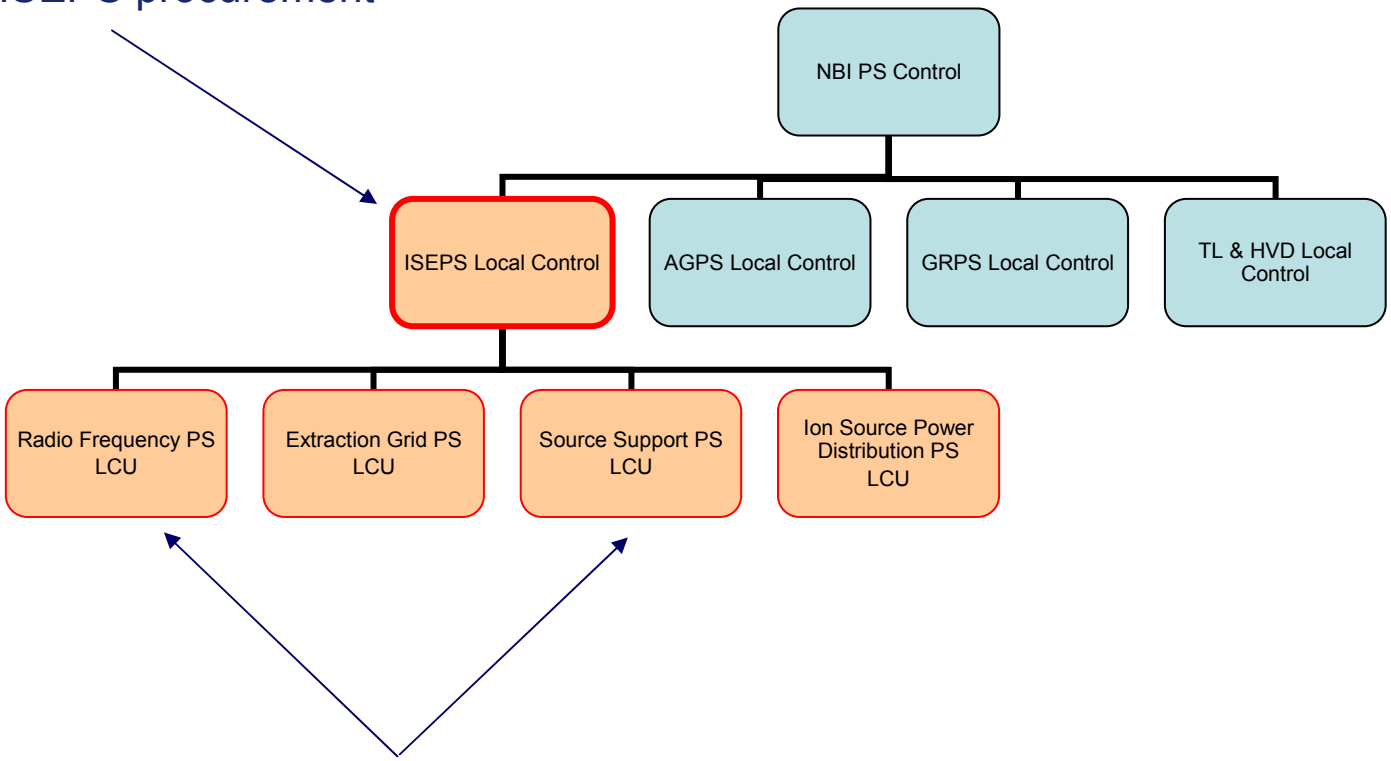


FUNCTIONS:

- Set-up parameters for the operation of the ISEPS and ensure correct operation during normal operation and during commissioning
- Allow local operation of ISEPS
- Provide monitoring, protection, interlocking, alarm handling, alarm logging, data collection and signal conditioning
- Exchange data and signals with NBI Plant Control System
- Exchange information with NBI Plant Interlock System
- Display status of all control and protective devices of ISEPS

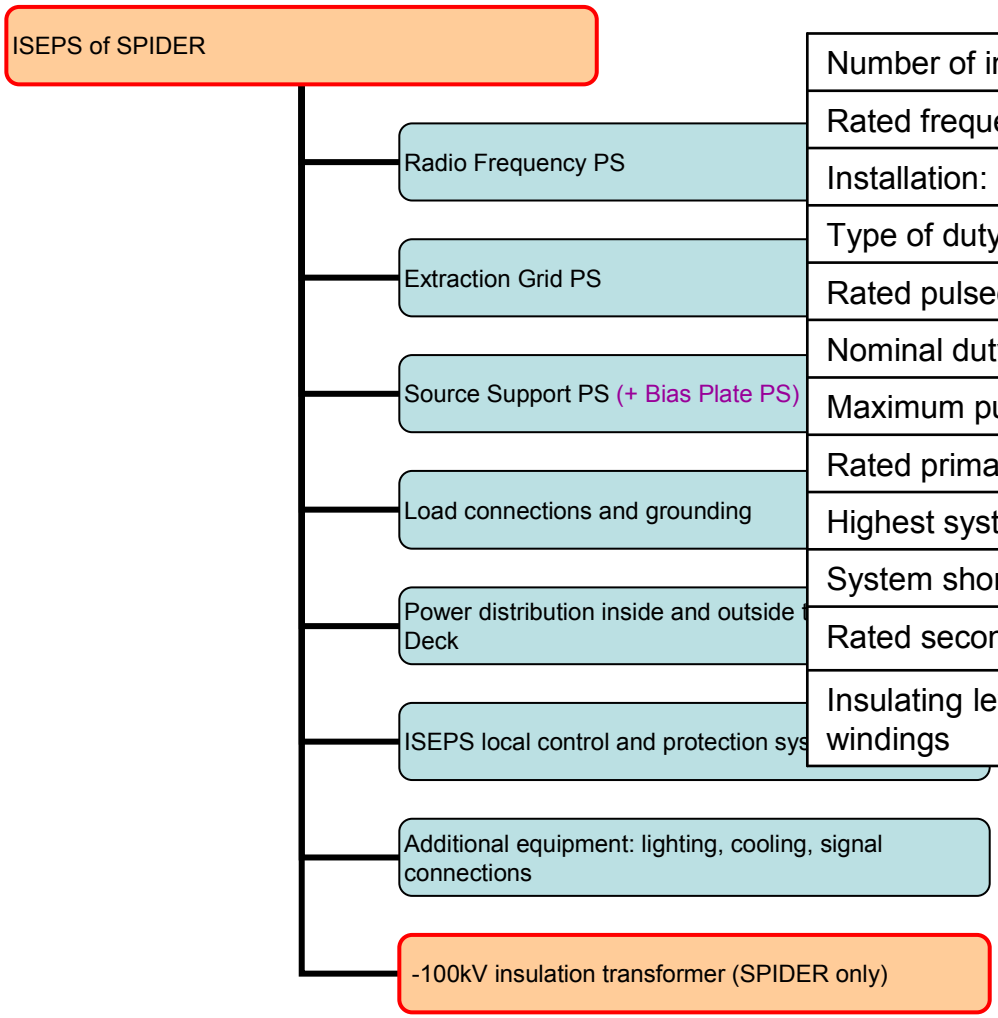
ISEPS main specifications – control & protection

All within ISEPS procurement



Individual Local Control Units

ISEPS main specifications – 100kV transformer



Number of input and output phases:	3
Rated frequency:	50 Hz
Installation:	outdoor
Type of duty:	pulsed
Rated pulsed power:	5 MVA
Nominal duty cycle at the rated pulsed power:	25% ON / 75% OFF
Maximum pulse duration:	3600 s
Rated primary voltage:	22 kV rms
Highest system voltage:	24 kV rms
System short circuit power:	0.85 GVA
Rated secondary voltage:	6.6 kV rms
Insulating level between primary and secondary windings	-100kV dc

Summary procurement 1: Ion Source and Extraction Power Supplies, 4 units needed

	SPIDER	MITICA	IHNB1	IHNB2
24 kV disconnector and earthing switch			✓	✓
Radio Frequency PS (RFPS)	✓	✓	✓	✓
Extraction Grid PS (EGPS)	✓	✓	✓	✓
Source Support PS (Plasma Grid, Bias, Starter Filament, Caesium Oven, Core snubber Bias)	✓	✓	✓	✓
Bias Plate PS (BPPS) and associated dummy load	✓			
Load connections and grounding	✓	✓	✓	✓
Power distribution inside and outside the HV Deck	✓	✓	✓	✓
ISEPS Local Control and Protection Systems	✓	✓	✓	✓
Additional equipment (lighting, cooling, signal connections)	✓	✓	✓	✓
100 kV Insulation Transformer	✓			
Dummy Loads	✓	✓	✓	✓
ISEPS Testing Transformer		✓	✓	
Special equipment necessary for the operation and maintenance	✓	✓	✓	✓

FUSION FOR ENERGY

Short-term

Procurement 2: High Voltage Deck and Transmission Lines for SPIDER

Call for Tender planned Q3 2009

Scope of supply – main components

The main components of this procurement are:

1. The Transmission Line, which has to connect the Ion Source and Extraction Grid Power Supplies (ISEPS) located inside the High Voltage Deck to the Ion Source and to transmit the electrical power for the beam acceleration;
2. The High Voltage Deck, which is the insulated platform hosting all the equipment forming the ISEPS;
3. Additional equipment including the Terminal Board, the insulated platform, the catwalk, an electrical-EMI screening, insulated tubes for cooling water supply and insulating support for Fiber Optic.

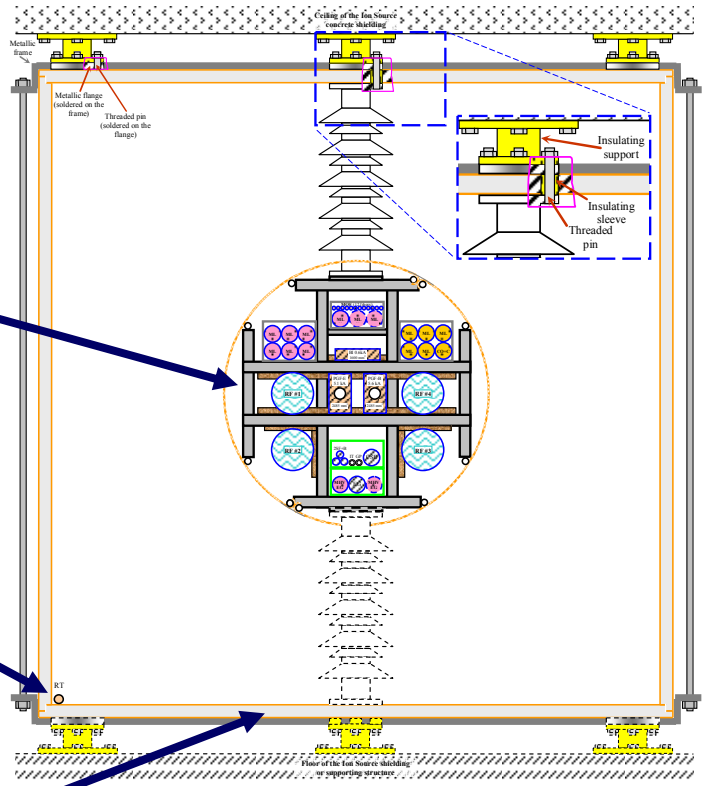
Again, the supply includes the Detailed Design, the Fabrication and factory testing, the transport, delivery and installation on site, the commissioning and acceptance testing on-site and the associated documentation an training.

1. The Transmission line

Inner conductor: cylindrical High Voltage electrostatic Screen (HVS) of 500mm diameter containing ISEPS power and measurement-control conductors coming from the HVD. The screen is polarized at the negative electric potential resulting from composition of AGPS and EGPS voltages; on the external screen surface core snubber rings are uniformly distributed along the line length.

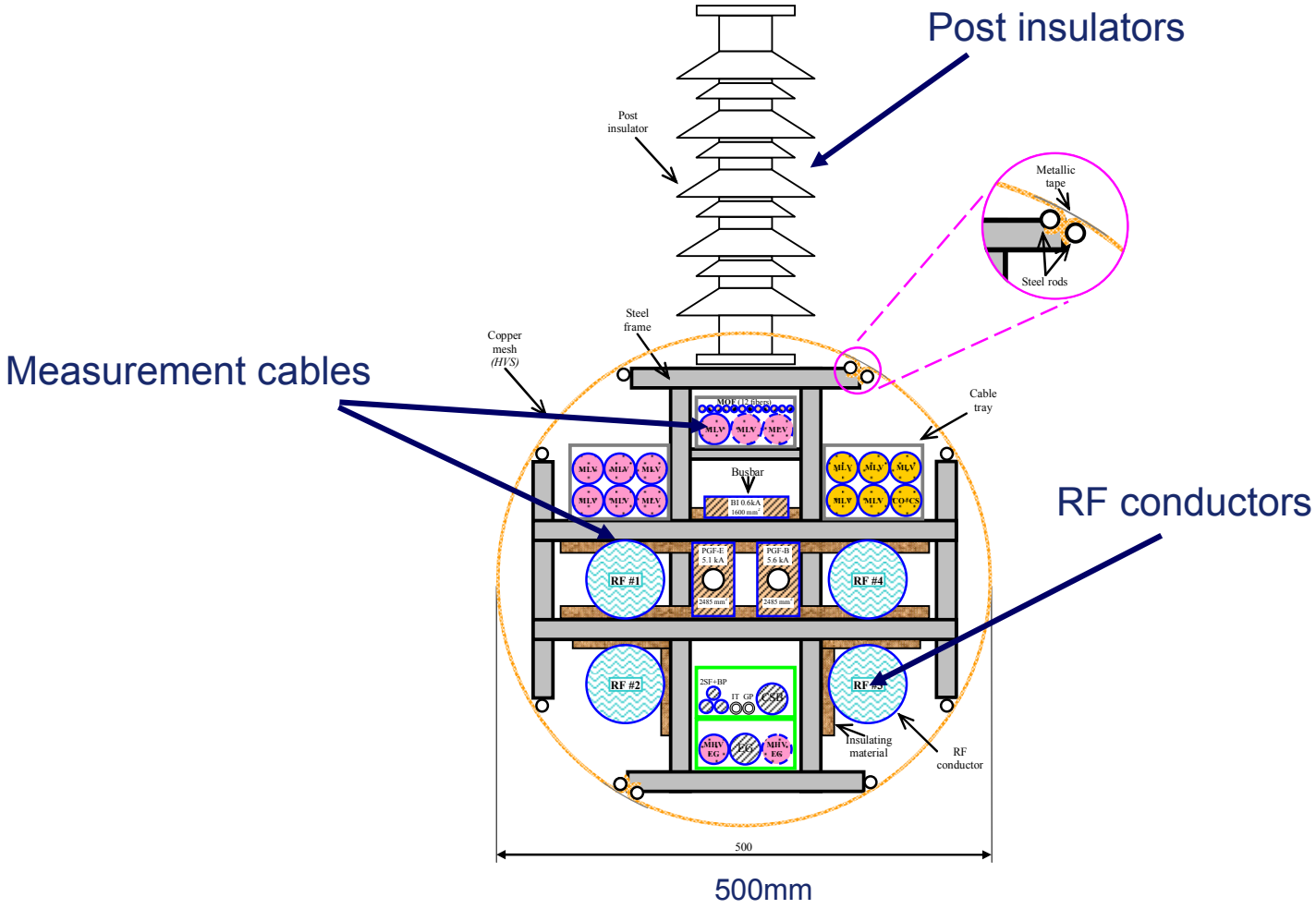
Conductor (RT conductor) which returns the accelerator current from the Grounded Grid towards the AGPS;

External conductor: double screening against Electro Magnetic Interferences (EMI) consisting in two metallic sheets separated by an insulating layer.



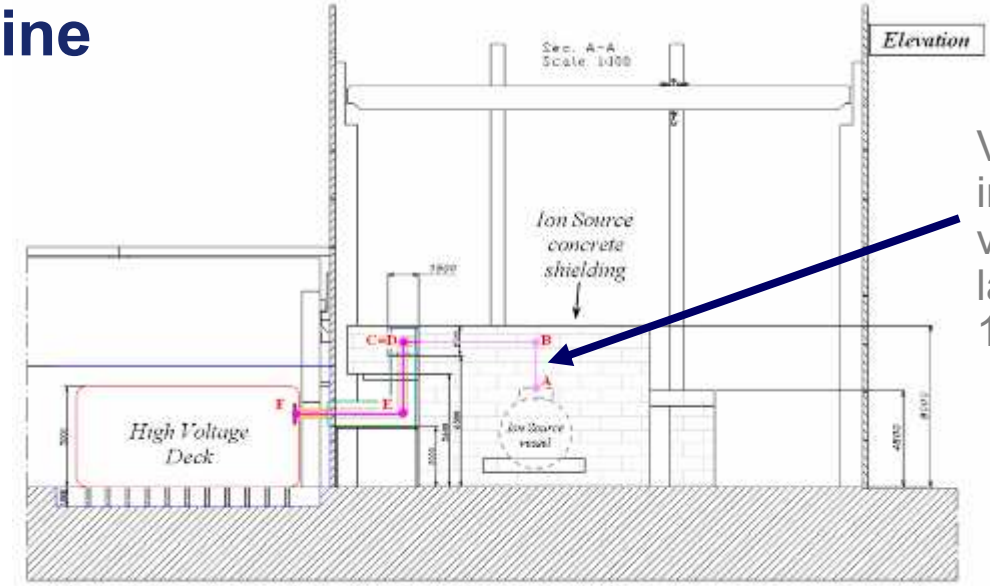
(Design for reference only)

TL Inner conductor

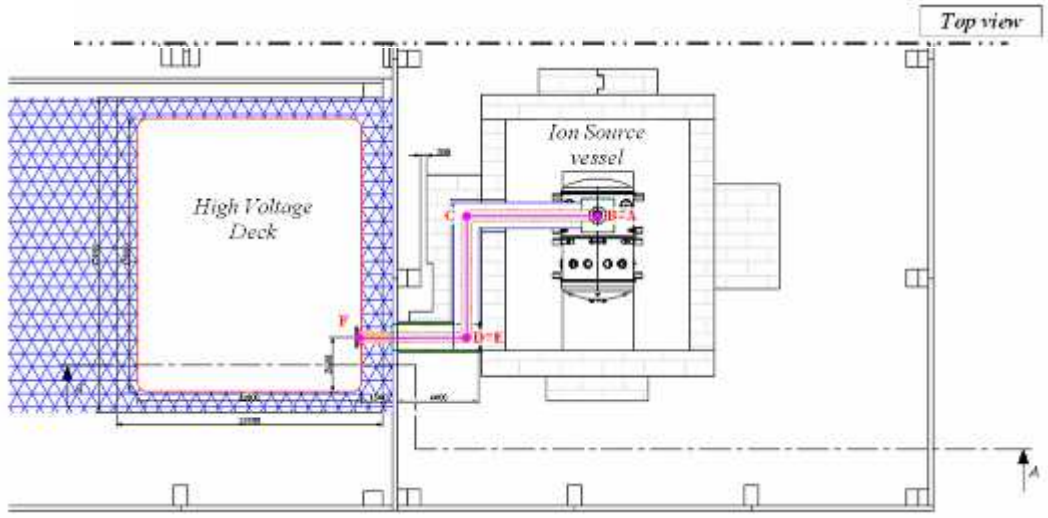


Transmission line routing

5 sections between the HV deck and the Source.



Vertical section interfaced with the vessel presents the largest cross-section 1.6m



2. High Voltage Deck

The High Voltage Deck (HVD) is an air insulated box, polarized at -100kVdc /ground.

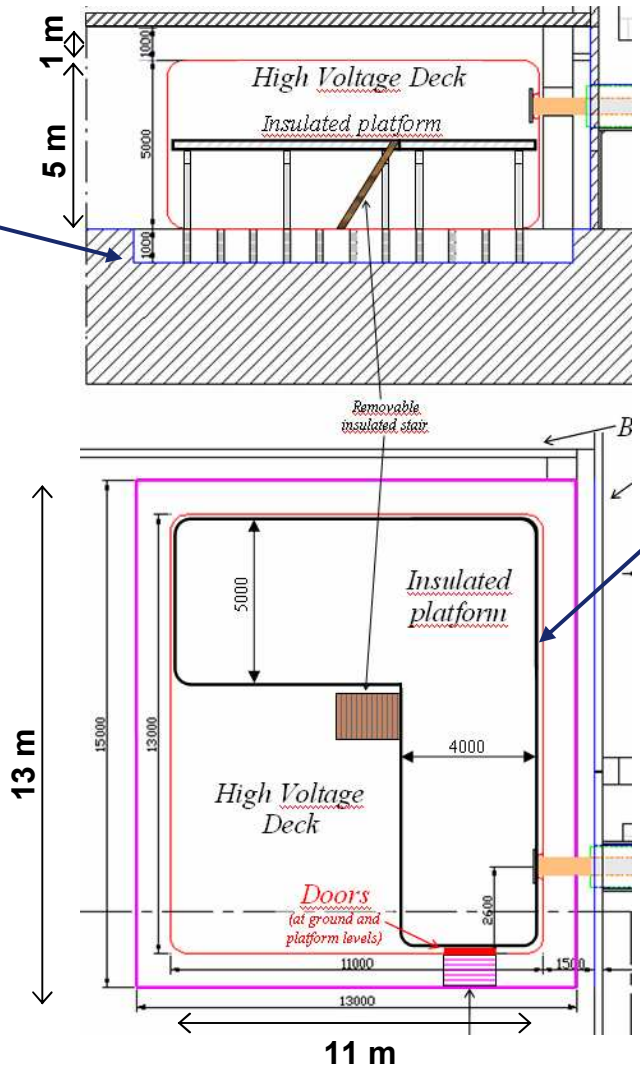
It contains all devices forming the ISEPS (such as transformers, power and control cubicles), the related diagnostics and also all the auxiliary equipment (lighting, low voltage AC distribution, ventilation system and water cooling circuits).

During operation the HVD is fed by an insulation transformer which provides main AC power supply via a 3-phase plus neutral insulated (100kV) cables routing.

In order to comply with the required insulation level, the overall HVD structure load has to be sustained by means of insulating supports with a dry arc height of 1m, in order to withstand steady state and transient voltage associated to accelerator grids breakdown events. The same clearance must be assured all around HVD structure.

HV Deck - Dimensions and load

HVD dimensions: 13m (L) x 11m (W) x 5m (H).
clearance to the roof ≥ 1 m.



1m pit

Total equipment load estimated at ~35 tons

Average per unit weight of 250 kg/m2 (Maximum load ~ 750kg/m2 locally)

Insulated platform

Estimated equipment load ~8 tons.

Accessible from outside by an insulated stair.

Accessible inside HVD from ground plan by means of a removable insulated backstairs.

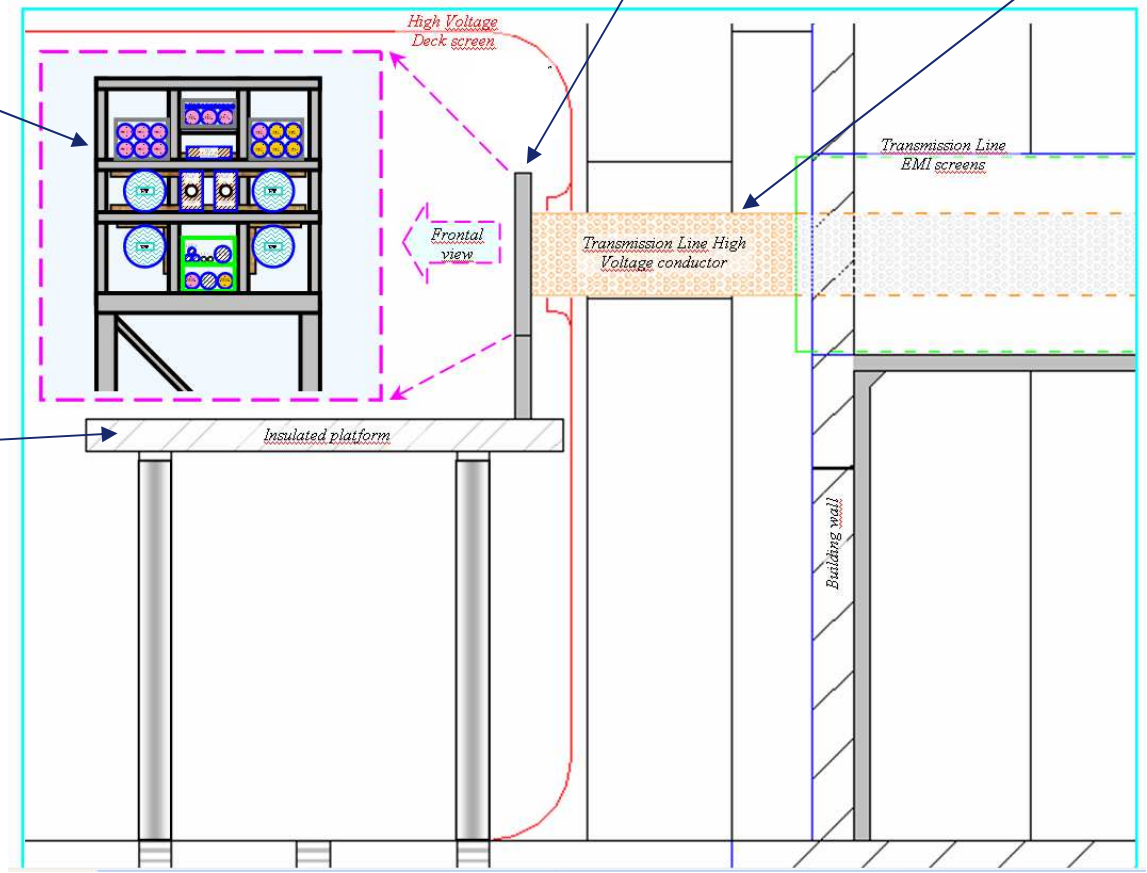
Interface HV Deck - TL

Terminal board

Only the inner conductor enters the HV Deck

Ion Source PS connections

Insulated support



FUSION FOR ENERGY

Medium-Term

Procurement 3: 100kV Power Supplies for SPIDER

Call for Tender planned Q4 2009

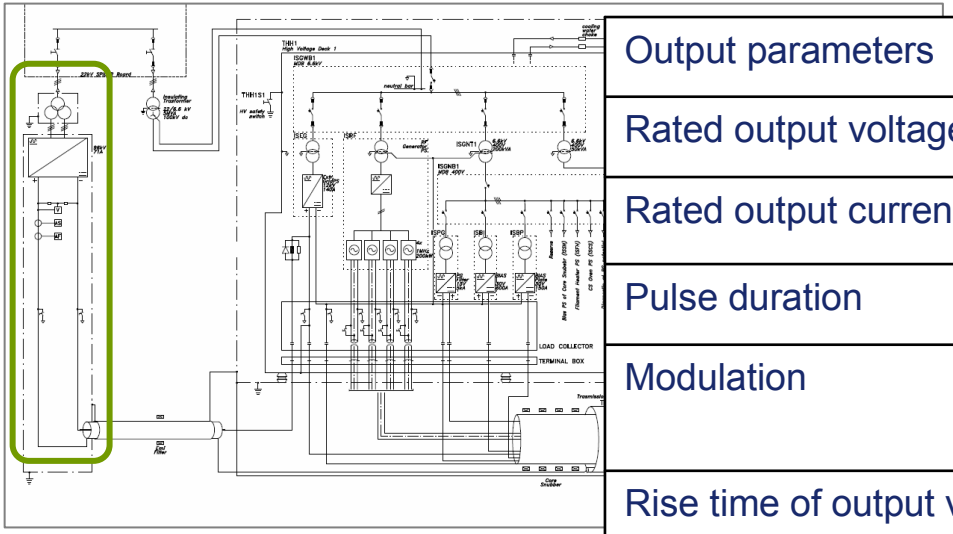
Scope of supply – main components

The main functions of the HV Power Supply unit is to supply, with the specified voltage regulation and control, the high voltage DC electrical power required for operation of SPIDER Ion source.

Specifications very similar to the PS procured by the Indian Domestic Agency for the Diagnostic Neutral Beam

The supply includes the Detailed Design, the Fabrication and factory testing, the transport, delivery and installation on site, the commissioning and acceptance testing on-site and the associated documentation an training.

100kV PS Preliminary specifications

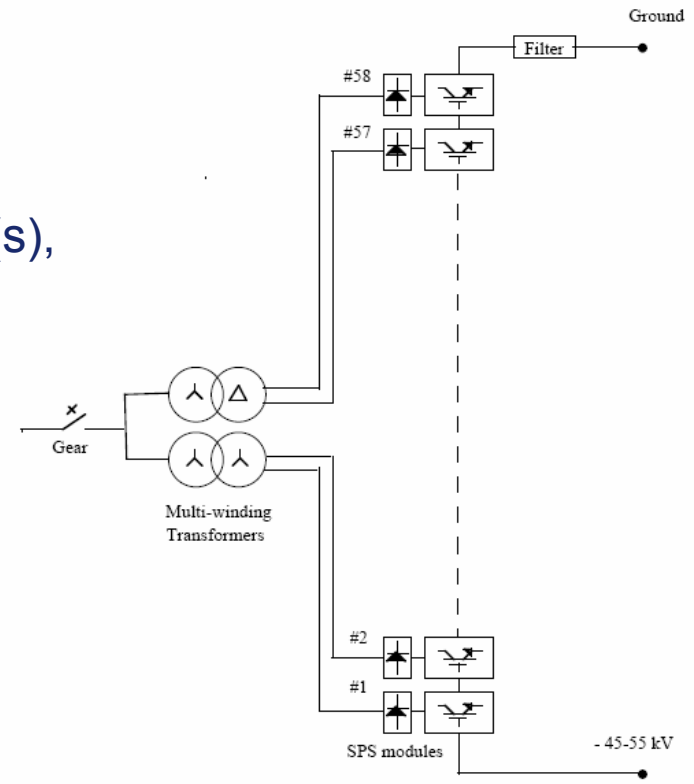


Output parameters	
Rated output voltage	- 100kV dc
Rated output current	71A dc
Pulse duration	Continuous up to 1 hour
Modulation	5Hz for 3 sec every 20 sec
Rise time of output voltage (10 – 90%)	0.5ms
Output Voltage stability	±1%
Duty cycle	25% pulse 75% OFF
Time to be ready for restart	20ms or less

100kV PS - line diagram

Working principle: numerous voltage steps, in series, that can be switched in and out, ensuring fast voltage modulation as per SPIDER requirements

Main components: multi winding transformer(s), SPS, Output filters, control



FUSION FOR ENERGY

Medium-Term

Procurement 4: AGPS, GRPS and NBPS Control for 1MV injectors

Call for Tender planned Q1 2010

Scope of supply – main components

1. Acceleration Grid power Supplies – AGPS (low voltage part)
2. Ground-Related Power Supplies - GRPS
3. Power Supplies Control & DAQ – for all Neutral Beam PS

The supply includes the Detailed Design, the Fabrication and factory testing, the transport, delivery and installation on site, the commissioning and acceptance testing on-site and the associated documentation an training.

1. Acceleration Grid PS

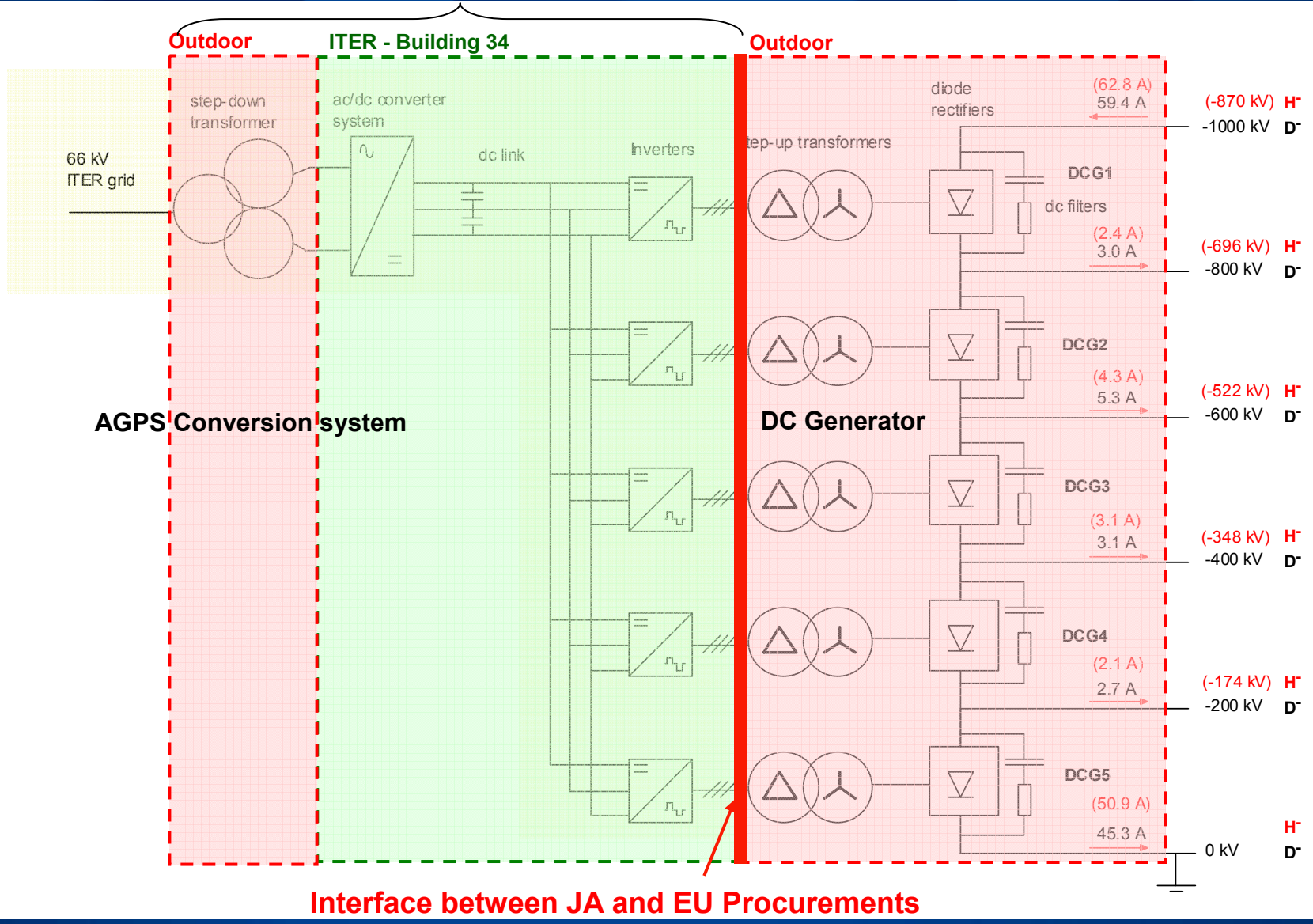
Functional specifications

Max. 54.7MW in D operation, nominal operating conditions

Main Power Supplies (EU) – per injector

72kV Disconnector – AGGS
22kV Step-down transformer - AGGT
AC-DC Conversion System (Converter + DC link) - AGRT
DC-AC Conversion System (5 Inverters) - AGGU

The step-up transformers and the High Voltage part are supplied by the Japanese Domestic Agency


Outdoor
ITER - Building 34
Outdoor
66 kV
ITER grid
step-down transformer
ac/dc converter system
dc link
Inverters
step-up transformers
diode rectifiers
(62.8 A)
59.4 A
(-870 kV) H-
-1000 kV D-
DCG1
dc filters
(2.4 A)
3.0 A
(-696 kV) H-
-800 kV D-
DCG2
(4.3 A)
5.3 A
(-522 kV) H-
-600 kV D-
AGPS Conversion system
DC Generator
DCG3
(3.1 A)
3.1 A
(-348 kV) H-
-400 kV D-
DCG4
(2.1 A)
2.7 A
(-174 kV) H-
-200 kV D-
DCG5
(50.9 A)
45.3 A
H-
0 kV D-
Interface between JA and EU Procurements

Acceleration Grid Power Supply

Disconnector

10,000 mechanical manoeuvres / 1,000 opening/closing cycles
Nominal current 600A r.m.s.
Short time withstand current 25 kA r.m.s. 1s
Highest system voltage 72 kV r.m.s.

66kV Step-down transformer

Oil immersed
3 input phases, 50Hz
Primary voltage 66kV, highest 72kV
Nb of pulses in lifetime 10,000

AC-DC Conversion System

12-pulse operation
Output: central point to ground, other two are +3.25kV and -3.25kV respectively
Switching semi-conductor

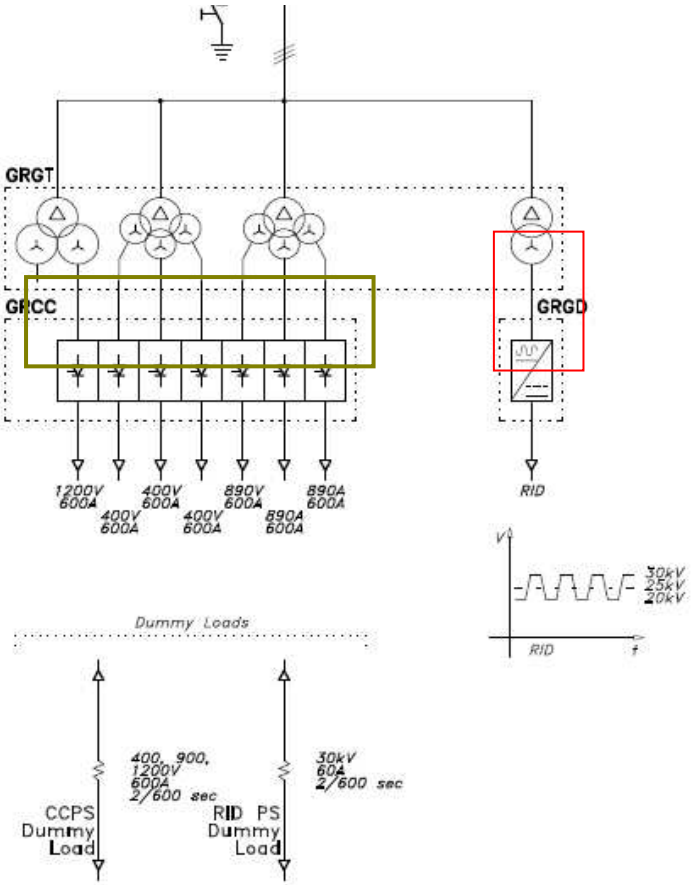
DC-AC inverters

Parameter	Value
Inverter topology	3-phase Neutral Point Clamped
Dc-link voltage:	
- nominal value [1]	6.5 kV
- Maximum variation under stationary regimes	±6 %
- Maximum variation under transients	±10 %
Output voltage waveform	three-level square wave with variable duty-cycle
Inverter frequency	150 Hz
Maximum inverter decoupling + stray inductances	110 µH
Maximum output dc current component [2]	1% of the rated output current of the inverter

2. Ground Related PS

- 24KV Disconnector – GRGS
- GR Transformers - GRGT
- Active Control Correction Coils (ACCS) PS - GRCC
- Residual Ion Pump (RID) PS - GRGD

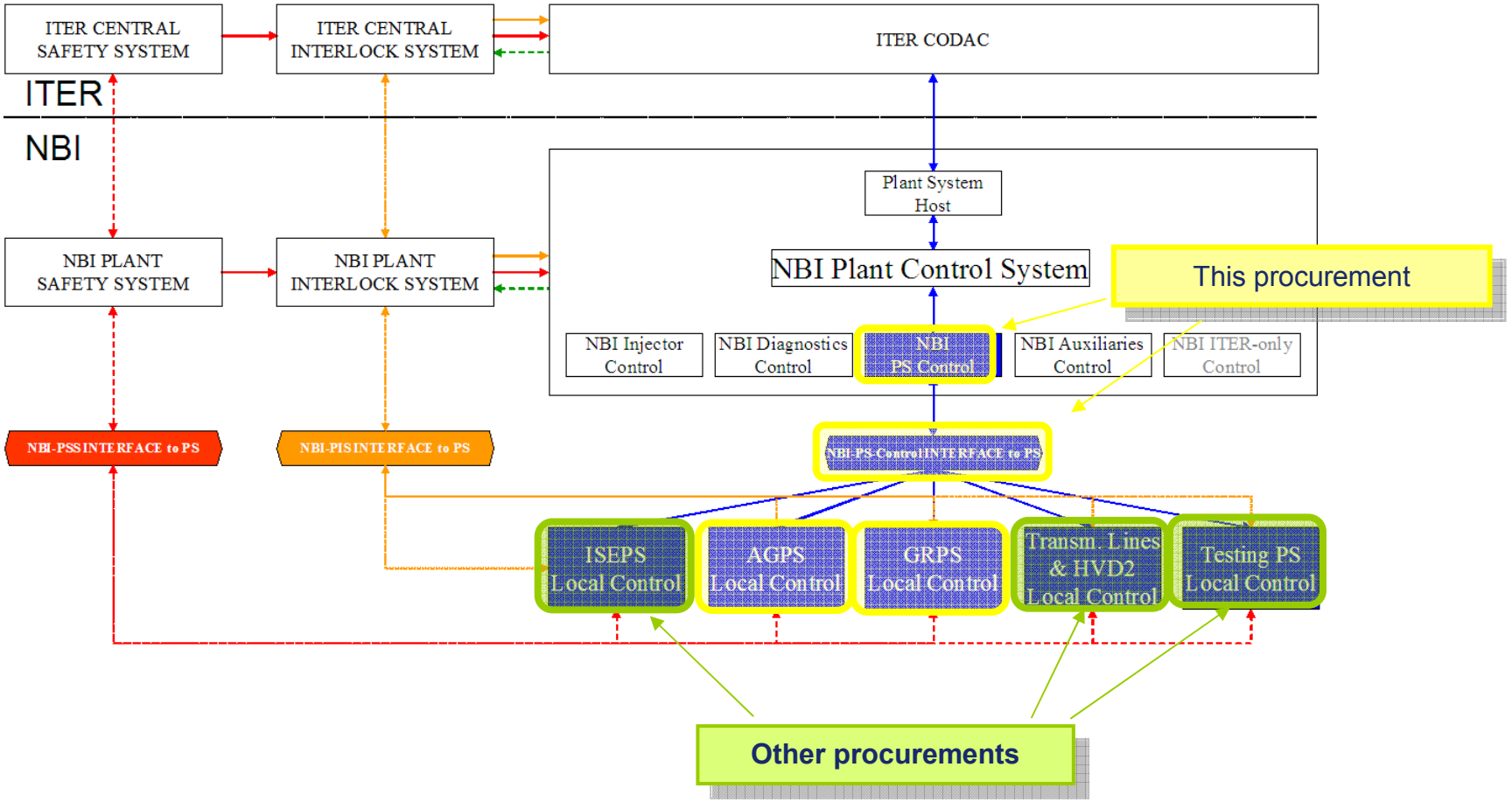
Characteristic	Value
Average voltage	25kV
Peak of alternative component	5kV
Voltage waveforms	Trapezoidal/Sinusoid
Rated nominal current	60A
Period (T)	20ms
Slope time for trapezoidal waveform (t/T)	1ms / 20ms



PS	Nominal current	Nominal Voltage
CCPS1	650 A	1000 V
CCPS2	650 A	500 V
CCPS3	650 A	500 V
CCPS4	650 A	1400 V
CCPS5	650 A	500 V
CCPS6	650 A	1000 V
CCPS7	650 A	1000 V

3. PS Control & DAQ

Functional structure of the NBI control, Interlock and safety System



Design General criteria

- **Physical separation** between Power Cubicles and Control Cubicles (e.g. different floors, rooms, segregated, etc.)
- Physical separation between "**Remote control**" room and "**Local control**" rooms
- "Local control" means that you can operate either **a single power supply** at a time **from its local control cubicle** or a subset of power supply from CODAC
- Flexibility

- Plant Control Design Handbook

FUSION FOR ENERGY

Medium-Term

Procurement 5: 1MV HV Deck and HV Bushing for 1MV NBI injectors

Call for Tender in 2010, Procurement strategy TBC

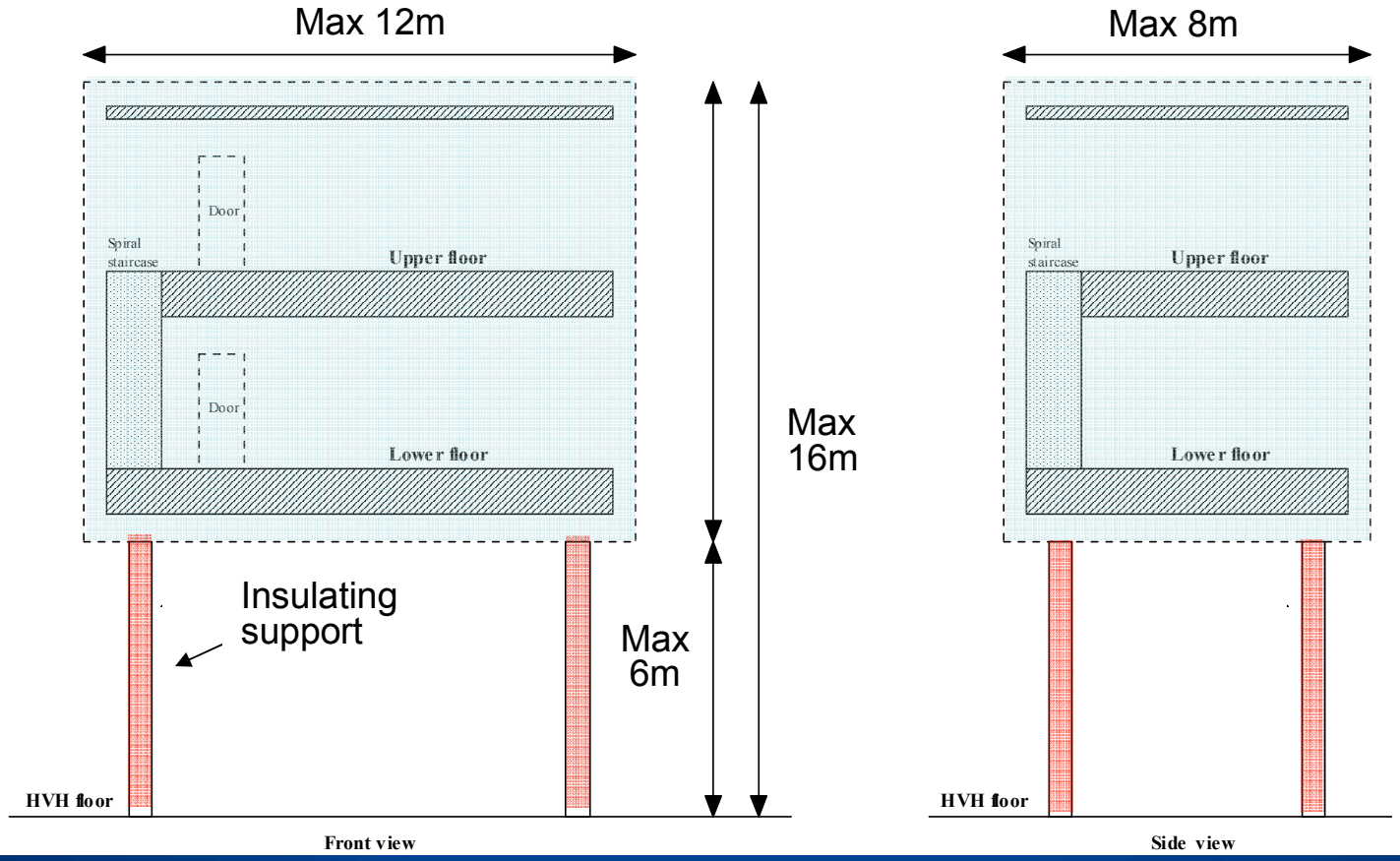
Scope of supply – main components

1. 1MV High Voltage Deck
2. 1 MV Bushing

The supply includes the Detailed Design, the Fabrication and factory testing, the transport, delivery and installation on site, the commissioning and acceptance testing on-site and the associated documentation an training.

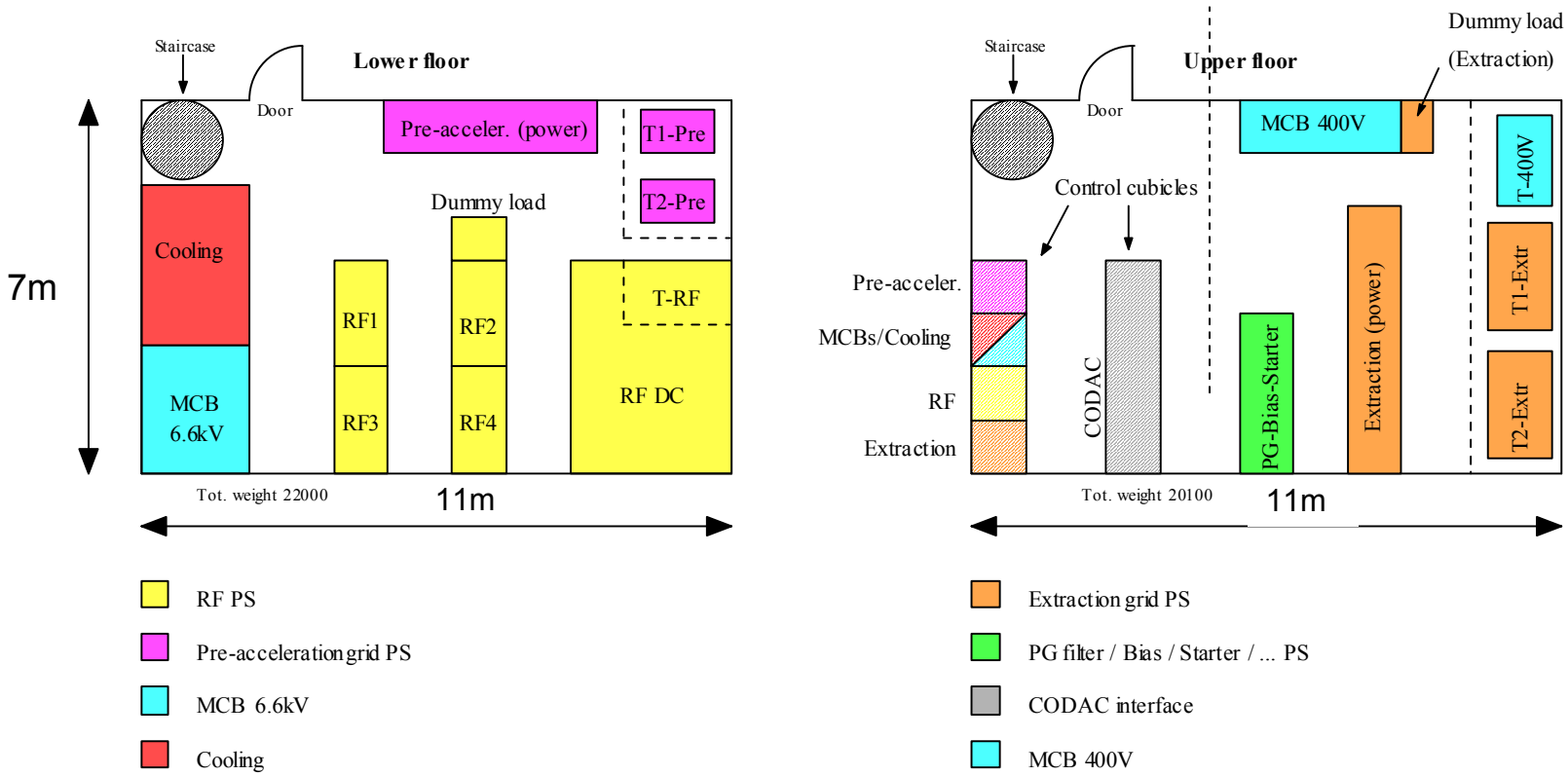
1. High Voltage deck (1/2)

- The High Voltage Deck 1 (HVD1) is an air-insulated Faraday cage which houses the power supplies of the Ion Source. During normal operation, the HVD1 is at the nominal potential of **-1 MV (dc)** with respect to ground and is fed by a single insulation transformer
- All equipment will be housed on two floors, with both floors accessible from outside



1. High Voltage deck (2/2)

- In ITER: Building 37 – hosting the Ion Source Power Supplies
- The mechanical structure have to withstand the total equipment load (c.a. **50 tons**)
- All supports rated for the nominal voltage of **-1 MV (dc)**

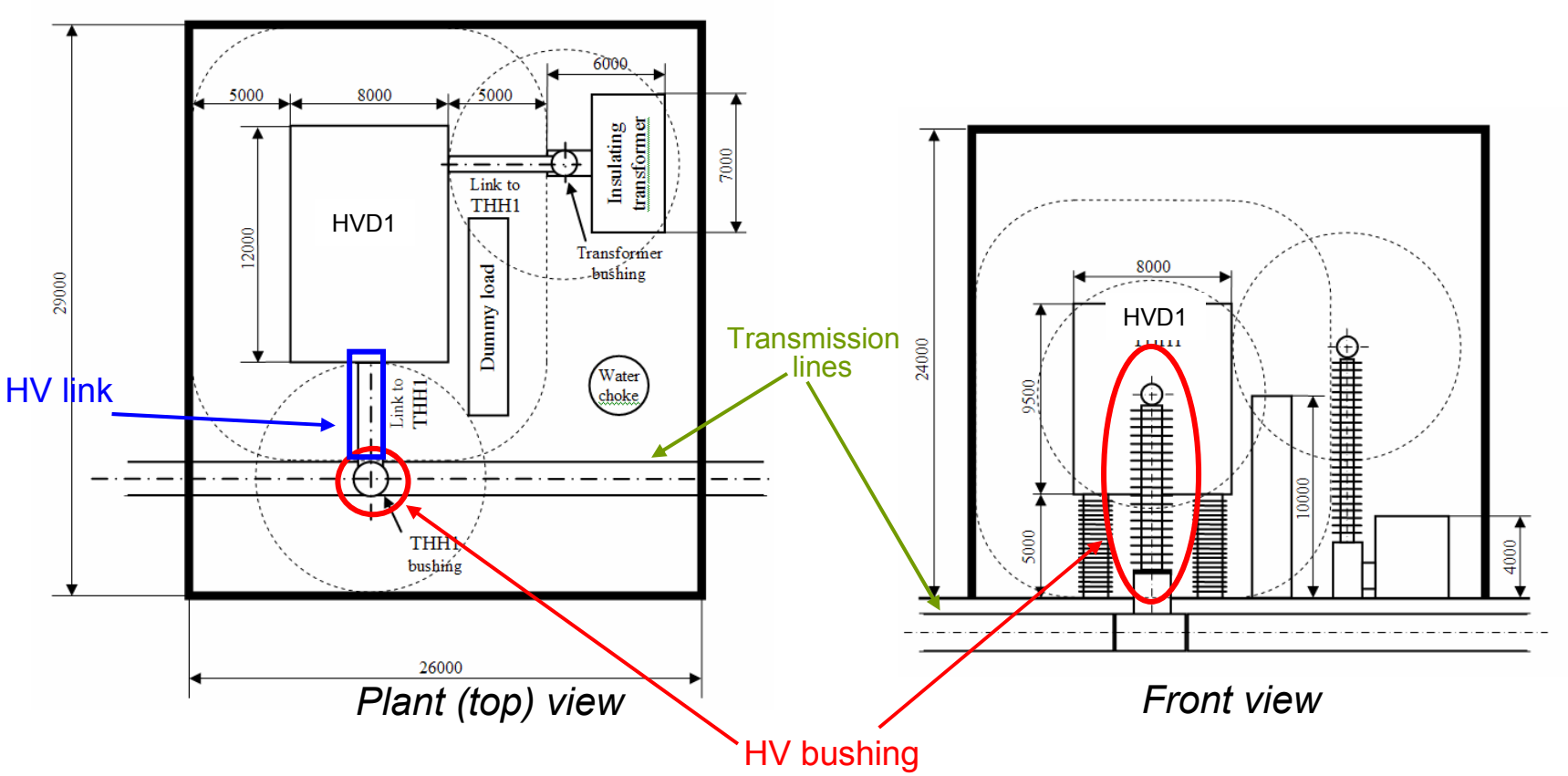


2. High Voltage Bushing

- Connects the -1MV DC air insulated High Voltage Deck to the gas insulated transmission line (Japanese procurement)
- Design and layout are only preliminary, currently under further analysis
- Priority on preserving the interface with the Japanese supply, provided a technical solution is identified

Bushing connection with the Transmission line

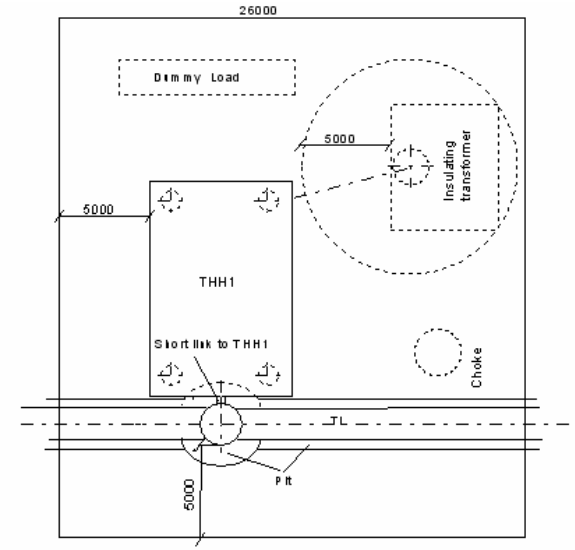
Reference layout – starting point

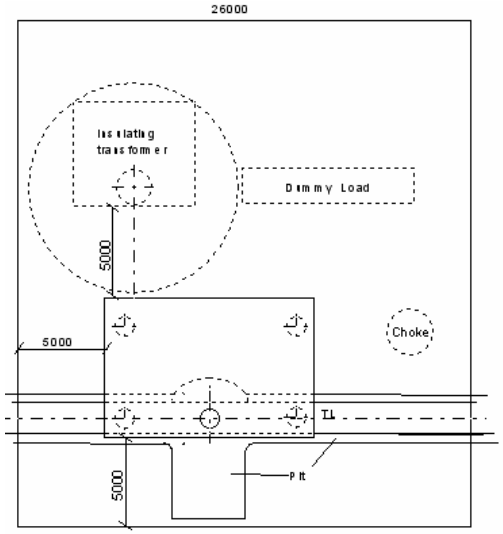


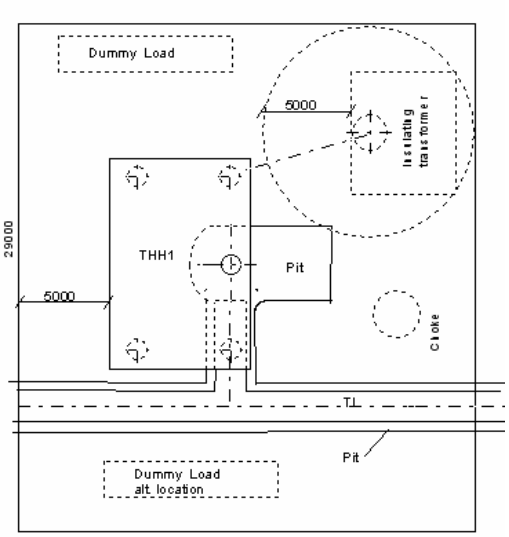
Bushing connection with the Transmission line

Several alternative layouts under consideration: reduce/remove the HV link, more compact layout, multiple bushing etc..

Some examples:







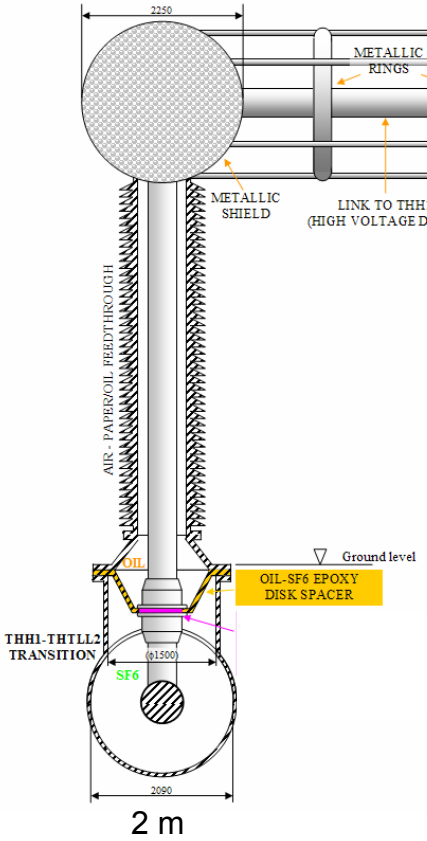
High Voltage Bushing design

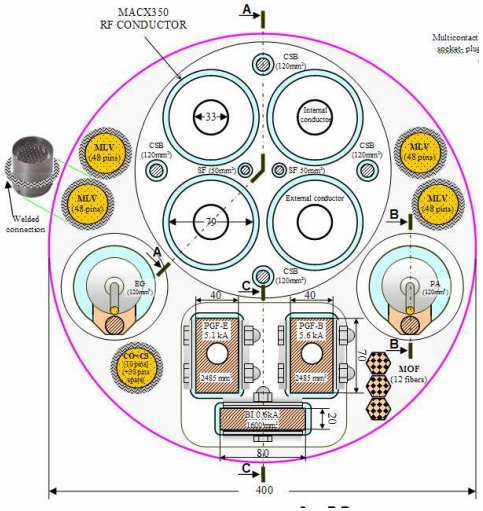
Bushing Design alternatives

Possible technologies:
- Paper oil
- Resin Impregnated Paper with SF6
- SF6 gas-filled

Outer covering:
- Porcelain
- Silicon rubber sheds

Design Challenges:
- High Voltage DC operation
- Frequent breakdowns
- Number of conductors to accommodate
- Interface with the transmission line





Section view of the bushing conductor

HV Deck and HV bushing procurement

To address these technical challenges, our objective is to encourage industry involvement in the detailed design phase for the bushing:

-> competitive dialog, or possible alternative procurement strategy to develop if needed more than one design solution

Start of the procurement procedure planned early 2010

FUSION FOR ENERGY

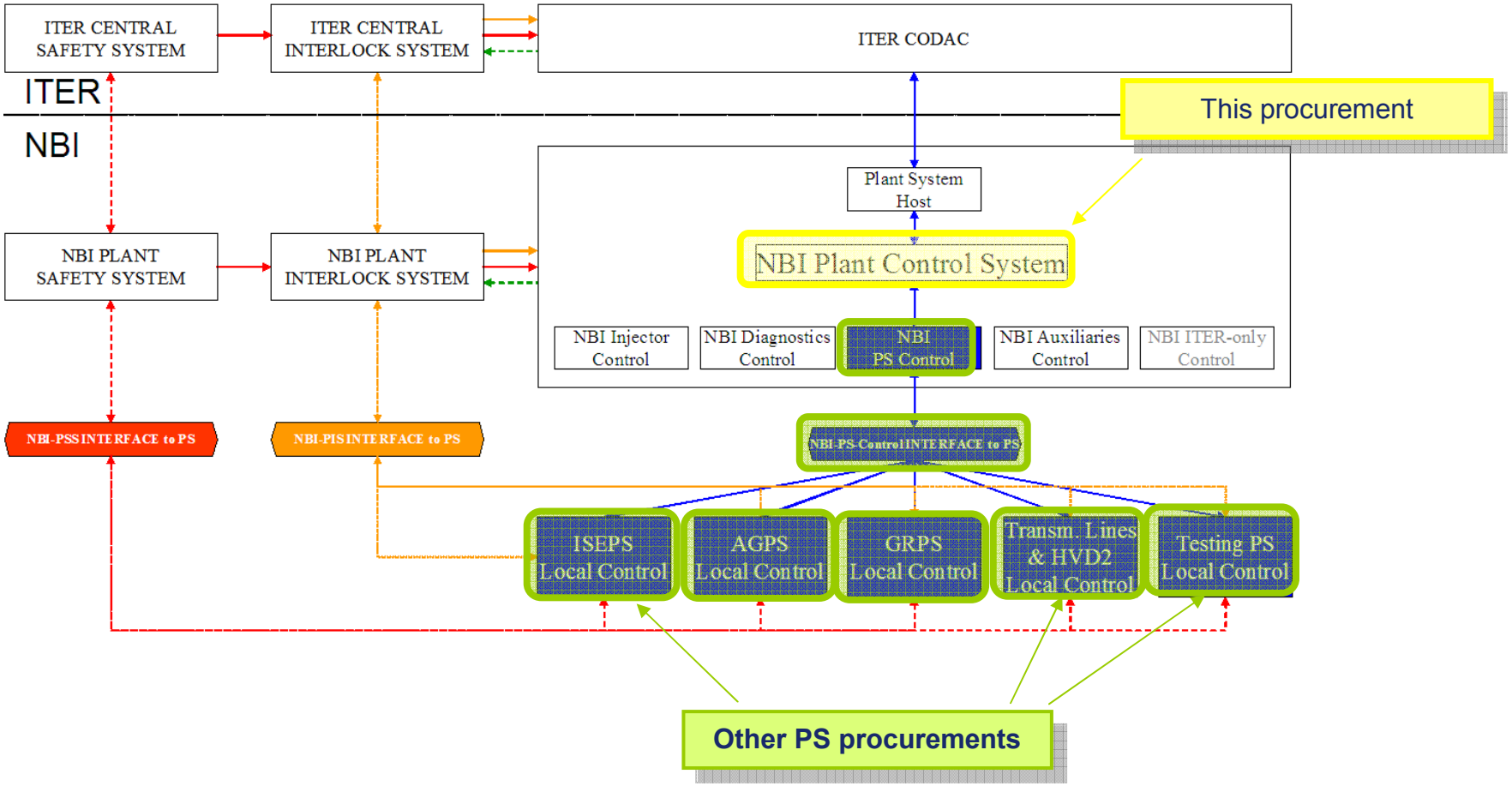
Longer-Term

Procurement 6: NB Control & DAQ for the NBI injectors

Procurement start 2011

Overall NBI Control & DAQ

Part of this procurement for historical reasons. Specifications still at an early stage
Procurement strategy still to be defined.



Neutral Beam Control and Data Acquisition System

The data acquisition system of the NB system will include the instrumentation needed to condition, record, display and analyse the measured signal coming from the beam line.

A preliminary list of measurement signals includes:

- Temperature measurements: neutraliser leading edge, RID, Calorimeter, duct liners, cryopump
- Measurement of gas flow at the neutraliser
- Measurement of flow rates, temperature and pressure at the entrance/exit of: Neutraliser, RID, Calorimeter, each of grid coolant manifolds, Arc coolant line, filament coolant line
- Measurements of currents and voltages of: each grid, the arc, the filaments, the bias
- Standard vacuum measurements both in the NB Vessel and in the NB Duct (Fast Penning Gauges and Residual Gas Analyser)
- Vertical magnetic stray field measurements (Hall effect probes)
- Pressure and temperature of the insulating gas
- Water conductivity
- Positional Transducer (calorimeter and fast shutter position)
- …

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).

Acknowledgements: contributions from ITER Organization, Consorzio RFX, F4E colleagues, external expert Dieter Hrabal

More information:

http://fusionforenergy.europa.eu

FUSION FOR ENERGY

Thank you!