IPP INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

ECRH system for COMPASS-U

MINISTRY OF EDUCATION, YOUTH AND SPORTS

Revision	Date	Description	Responsible
1	8.10.2023	Initial release, description of tenders scope and introduction of IPP	Bogar
2	17.10.2024	Added informations about preliminary proposed contract information (slides 13 to 24)	Farnik

Institute of Plasma Physics

IPP (www.ipp.cas.cz)

- Founded in 1959 (64 years ago)
- Actual director: **Radomir Panek**
- IPP has 3 Divisions and >400 employees

Fusion Plasma Division

(former TOKAMAK department)

- Head: **Martin Hron**
- Deputy: **Michael Komm**
- Created in 1977 (46 years ago)
- Has ~100 employees
- 3 departments:
    - High-Temperature Plasma Physics Dpt. (Michael Komm)
    - Theory and Modelling Dpt. (David Tskhakaya)
    - Technological Development Dpt.(Josef Havlicek)
- Devices:
    - CASTOR (GOLEM) 1977-2006
    - COMPASS 2006-2021
    - COMPASS Upgrade 2026 on

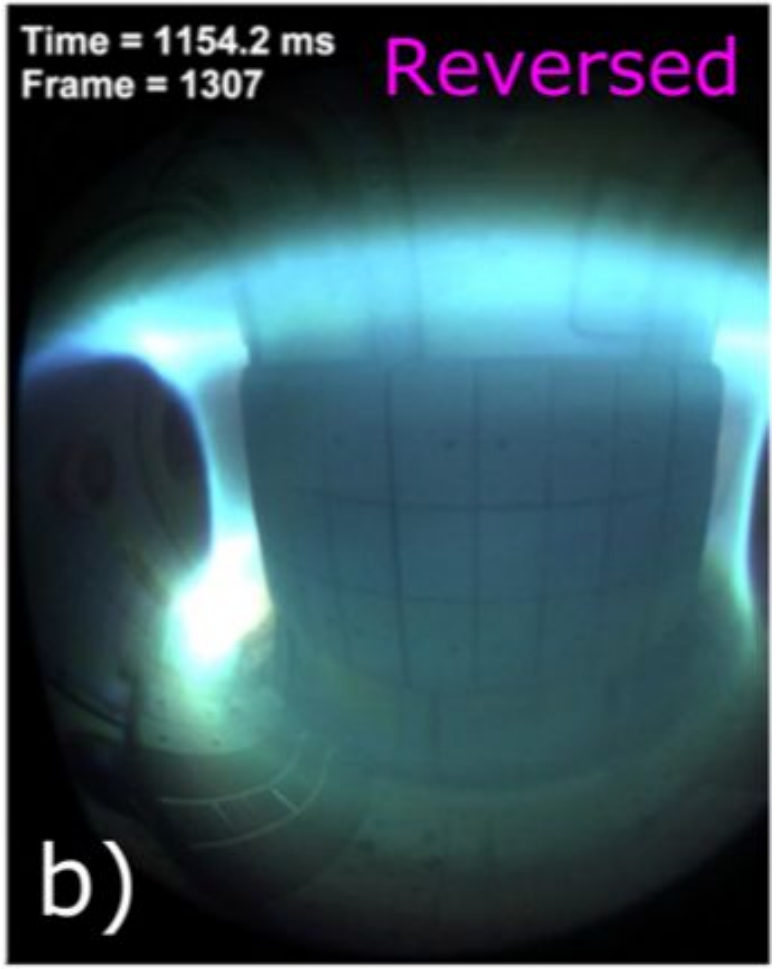
COMPASS

COMPASS was operated in the IPP CAS since 2009 and it was shut down in August 2021. COMPASS was one of few devices with an **ITER-like plasma shape**. Its **flexibility**, extensive set of **diagnostics** and **NBI** contributed in closing the gaps of key issues in fusion research in support of **ITER** and **DEMO**, such as

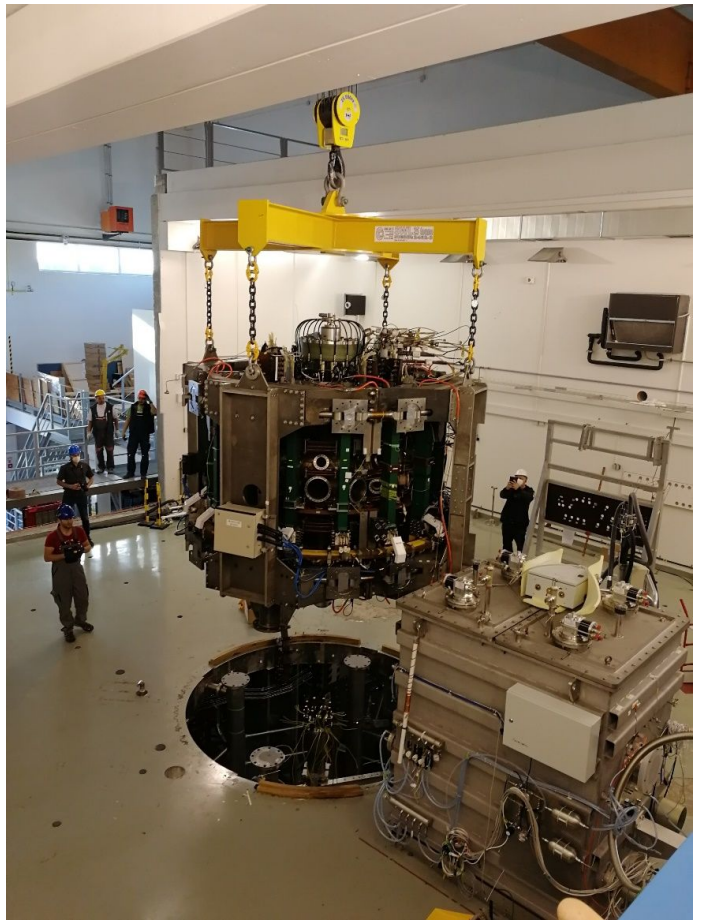
- edge and SOL physics
- L–H transition
- runaway electrons
- disruption studies
- plasma-wall interaction

COMPASS was very effective for testing new ideas and concepts in the area of **plasma control** and **diagnostics development**, which were implemented on larger devices.

"Overview of the COMPASS results, "M. Hron, Nucl. Fusion 62 042021 (2022)

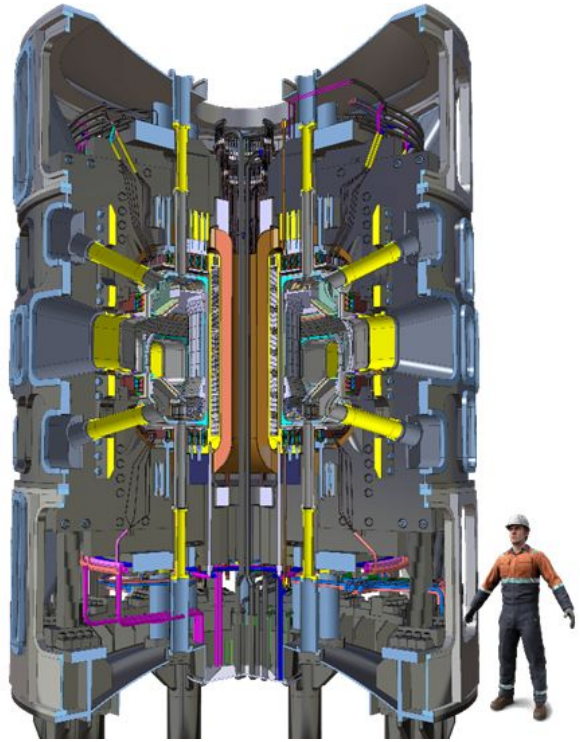


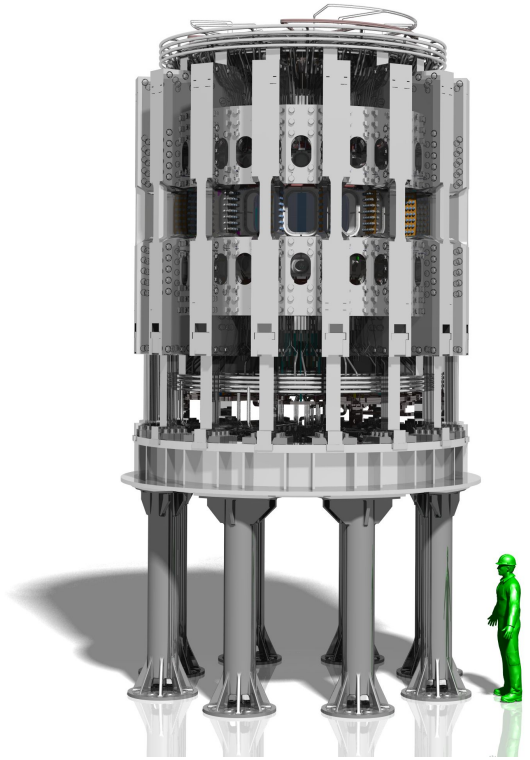
COMPASS officially ended its operation in August 2021, after more than 20k discharges

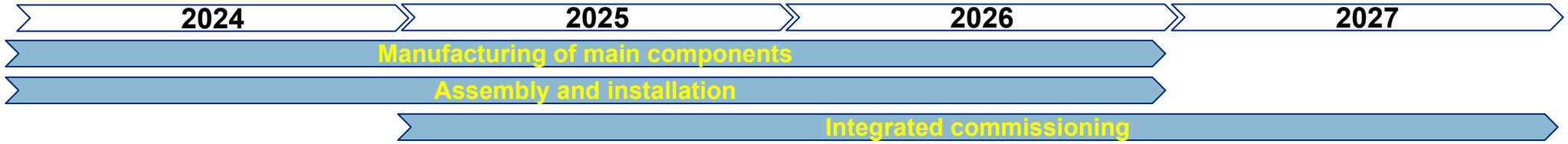


- **Project status**: final design review, tenders
- **Individual systems:**
  - Cryostat
  - Support structure
  - TF coils
  - PF coils + central solenoid
  - Vacuum vessel
  - Plasma facing components
  - Cryogenics
  - Power supply system
- **Plasma heating:** NBI, ECRH
- **Diagnostics design:** ongoing

- **Timeline** of the project:







Main parameters

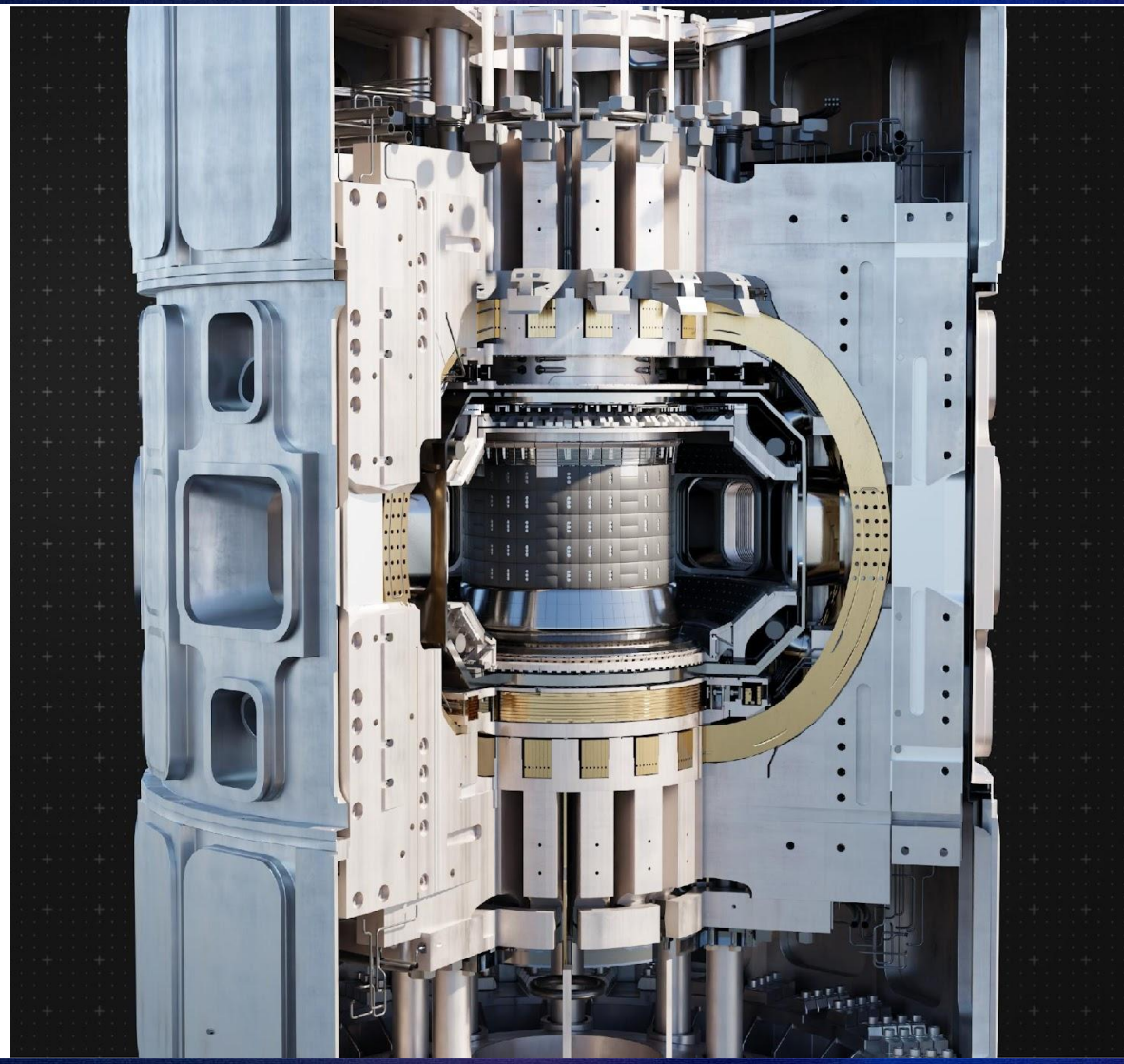
- Toroidal magnetic field $B_t = 5$ T
- Plasma current $I_p = 2$ MA
- Major radius $R_g = 0.894$ m
- Minor radius $a = 0.27$ m
- Aspect ratio $A = 3.3$
- Triangularity $\delta = 0.3\text{-}0.6$
- Elongation $\kappa = 1.8$
- Enough space for different divertors
- Metallic first wall
- Vacuum vessel operation temperature up to 300°C (goal 500°C)

Plasma shapes

- single lower null, neg. triangularity with limited parameters (Phase 1-2)
- double null (Phase 2-3)
- snowflake, negative triangularity (Phase 3-4)

Plasma heating power

- Phase 1 $P_{NBI} >= 3$ MW, $P_{ECRH} = 1$ MW (P*B/R ~ 25)
- Phase 2 up to $P_{NBI} = 8$ MW, $P_{ECRH} = 10$ MW (P*B/R ~ 100)



Infrastructure

Planned construction works

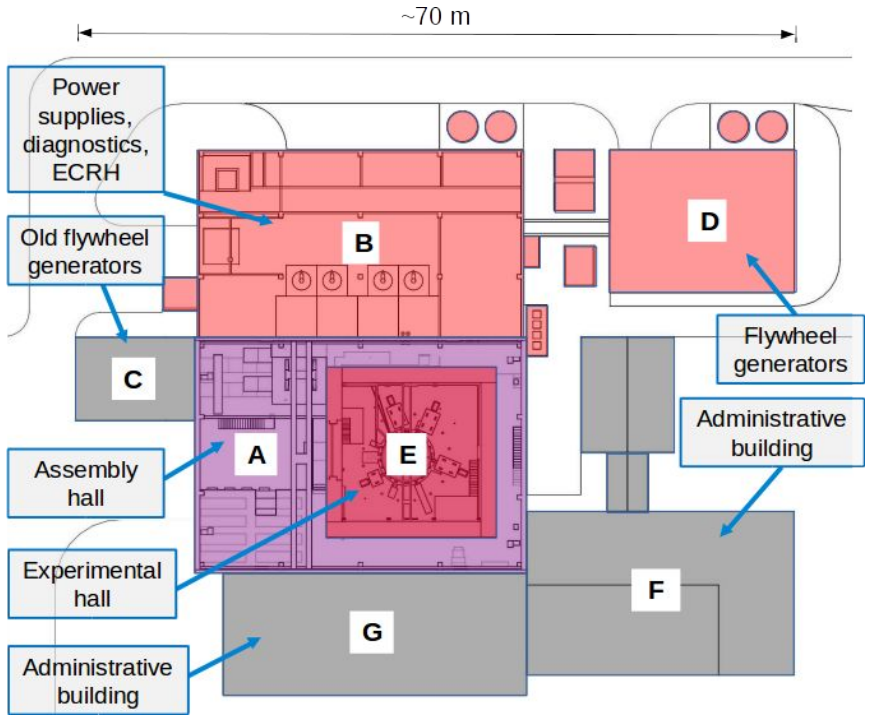
Phase 1:

- modification of the existing experimental hall
- Additional 90 cm of concrete (1.5 m in total)
- New 0.8 m thick base concrete slab
- new concrete floor, new concrete ceiling
- Additional steel floor in the assembly hall

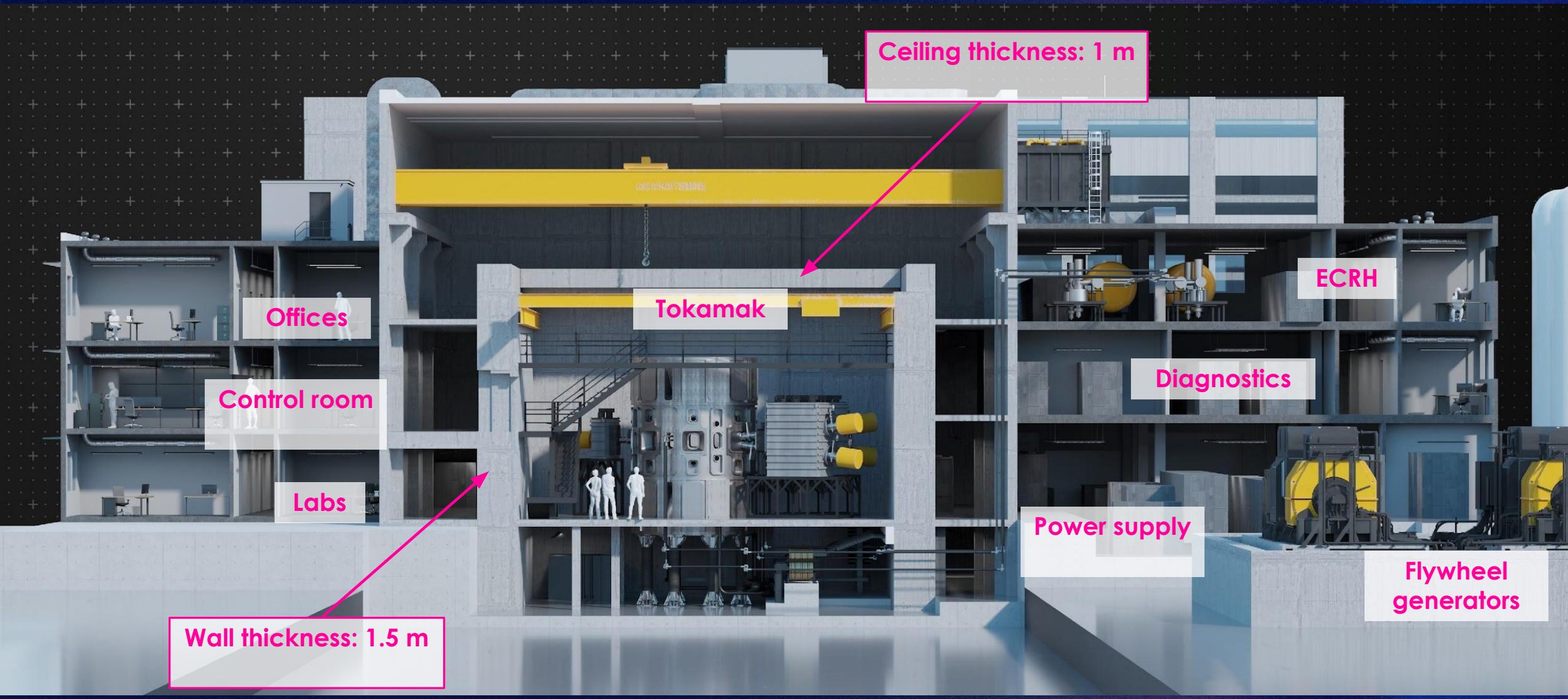
Phase 2:

2023-2024

- New hall for power supplies, diagnostics and ECRH
- New hall for flywheel generators
- New liquid nitrogen reservoirs, cooling stations, transformers etc.



Infrastructure



ECRH system

Specifications for the components of the ECRH system

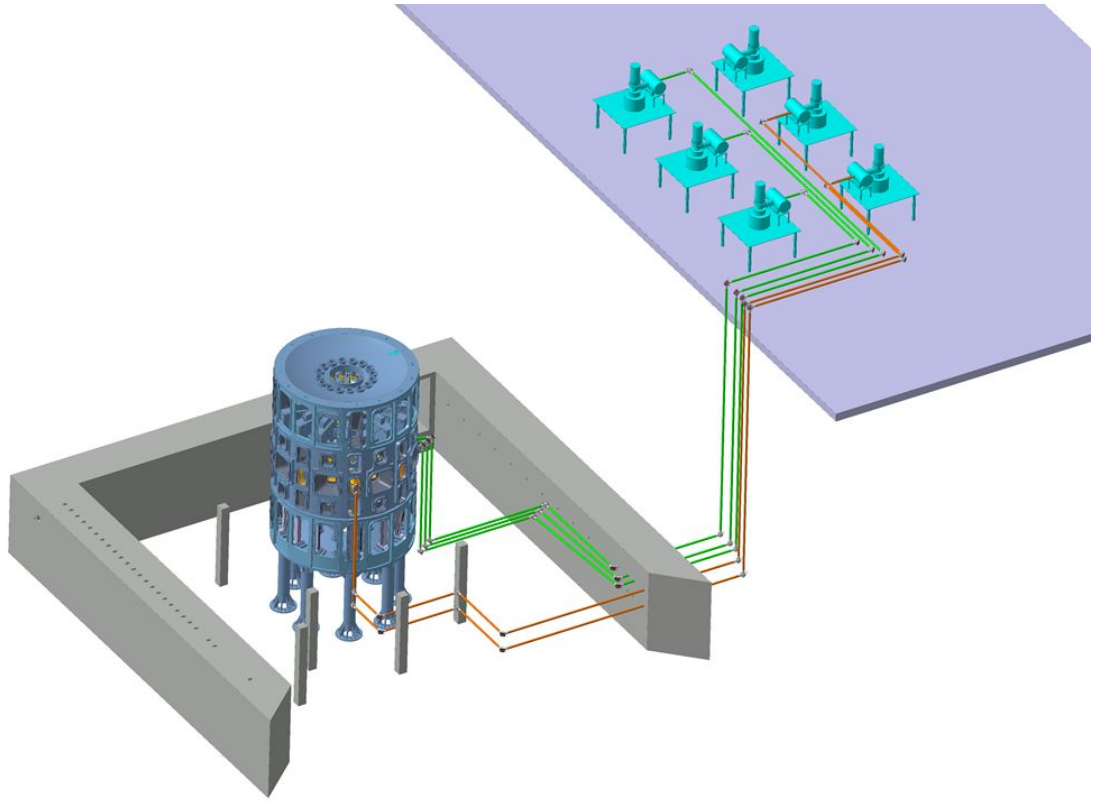
Gyrotrons:
multiple freq, 140 GHz main, possibly also 105, 170
>0.9 MW, ~15 s pulse length

Waveguides: 63.5 mm diameter, total length < ~30 m

Launchers: large equatorial port, steering mirrors

Deposition on-axis is achieved for B_t 2.5 and 5 T

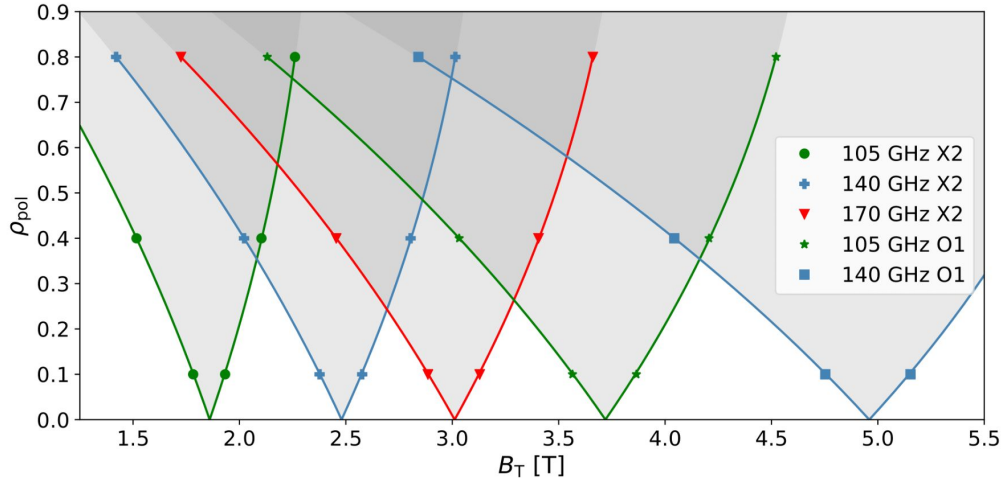
Control system, sniffer probes, arc detectors

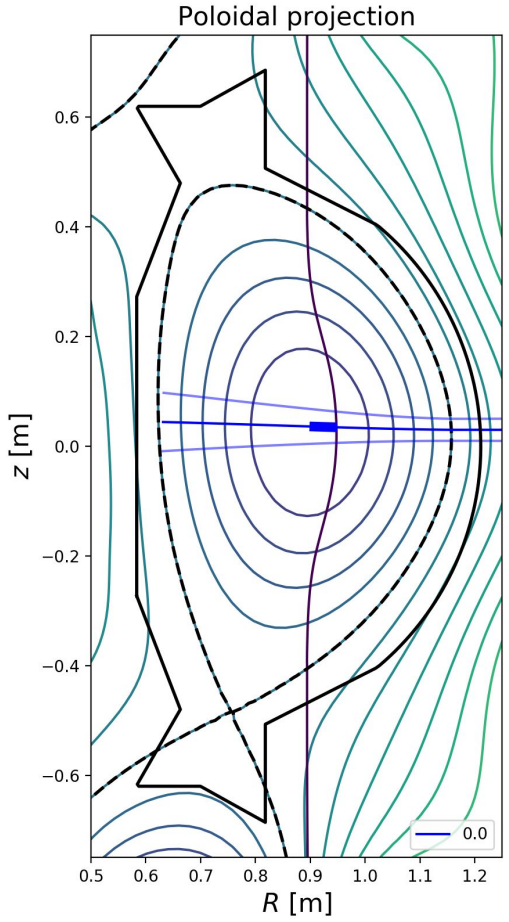


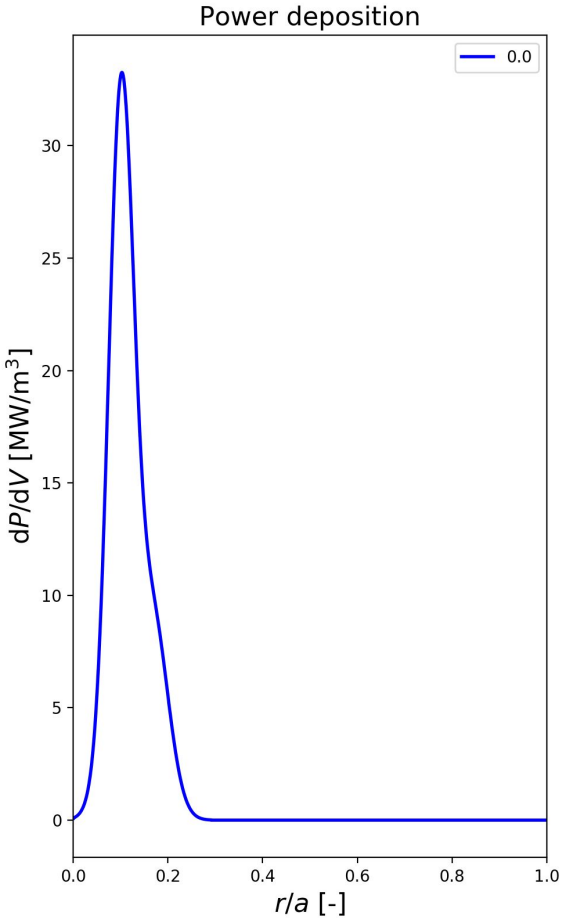
Heating strategies

B_t [T]	$\langle n_{co} \rangle$ [m^{-3}]	Operation mode	f [GHz]
2.5	1.1×10^{20}	X2	140
3.0	1.7×10^{20}	X2	170
3.8	1.3×10^{20}	O1	105
4.3	2.0×10^{20}	O1, toroidal steering	140
5	2.3×10^{20}	O1	140

Different frequencies allow wave deposition with different magnetic fields and at different radial locations







HVPS and control system

HVPS for ECRH will be placed on ground level of new building (see slides 7-8)

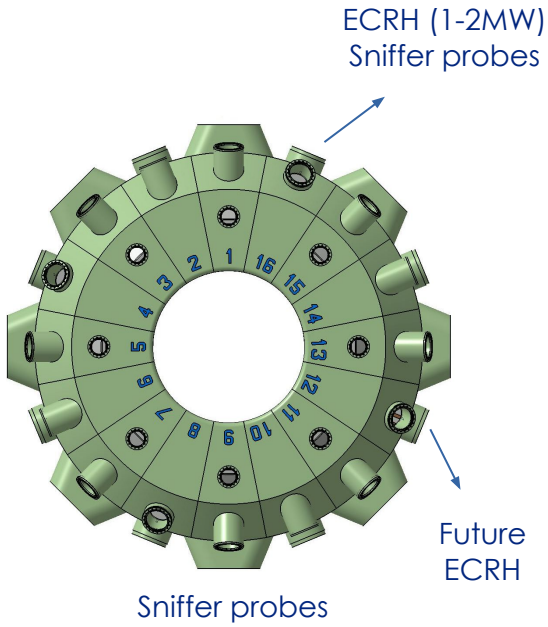
The system must be equipped with real-time control for failures

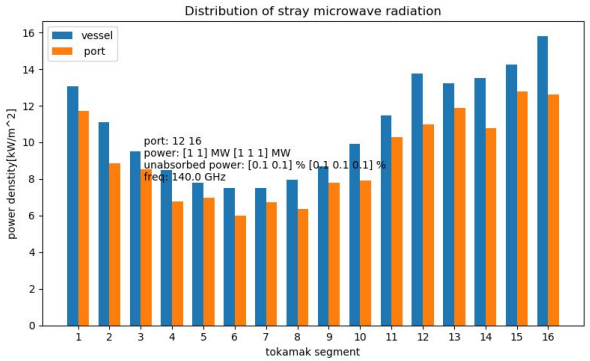
- sniffer probes will detect stray radiation in the plasma volume
- arc detectors will be installed in critical points along the transmission line

Sniffer probes and arc detectors represent the main interlock systems

Additional control parameters:

- polarization measurements in dedicated miter bends and at mirrors
- control of voltage in power supply and body current (at gyrotron)





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Tender technical specification

The Seller Scope and deliverables

Physical deliverables

- **Gyrotron tube** with all the subsystems (tube, ion pumps, X-ray shielding, electron gun, sweeping magnets and its power supplies, sensors etc.
  Superconducting magnet (cryo-compressor and lines, power supply, sensors and alignment tooling etc.)
- **Cathode**
- **HV components** (oil tank, HV connectors, cooling of the oil etc.)
- **MOU** (pumping port, window, arc detectors etc.)
- **Support structure** (for gyrotron, tank, MOU)
- **Cooling** (windows and hoses)
- **Dummy loads** (very short pulse, short pulse for testing)
- **Others** (tooling and instrumentation for maintenance, operation and testing)

Please specify quotation for the whole system, its delivery and services.

Tender

All the shown figures and informations are preliminary and can be changed in final tender documentation.

Summary of the current requirements for the gyrotrons

Operating frequencies	**105±5, 140±5, 170±5 GHz**
Output power	>0.9 MW at 140 GHz largest possible at other frequencies
Pulse length	15 s at 140 GHz what is possible at other frequencies?
Duty cycle	2%
Mode purity	>95%
Efficiency	>45%
Modulation frequency	1 kHz

The RF Source shall have a frequency, power and pulse length capability as defined in the table. Output power is defined as power coupled into the 1m corrugated waveguide in the HE11 mode.

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Please fill know parameters in the table with your proposed product specification

Sum of output power at all 3 frequencies will be probably one of the determining factors

Frequency [GHz]	Pulse length	Mode purity	Efficiency	Cathode voltage	Anode voltage (in triode conf.)	Body voltage	Collector voltage	Beam current	Output power [MW]
[around 140] GHz									
[around 105] GHz									
[around 170] GHz									

Gyrotron Output power is "power coupled into the waveguide in the HE11 mode"

Power value should be established via an HE_{11} mode purity content measurement (or calculation at design review), and a total power into the load measurement (or calculation at design review) This should be after a minimum of 1m of 63.5mm diameter, corrugated waveguide.

Document deliverables

- **General documentation**
- **3D CAD and 2D Drawings (drawing type and detail dependent on component / sub-system)**
- **Analysis** (stray radiation, iron in the building, horizontal movement, lifting instruction)
- **Factory Acceptance Test and Build Tests** (plan and reports)
- **Site Acceptance Test and Commissioning** (plan and reports)
- **Operations and Maintenance instruction**

FAT description

- Full performance test
- power coupled into the HE11 mode = HE11 mode purity content x total power into the load measurement after > 1 m of 63.5mm corrugated waveguide
- Frequency measurement, Reliability test, MOU test
- The FAT shall take place at the Seller's premises. The Seller shall perform, document, and report to the Buyer, the results of all FATs.

SAT description

- SAT are defined as the tests required to accept all equipment following delivery to site, and initial assembly prior to horizontal movement of the assembly into its final position. (vacuum tests, assembly and dimensions, magnetic field measurements and re-test and alignment after the movement, **no RF tests**)

Commissioning

- Integrated test together with the HVPS and control system
- Full performance test
- The Commissioning tests are the formal tests required to demonstrate that the RF Source fully meets the specifications.

Milestones, deadlines and preliminary proposed payments

Deadline	Payment	Project milestones / review points
		Kick-Off Meeting
4 weeks after the Contract becomes effective	advance payment 5%	Technical Specification and Requirements for the High Voltage Power Supply
8 weeks after the Contract becomes effective	advance payment 15%	Design Review of long lead item
06/2025	advance payment 30%	Design Review of RF Source
	advance payment 20%	Factory Acceptance Tests (tube)
		Factory Acceptance Tests (magnet)
		Factory Acceptance Tests (auxiliaries)
		Delivery
11/2026		Site Acceptance Tests
12/2026	payment 30%	Assembly and horizontal movement
Start of commissioning no later than 12/2027		Commissioning of integrated RF Source System.
1 Month after end of COM		Contraction completion and close out

Requirements of horizontal movement

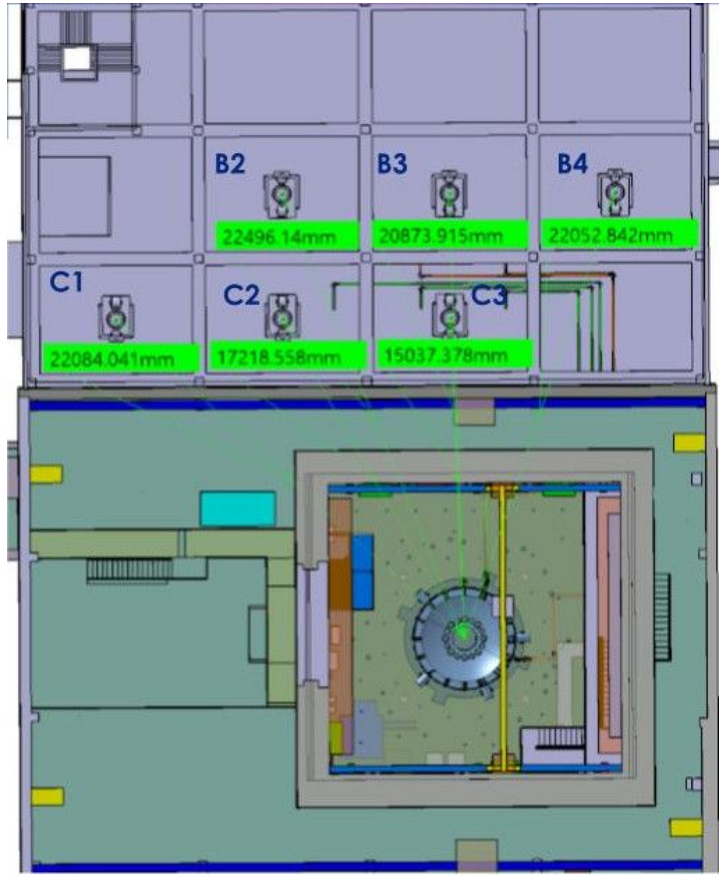
- A temporary crane will then be used to make the overall RF Source assembly. After assembly, the gyrotron will need to be moved to its final location.

- Once the initial assembly is completed in the assembly area, a horizontal transportation step is required to move the RF Source assembly to its final location. This may be via castors, air pads, or a rail system; the Seller's advice and input to this process is required.

- The Seller with the contribution of the Buyer shall prepare an analysis that describes the assembly and the moving of the gyrotron horizontally. The procedure for assembling the gyrotron is fully under the control of the Seller.
- The procedure for the horizontal movement of the gyrotron will be created by the joint efforts of experts from both sides. The analysis and instructions shall be sufficient for a trained team to be capable of assembling this gyrotron.

Stray magnetic field

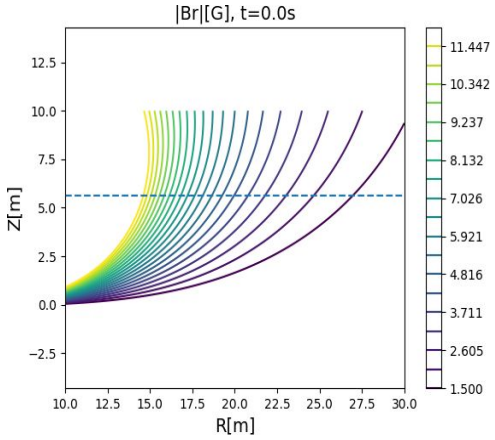
Stray field from tokamak currents calculated in worst-case scenario, at t=0 (maximum currents)

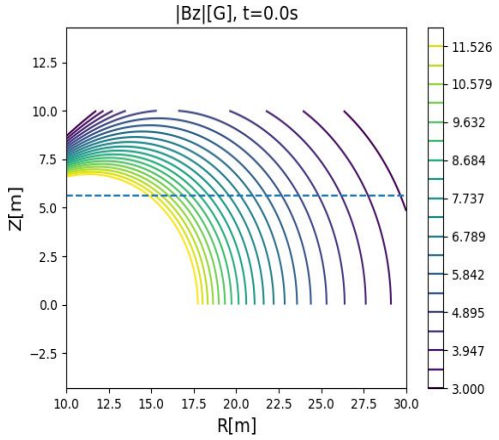


Gyrotron shall meet its requirements with no degradation in performance when housed in an environment with the vertical component of the **stray magnetic field 10 Gauss**.
Gyrotron shall meet its requirements with no degradation in performance when housed in an environment with the radial component of the **stray magnetic field 10 Gauss.**

position	C1	C2	C3	B2	B3	B4
Z	5.6					
R	22.08	17.22	15.04	22.5	20.9	22.05

5400	|Br| [G]	3	7	11	2.8	3.6	3
5T, 1.6MA	|Bz| [G]	5.6	9.2	11.6	5.4	6.3	5.6





Warranty

- Warranty minimal 12 mount from the sight of Handover protocol of Acceptance
- The Seller is responsible for the warranty on all product delivered as a scope of the tender.

Penalties

- Delay - EUR 250.-/day.
- if the Seller fails to remove ascertained defects a - 0.05 % of Purchase Price of the Gyrotron/week
- if the Seller is in delay with the removal of a defect (including those under warranty) - EUR 1000.- /week
- if the Seller fails to provide the Buyer with the technical assistance required EUR 400,000.-
- In case of delay with the payment of the Total Purchase Price or any part thereof the Buyer undertakes to pay to the Seller also an interest at the statutory rate.

These are considered proposals ready to be discussed

Bank guarantees

- At the time of signing the contract bank guarantee in the amount of **10 % of the Purchase Price** of the Gyrotron excluding VAT. Until the handover of the Gyrotron.

- After the SAT there will be bank guarantee in the amount of **3 % of the Purchase Price** of the Gyrotron excluding VAT. During warranty period.

These are considered proposals ready to be discussed

Timeline

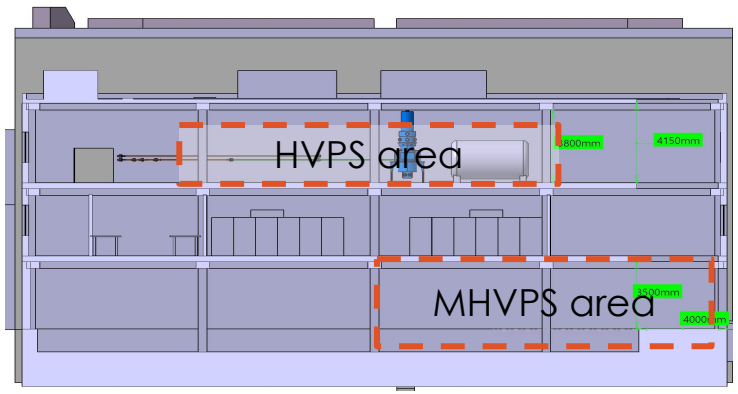
- **end of 2024** - launching the tender
- **1 month** for the preparation of the bid
- **end of 2026** - Completed assembly of the gyrotoron, horizontal movement at the final position and SAT test report

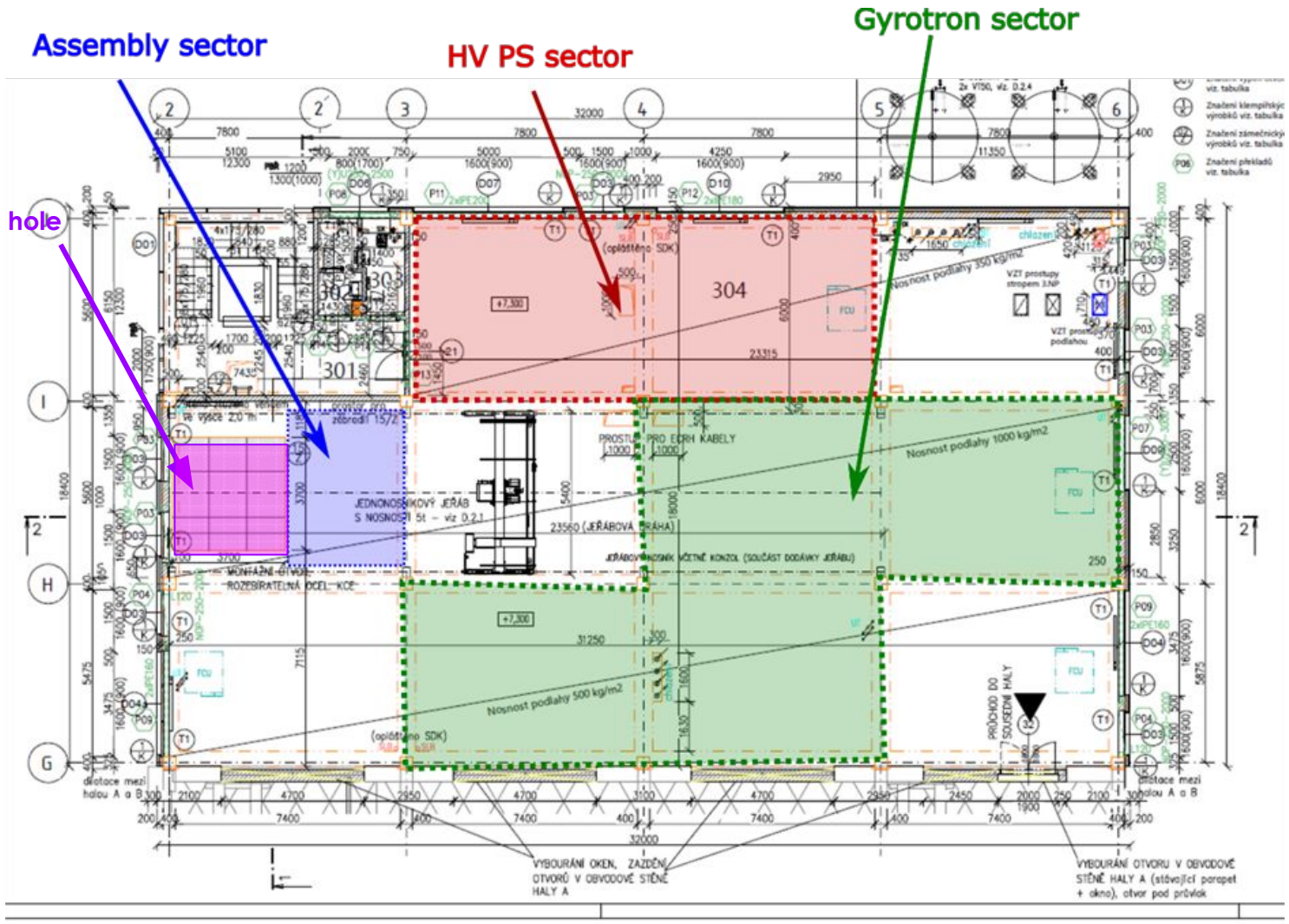
Allocated space 1

Third floor: entirely dedicated to ECRH

Possible to fit up to 6 gyrotrons

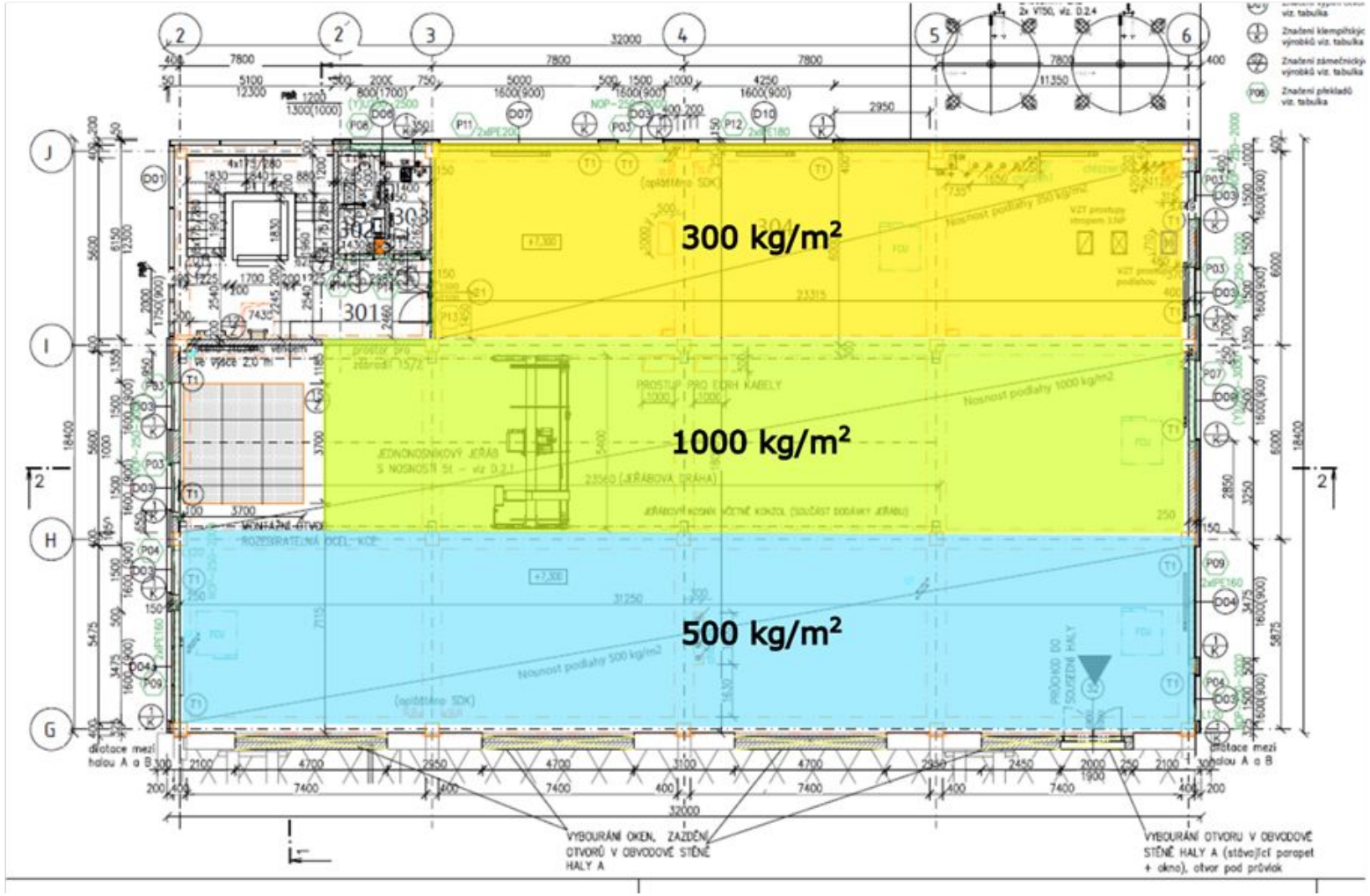
ECRH HVPS will be located at ground floor





Allocated space 2

Assembly area and final position of the gyrotron (from this tender) allow 1000 kg/m2 average floor load.



Questions

Specific questions

- What contract penalties (to be proposed by the Buyer) are acceptable?
- What kind of warranty service and support can you provide?
- What bank guarantees are acceptable?
- Can the gyrotron deliver the required parameters if the stray field is 10 Gauss in horizontal and vertical direction?
- What are the maximum values of the stray field components in which the gyrotron can operate.
  - ~~What is the maximum tolerance for stray magnetic field (vertical and horizontal components)?~~
  - ~~Will the auxiliary power supply, cooling circuit and MOU be provided together with the gyrotron?~~
  - ~~Does the magnet comes with the coldheads and compressor? And the MOU with the diamond windows?~~
  - ~~What kind of warranty service and support can you provide?~~
  - ~~Do you provide service and support after the warranty?~~
  - ~~What is the life expectancy of the main components?~~
  - ~~In what form do the SAT and FAT tests take place?~~
  - ~~On what parameters are you able to perform FAT (power, pulse length)?~~
  - ~~How do you perform measurements of output power and mode purity?~~
  - ~~What parts of the control system and interlocks are delivered with the gyrotron?~~
  - ~~Is some training for technicians, for use and maintenance of the gyrotrons, included~~