Power Plant Design Overview

Presentation to the US DOE

7 August 2003

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Basic Safety Principles

Nuclear power production with:

- No credible event that will necessitate sheltering or evacuation of public living at site boundary (400 m)
- No need for **active** engineered safety systems
- No need for early operator intervention (>24h Design Goal; ~96 h Achieved)

Basic Safety Principles

Safety Achieved By:

- **Control of heat production**
  - Limit excess reactivity
  - Strong negative temperature coefficient
- **Control of heat removal**
  - Large heat capacity
  - Passive heat removal to cavity coolers
- **Control of chemical attack**
  - RPV penetrations designed as pressure vessels
  - Low radioactivity allows early access

Possible Plant Design Choices

- Coated particle fuel in block or pebble
- High or medium temperature operation
- Direct or indirect power conversion cycle
- Single or multi shaft power conversion in case of direct cycle

Selected Plant Design

- Direct cycle power conversion
- Coated particle fuel in pebble
- High temperature operation
- Multi shaft power conversion

Demonstration Plant Specification

- Recuperative direct Brayton cycle with inter-cooling
- Output to the Grid: 160 to 165 Mwe at 28°C CWT
  165 to 170 Mwe at 18°C CWT
- House electric load: < 5MWe
- Ramp Up: 0% to 50% MCR within 30 minutes
  50% to 100% MCR within 2 minutes
- Ramp Down: 100% to 50% MCR within 2 minutes
- Continuous operating power range: 20 to 100% MCR
- Load rejection w/o trip: 100%

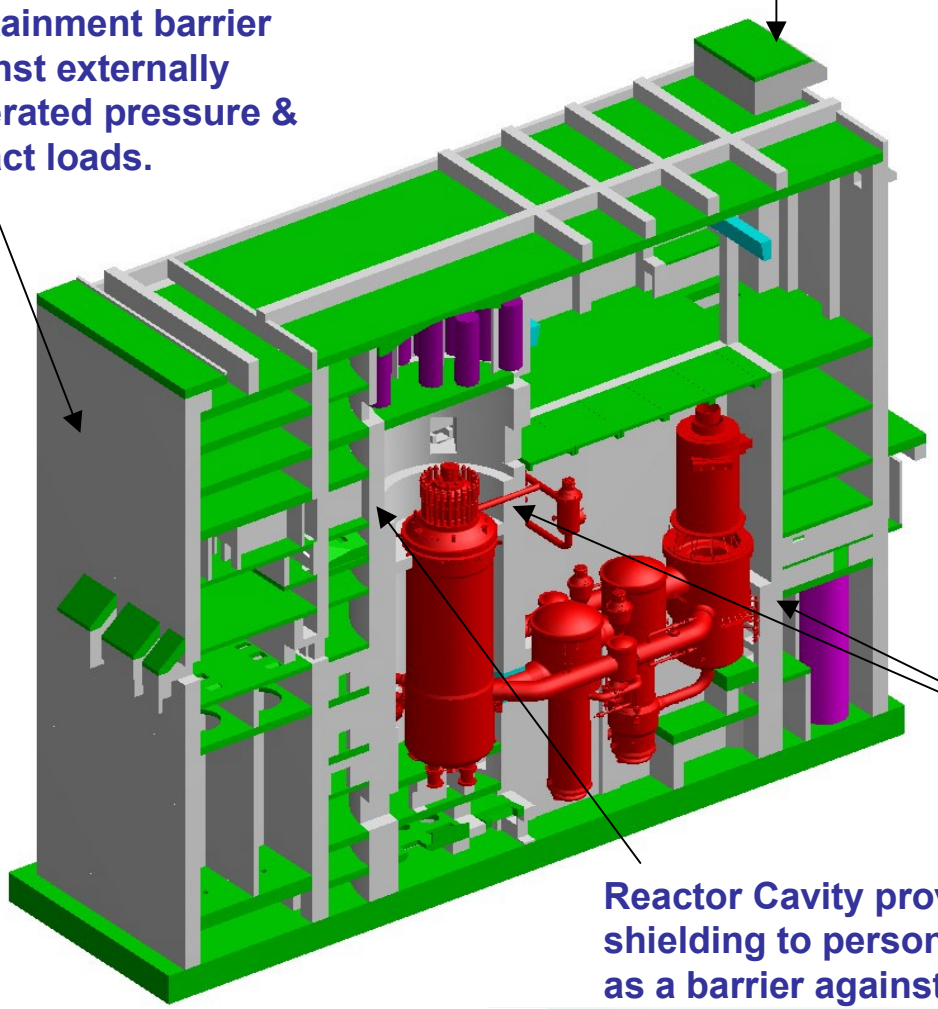
Demonstration Plant Specification

- Base construction cost: $1000/kWe
- Construction schedule (first concrete to fuel load): 30 months
- General overhauls: 30 days per 6 years
- Fuel costs: 4 mills/ kWh
- O&M costs: 5 mills/ kWh
- Seismic: SSE 0.4 g
- Aircraft: < 2.7 ton (no penetration)
  - Boeing 777 (penetration of outside shell and not the citadel;nuclear safety not compromised)

Demonstration Plant Specification

- Start from full shutdown (RSS inserted) to synchronization within 36 hours
- Black Starting is optional
- After LBE, 24 hours are allowed before operator action is required
- Availability : 95%
- Efficiency: > 41% at 28°C CWT
- > 42% at 18°C CWT
- Spent Fuel Storage: 40 years on-site

Module Building

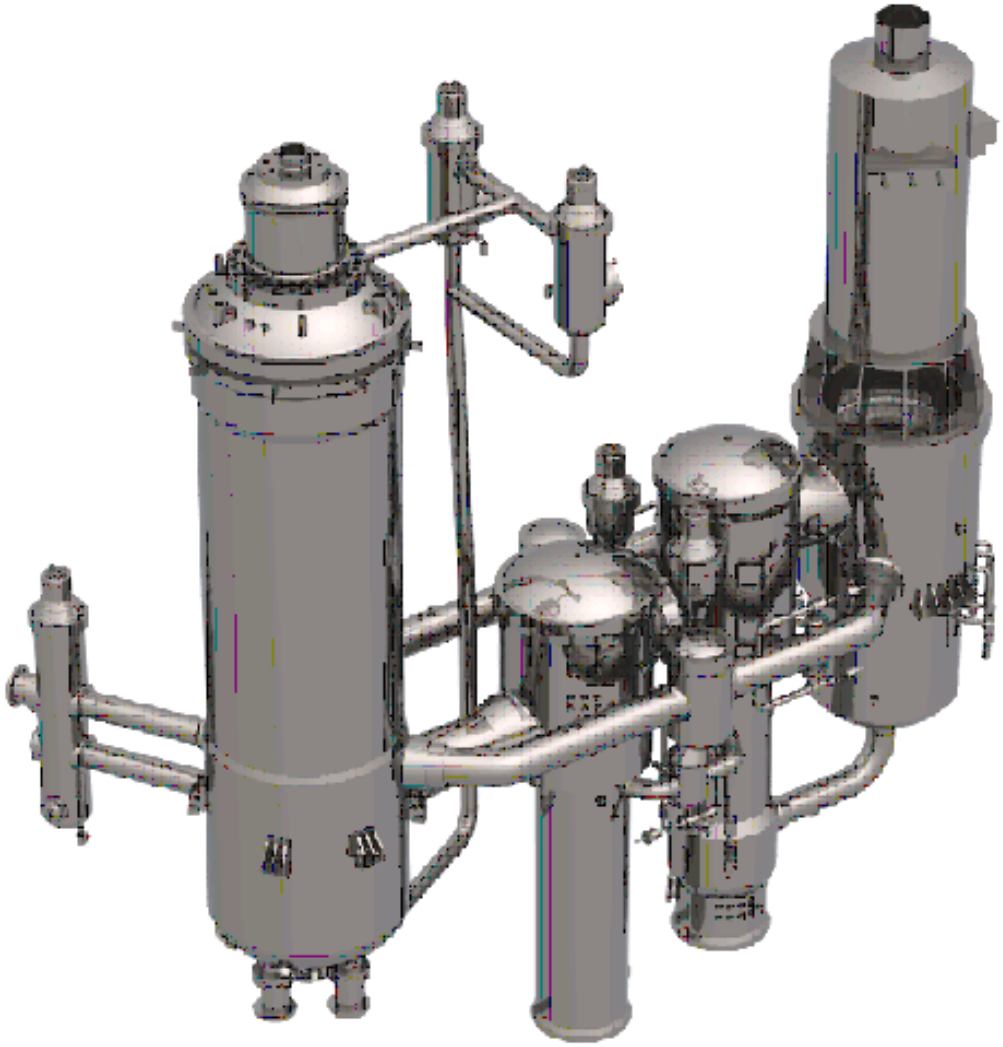


SPECIFICATION

Height total	62.9 m
Height above ground	40.9 m
Depth below ground	22 m
Width	37.0 m
Length	66.1 m
Levels (floors)	11
Material	40 MPa concrete
Seismic acceleration	0.4 g
Aircraft crash	< 2.7 ton no penetration 777 penetration outside shell; nuclear safety not compromised

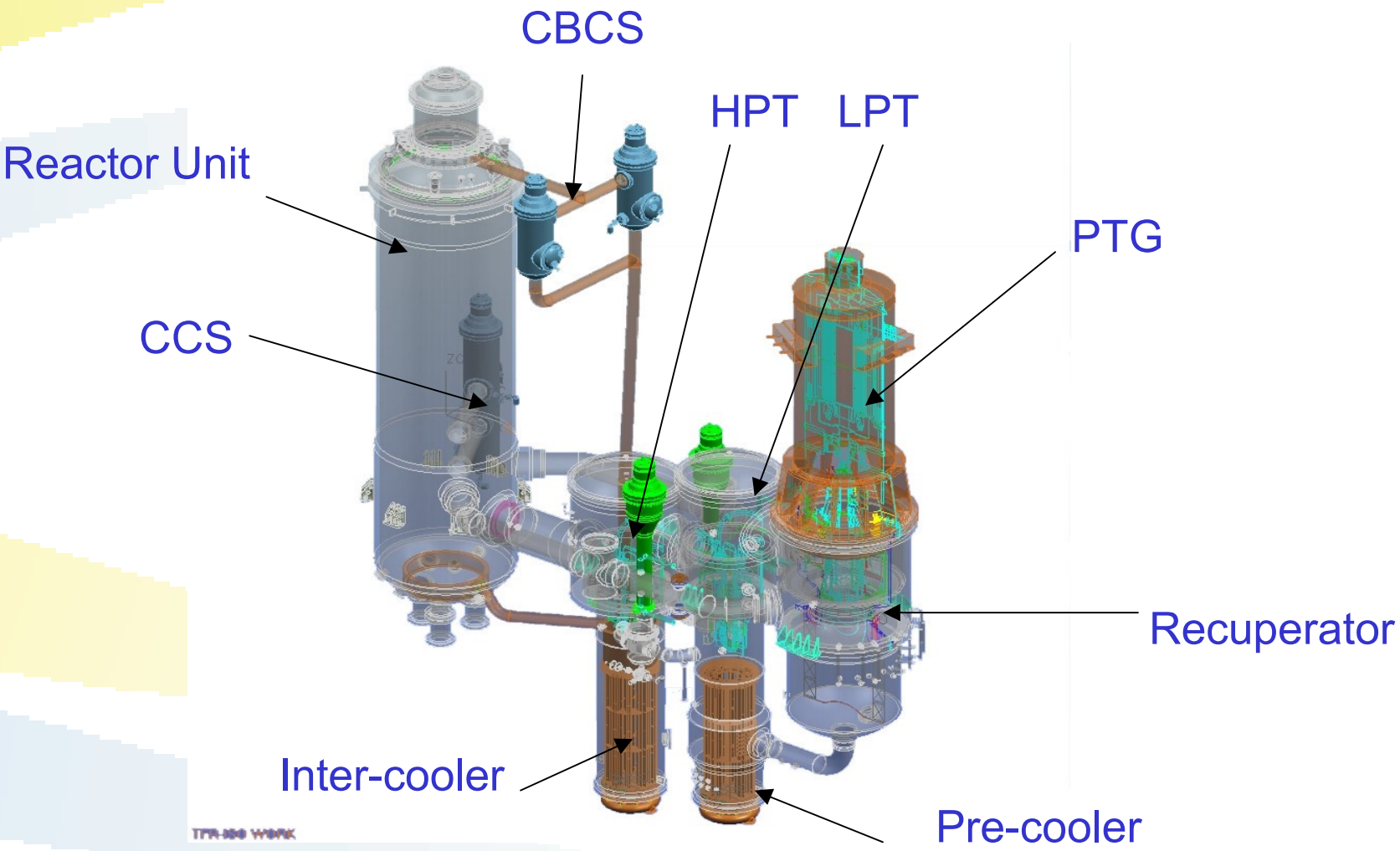
Main Power System

Main Power System

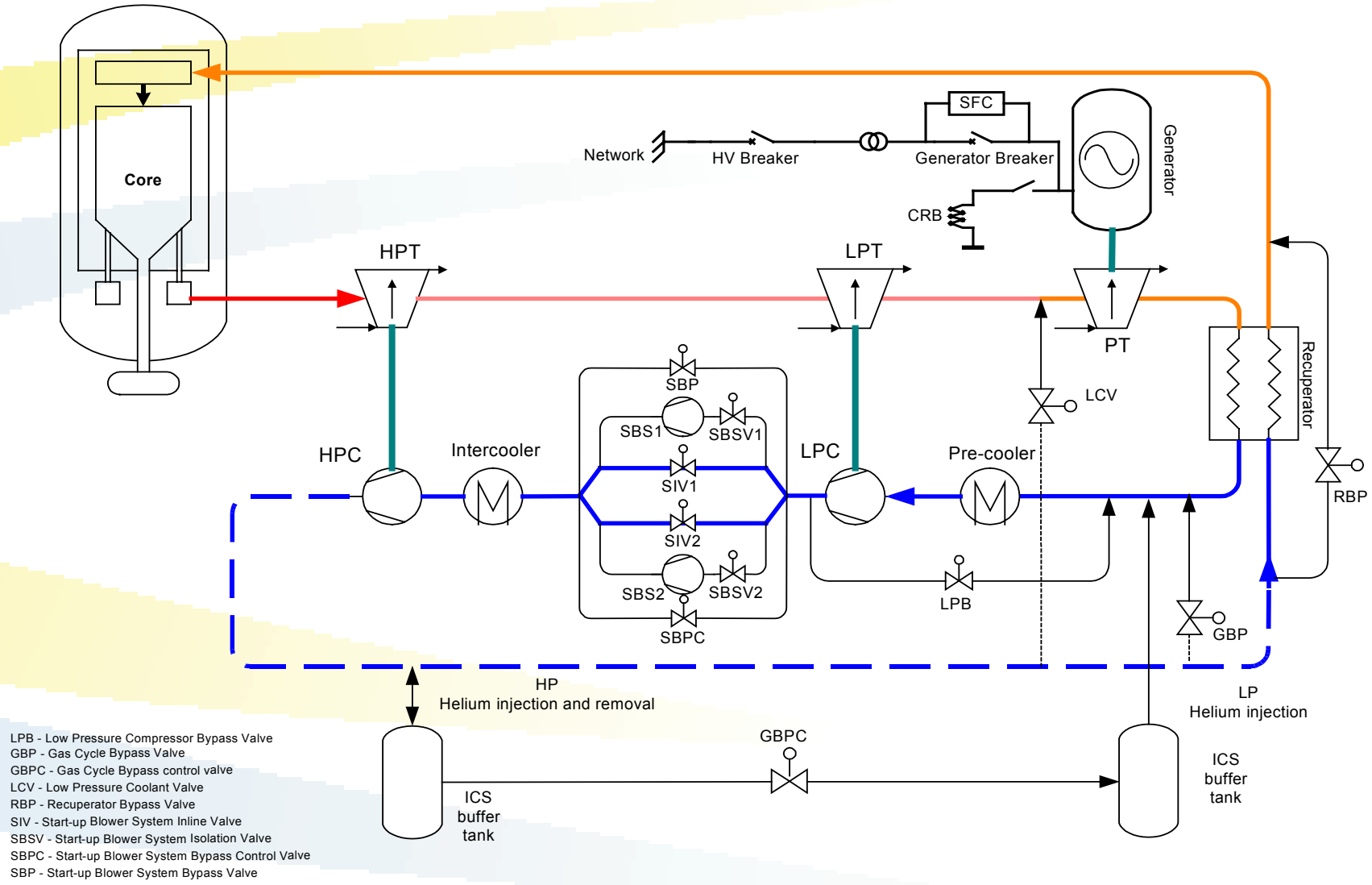


Specification	
Power output:	400MWt
	165 Mwe
Coolant:	Helium
Coolant pressure:	9 Mpa
Outlet temperature:	900°C
Total mass:	~4000 t
Helium mass:	10380 kg
Net cycle efficiency:	41%

Main Power System

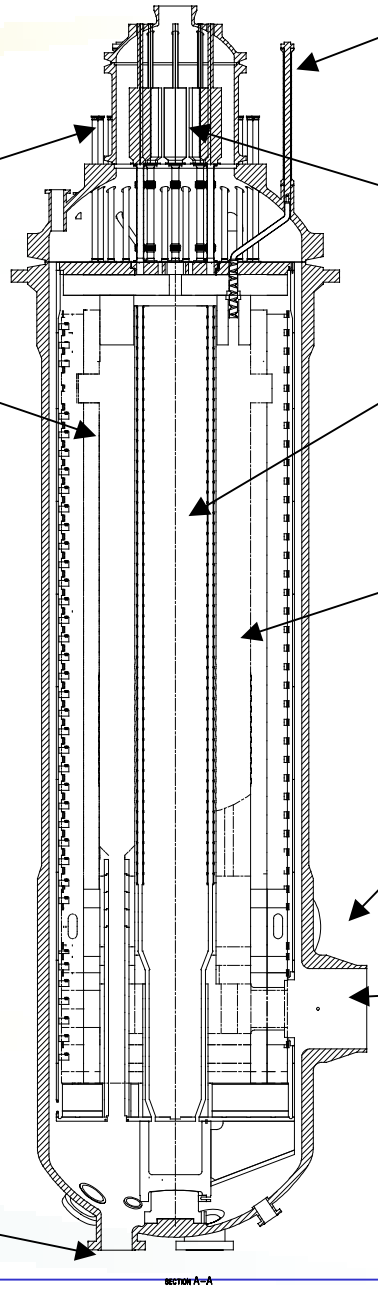


Schematic Diagram of the PBMR Main Power System



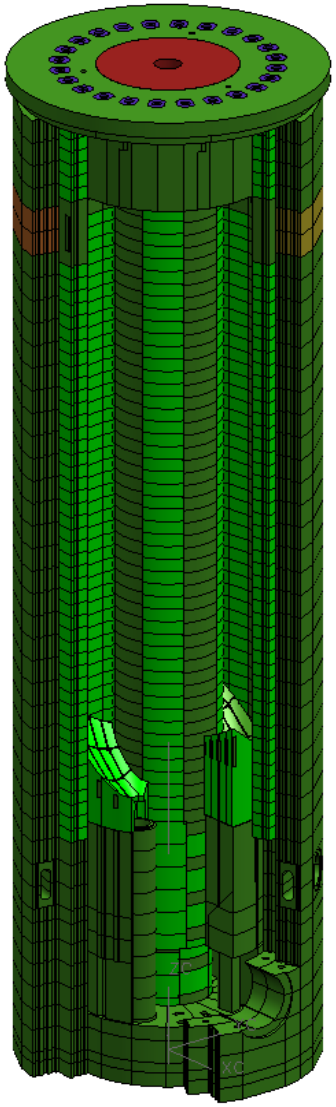
LPB - Low Pressure Compressor Bypass Valve
GBP - Gas Cycle Bypass Valve
GBPC - Gas Cycle Bypass control valve
LCV - Low Pressure Coolant Valve
RBP - Recuperator Bypass Valve
SIV - Start-up Blower System Inline Valve
SBSV - Start-up Blower System Isolation Valve
SBPC - Start-up Blower System Bypass Control Valve
SBP - Start-up Blower System Bypass Valve

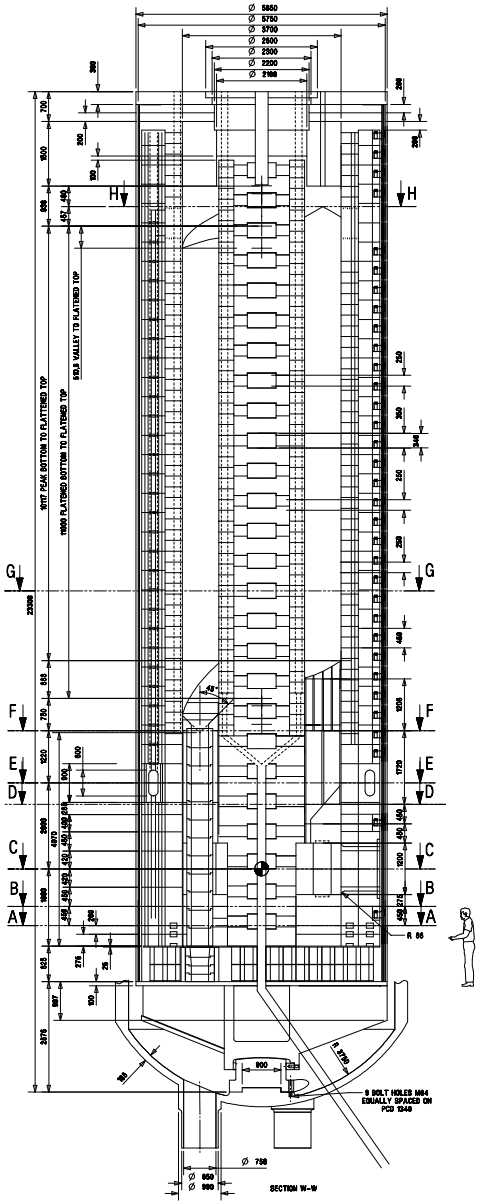
Reactor Unit Vessel Assembly



SPECIFICATION	
Total height RPV	30 m
Inside dia. RPV	6.2 m
Coolant	Helium
Max. helium pressure	9 MPa
Normal Ops. temp. of RPV	300°C
RPV vessel material	SA 508 Forgings
RPV mass assembled	~1700 t
RPV vessel mass	1000 t (lid included)

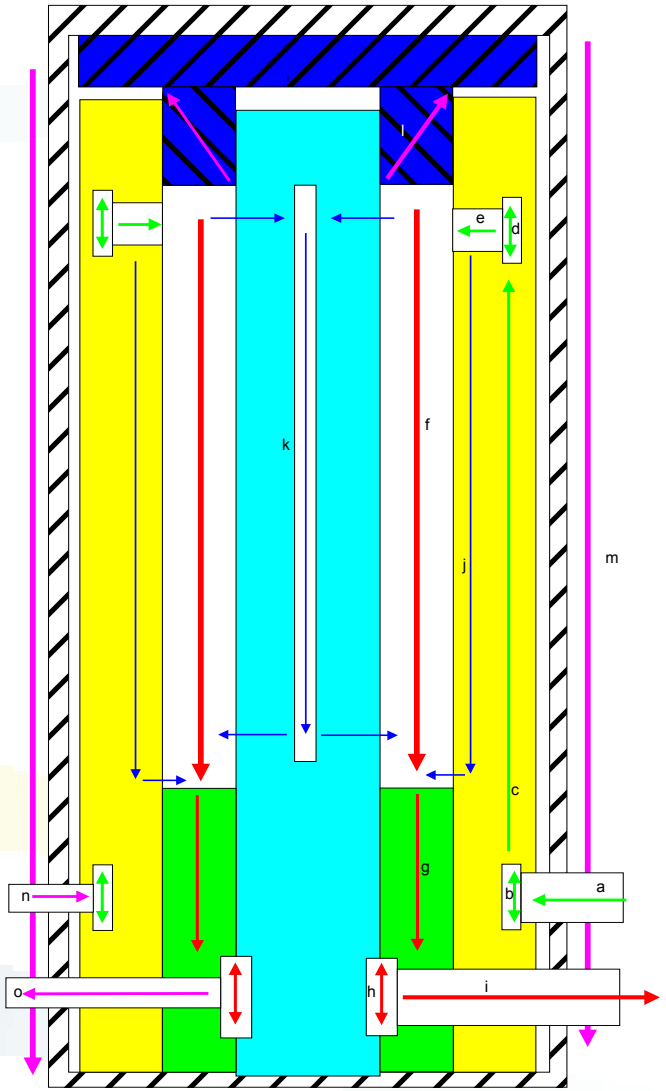
Core Structure Assembly





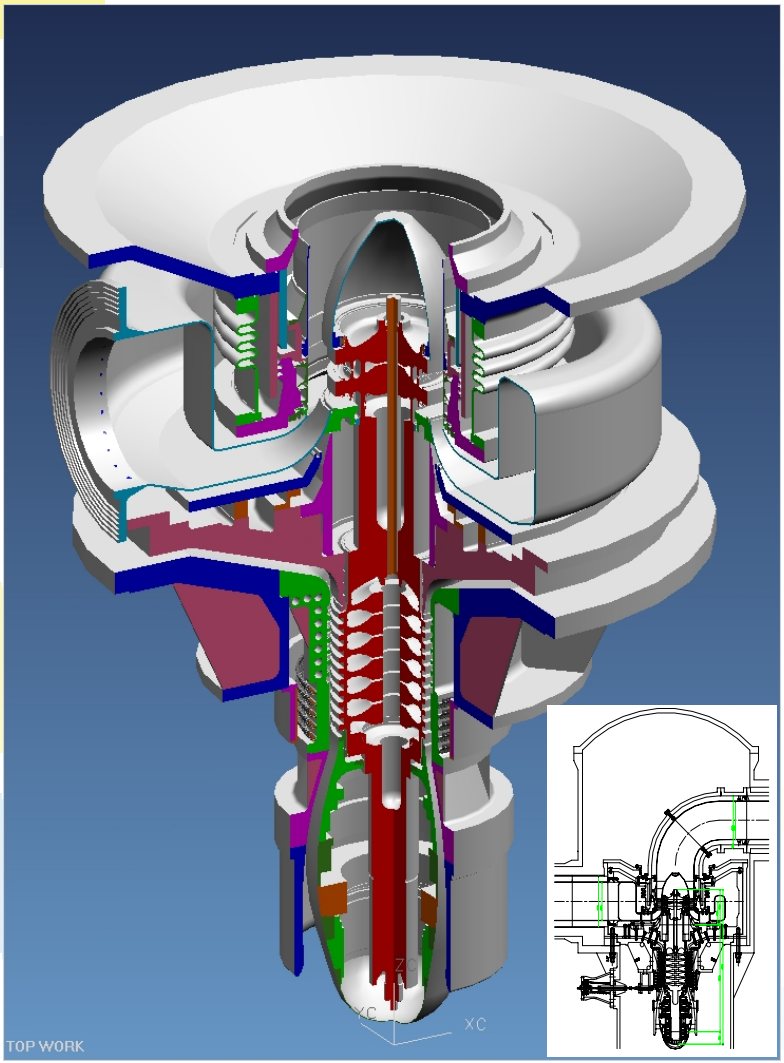
SPECIFICATION	
Total height of core barrel	22 m
Outside dia.	5.85 m
Coolant	Helium
Max. operating pressure	9 MPa
Max gas outlet temp.	900°C
Barrel material	316 Stainless
Barrel structure mass	250 t
Graphite mass	390 t

Primary and Secondary Coolant Flow Paths in core Structures

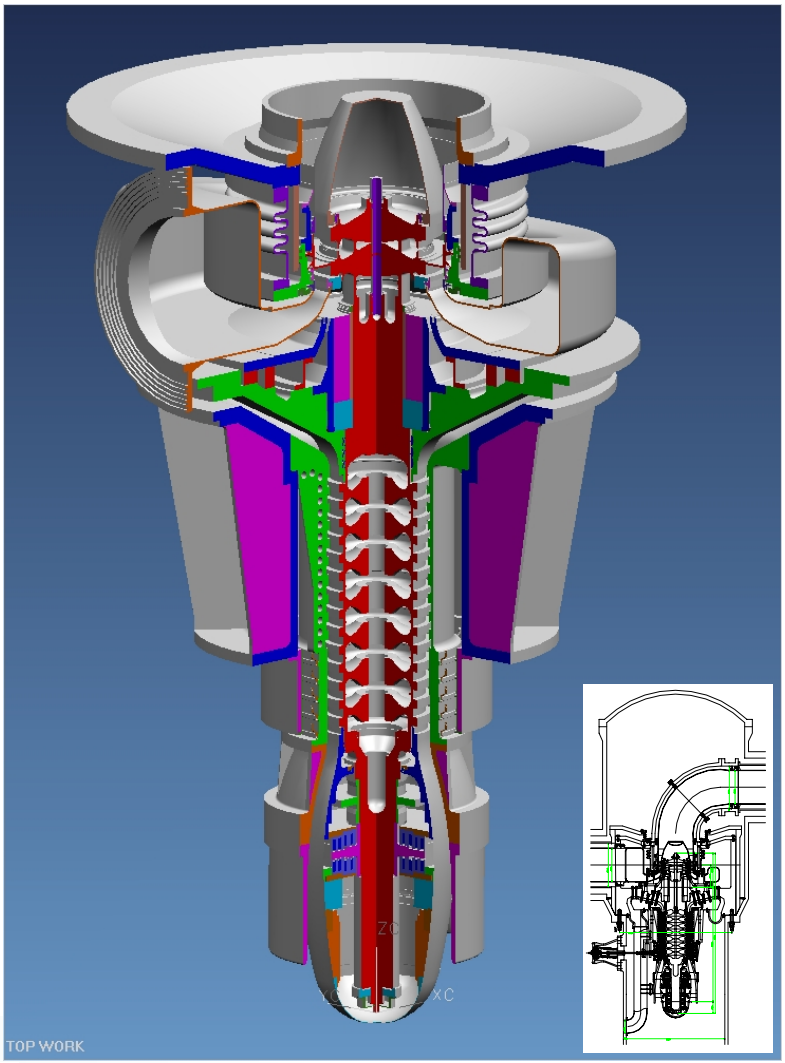


Turbine Units

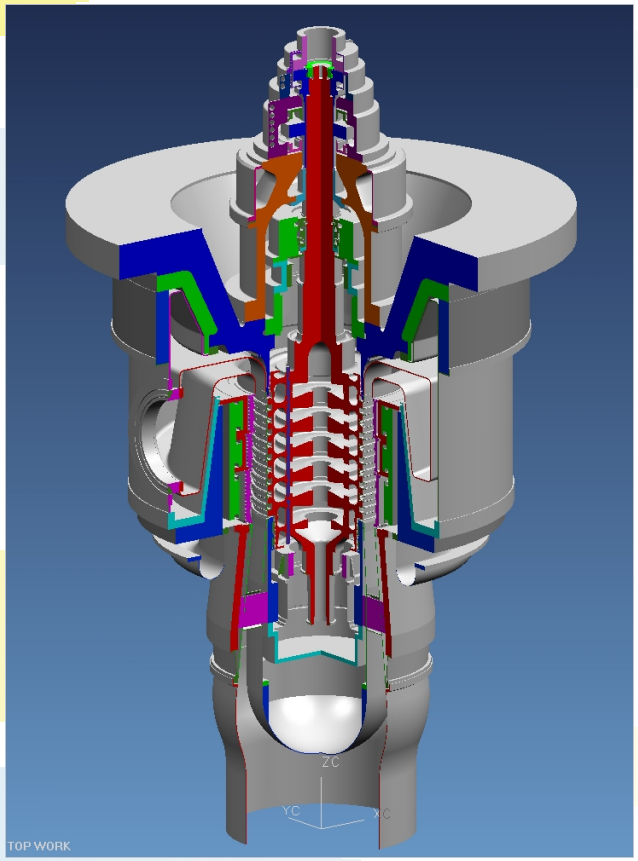
High Pressure Turbine Unit



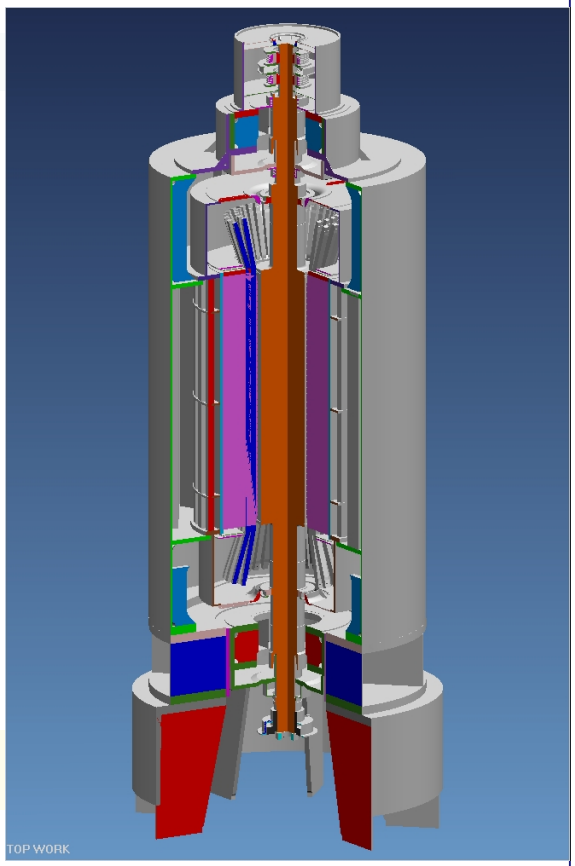
Low Pressure Turbine Unit



Power Turbine Generator



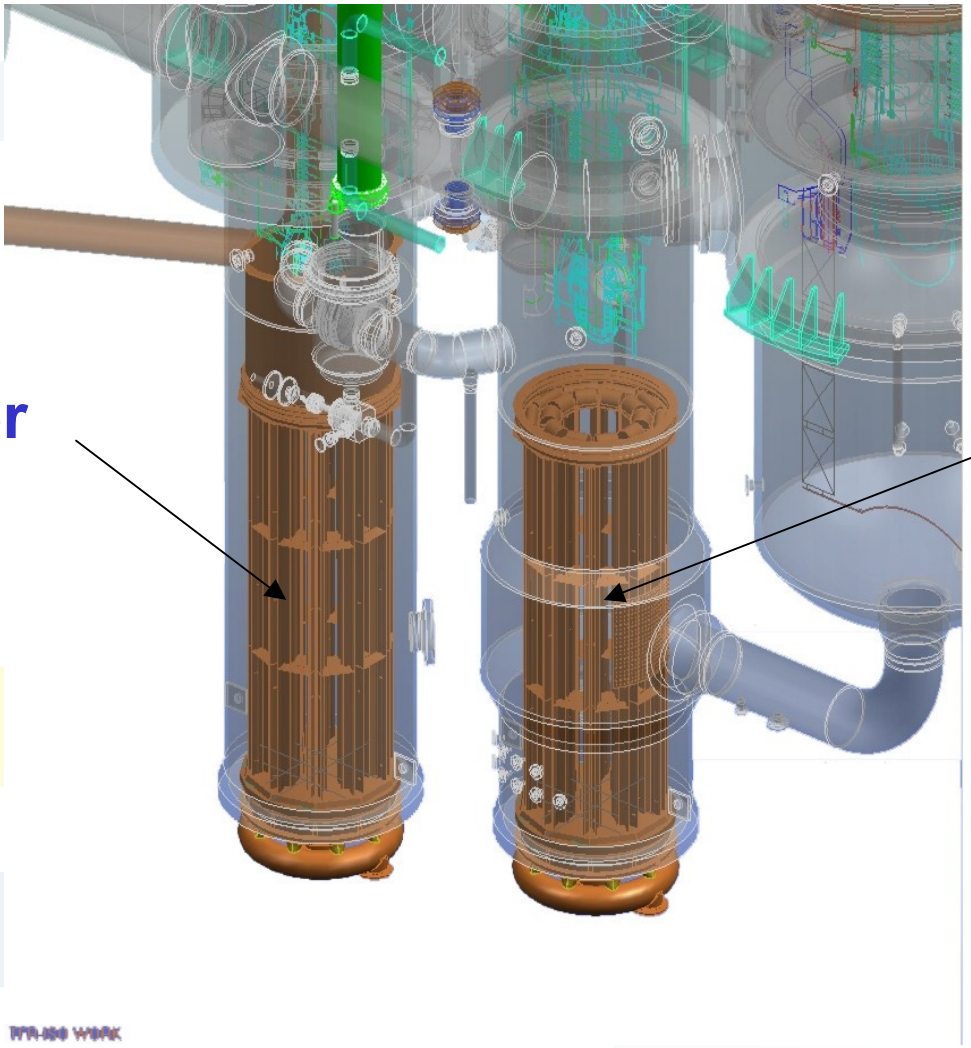
Power Turbine Unit



Power Generator

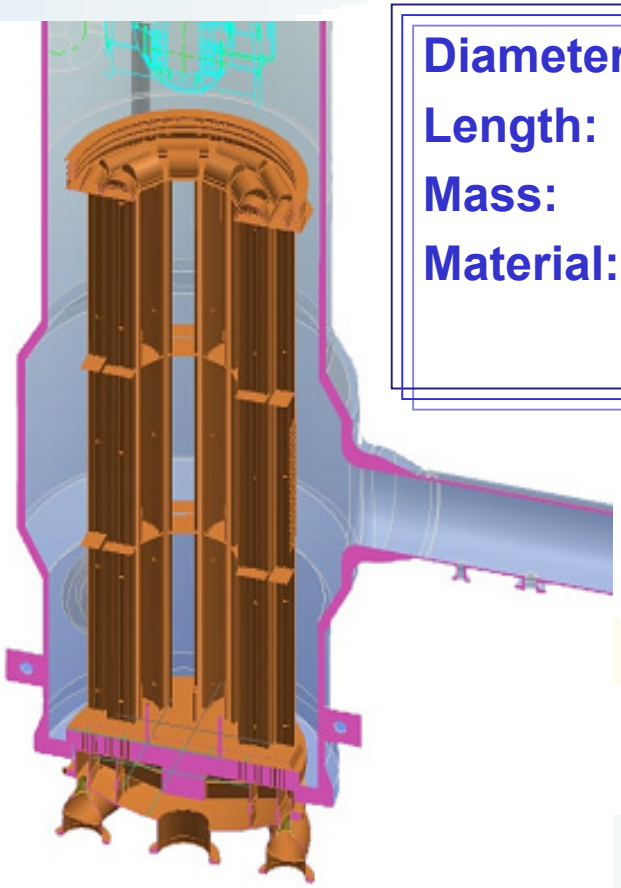
SPECIFICATION	
Total PTG Shaft Length	20.1 m
Total PTG Shaft Mass	88 t
PG:	
Coolant	Air
Height (Inlet to Top)	17.2 m
Mass PG	326 t
PG Frequency output	50 Hz
PG Power output	180 MW , 11 kV PF=0.85
PTU:	
Medium	Helium
Height PT (Inlet to Outlet)	4.4 m
Tip Dia. (typical)	2.1 m
Mass PT	338 t
PT speed	3000 rpm
Stages	10
Efficiency	93.5%
Mass flow	194 kg/s

Position of Pre- and Inter-coolers



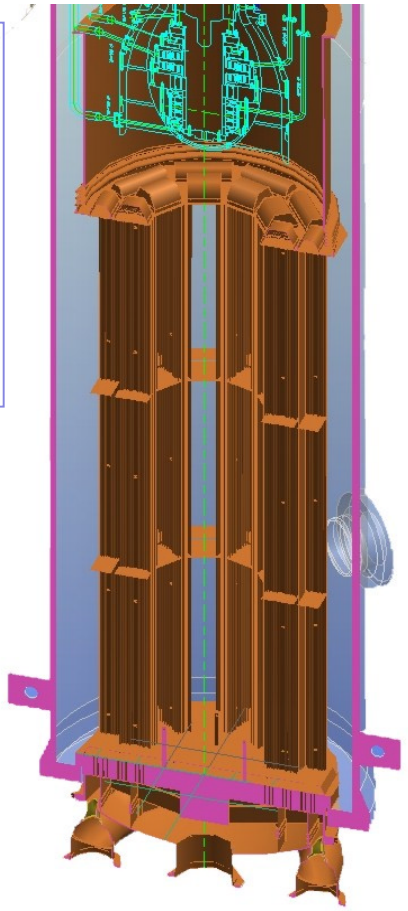
Pre-cooler and Intercooler

Pre-cooler

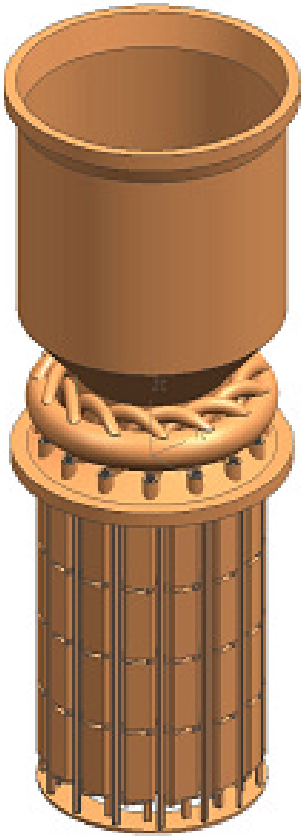


Diameter: 2.7 m
Length: 6.0 m
Mass: 50 Tonnes
Material: Carbon steel tubes/ Aluminium fins

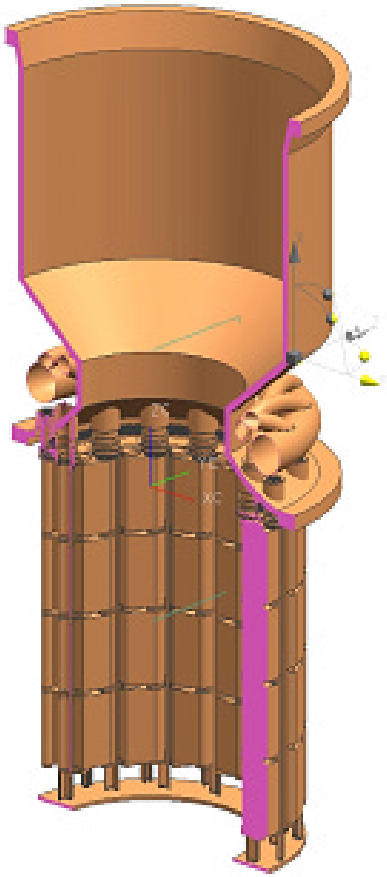
Inter-cooler



Recuperator

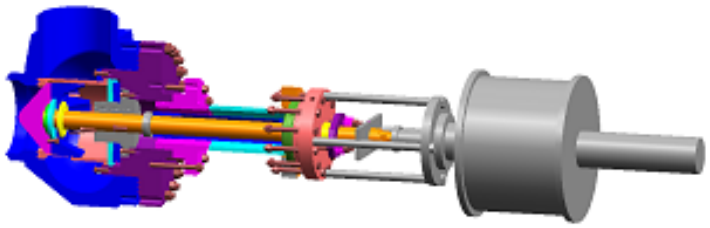


Diameter:	**5.5 m**
Length:	**5.0 m**
Mass:	**60 Tonnes**
Material:	**SS 304**

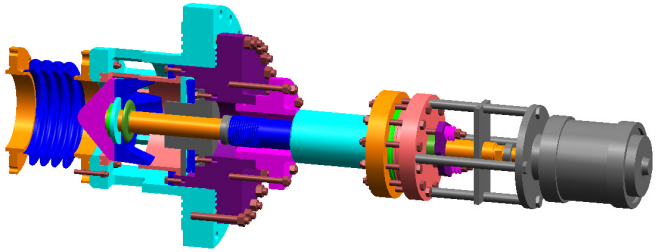


Gas Cycle Valves

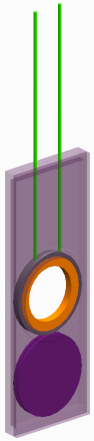
Gas Cycle Bypass Valve



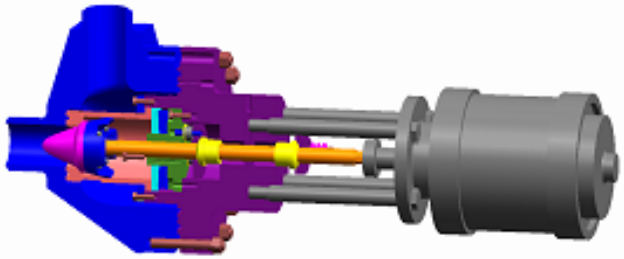
HP & LP Coolant and SBS Control Valve



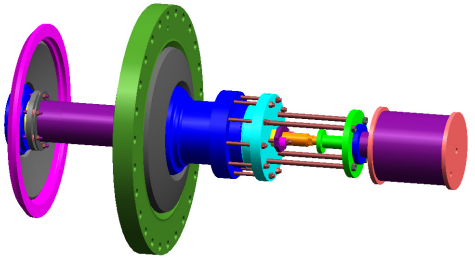
Maintenance Shut-off Disc



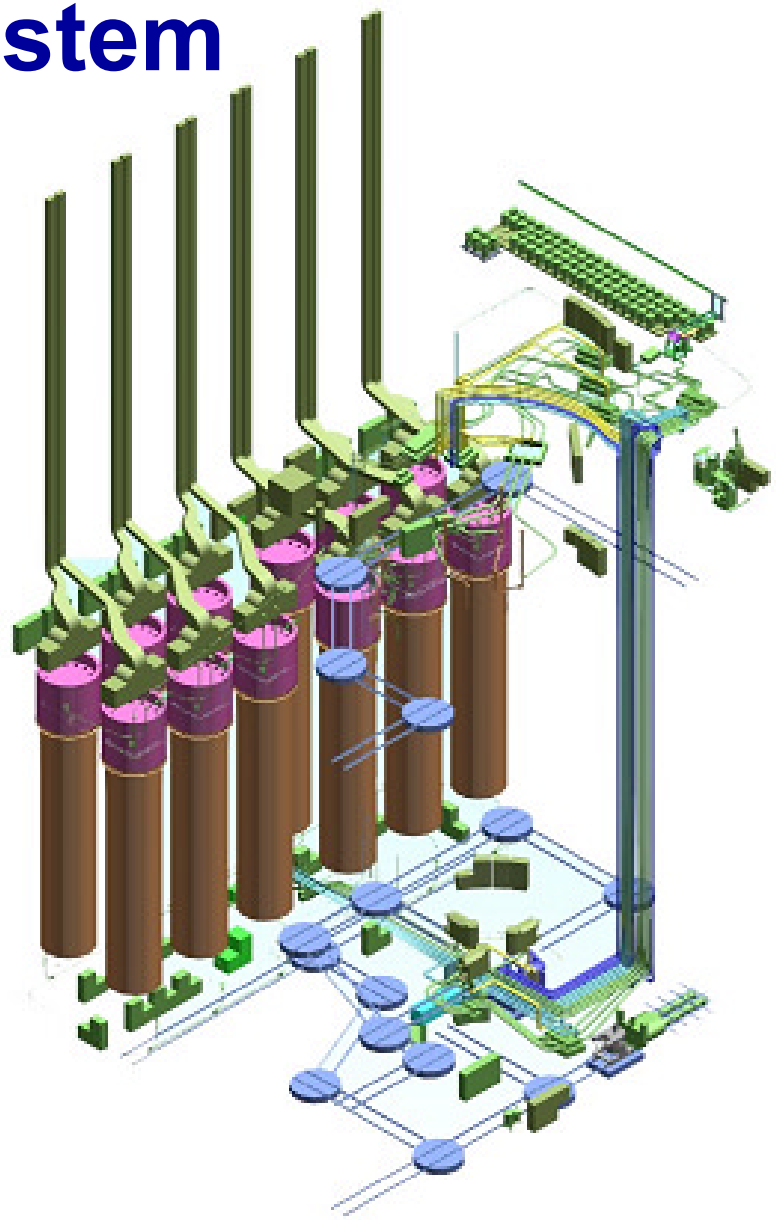
HPC, LPC & Recuperator Bypass Valve



SBS Inline Valve

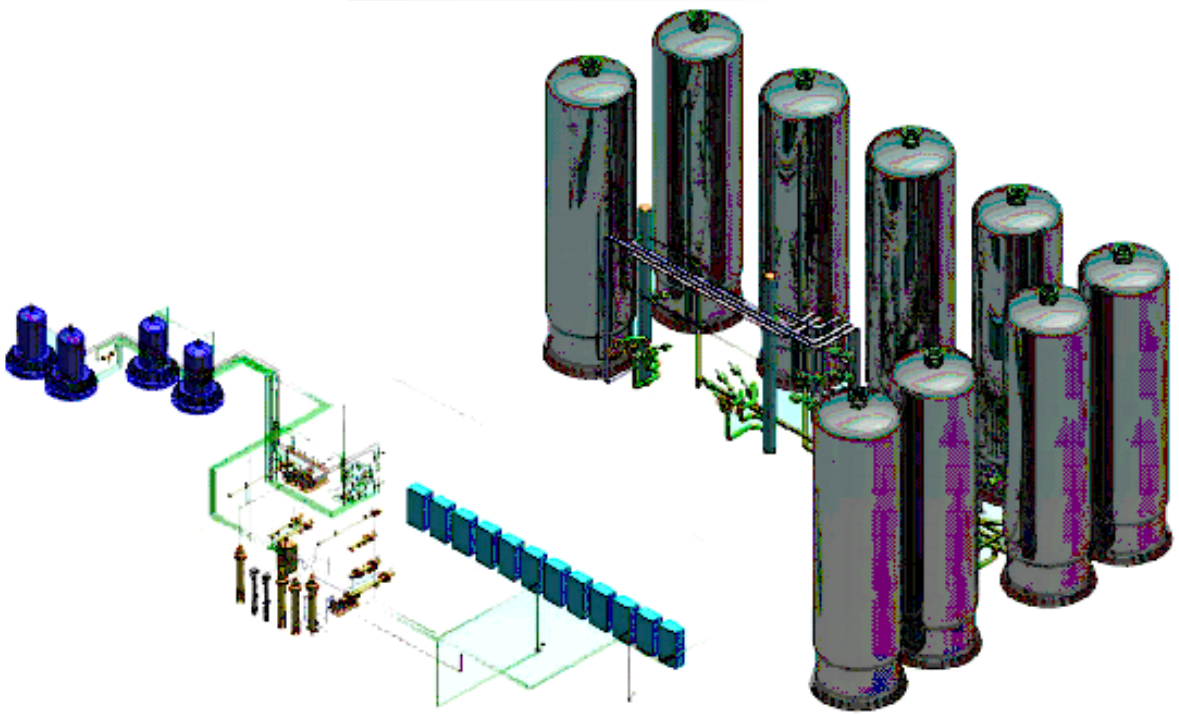


Fuel Handling & Storage System



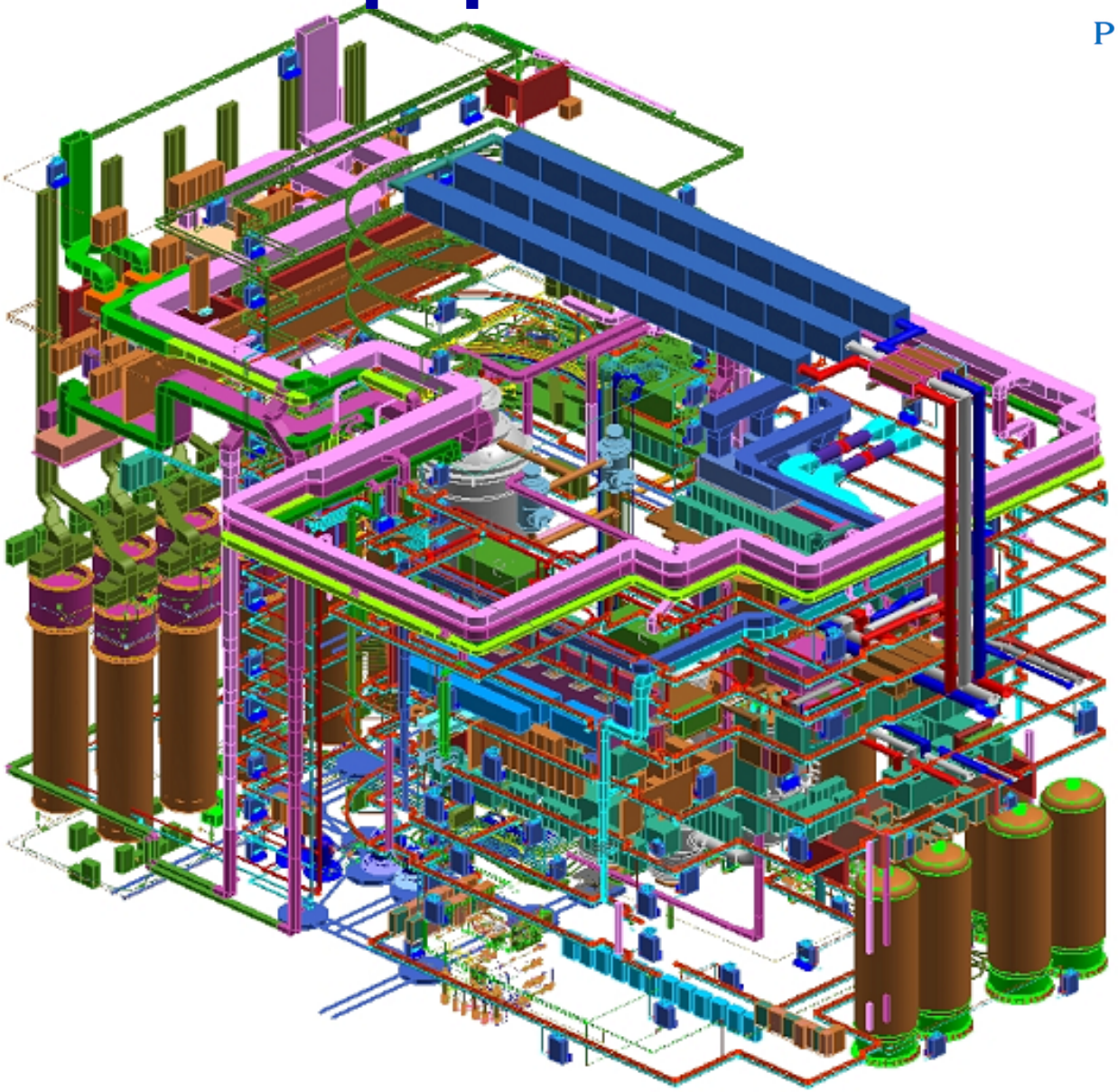
SPECIFICATION	
Medium	Helium
Daily sphere circulation rate	2900
Hourly sphere circulation rate	500/600
Daily operating time	12 hours
Number of fuel passes through core	6
Operating pressure	1 – 9 MPa
Operating temperature	20 - 260ºC
Fuel spheres in core	451555
Fuel sphere feeding points	3
Core defueling points	3
Fresh fuel storage capacity	70 canisters
Fresh fuel canister capacity	1000 spheres
Spent fuel storage capacity	6 000 000 spheres
Number of spent fuel tanks	10
Spent fuel period	80 yrs.

Helium Inventory Control System

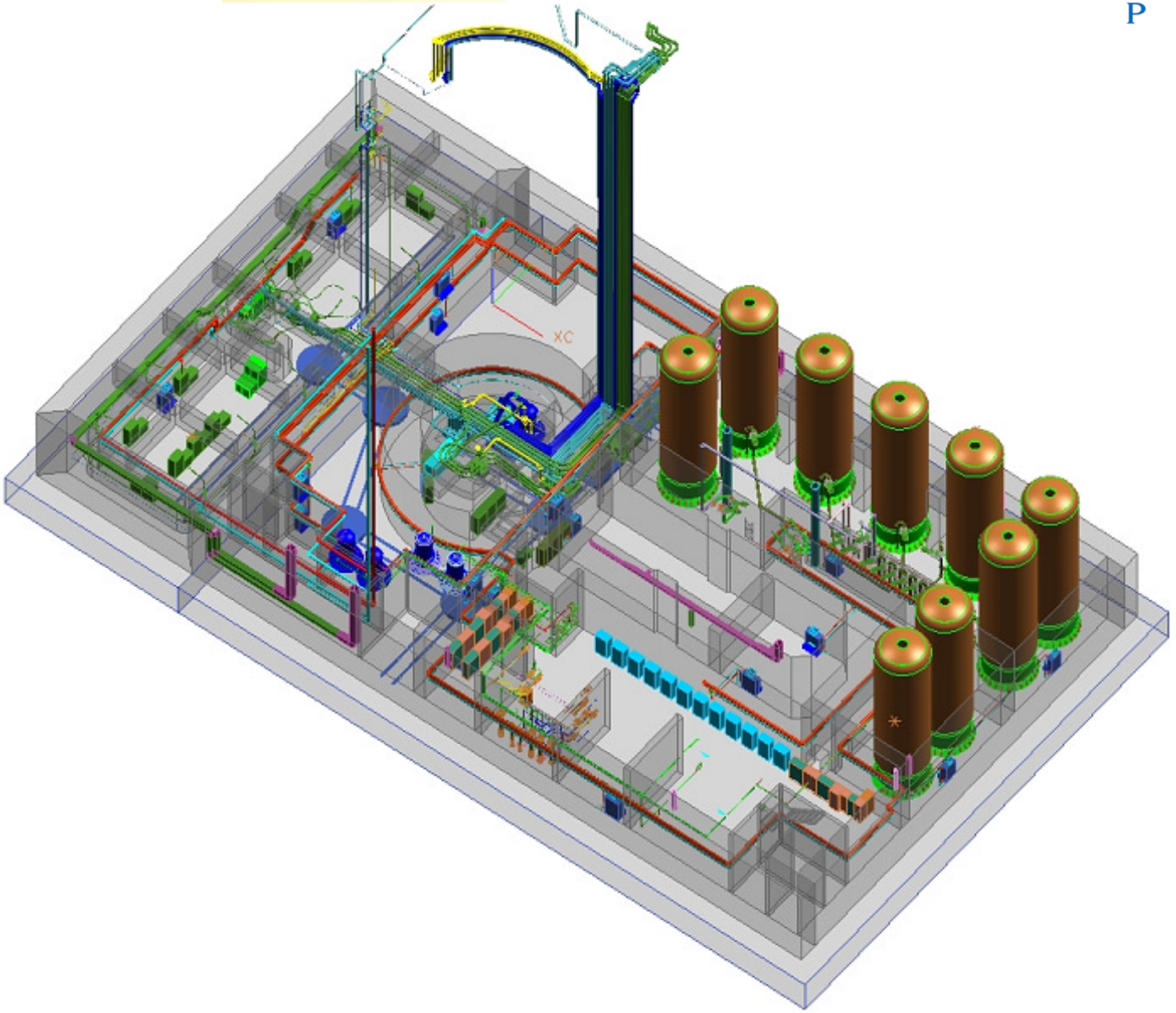


SPECIFICATION	
ICS:	
Medium	Helium
Storage Capacity	12300 kg
Storage pressure	6.2 -9.4 MPa
Flow rate @ 10% inventory	13 kgs
High pressure	
compressor flow rate	9 kg/min
Multipurpose	
compressor flow rate	35 kg/hr
Mass of tanks	135- 200 t
HPS:	
Bypass flow rate	0.5 µm
Filters dust particles	> 0.5 µm
Removes gaseous impurities:	
H2	< 1 ppmv
00	< 1 ppmv
C02	< 0.1 ppmv
H20	< 0.1 ppmv
CH4	< 1 ppmv
N2	< 1 ppmv
HMS:	
Replenishes daily leakage	8 kg/day
Storage Capacity	432 kg he1ium
Containment	18 packs of 16 cylinders each
Cylinder capacity	1.5 kg he1ium @ 220 bar

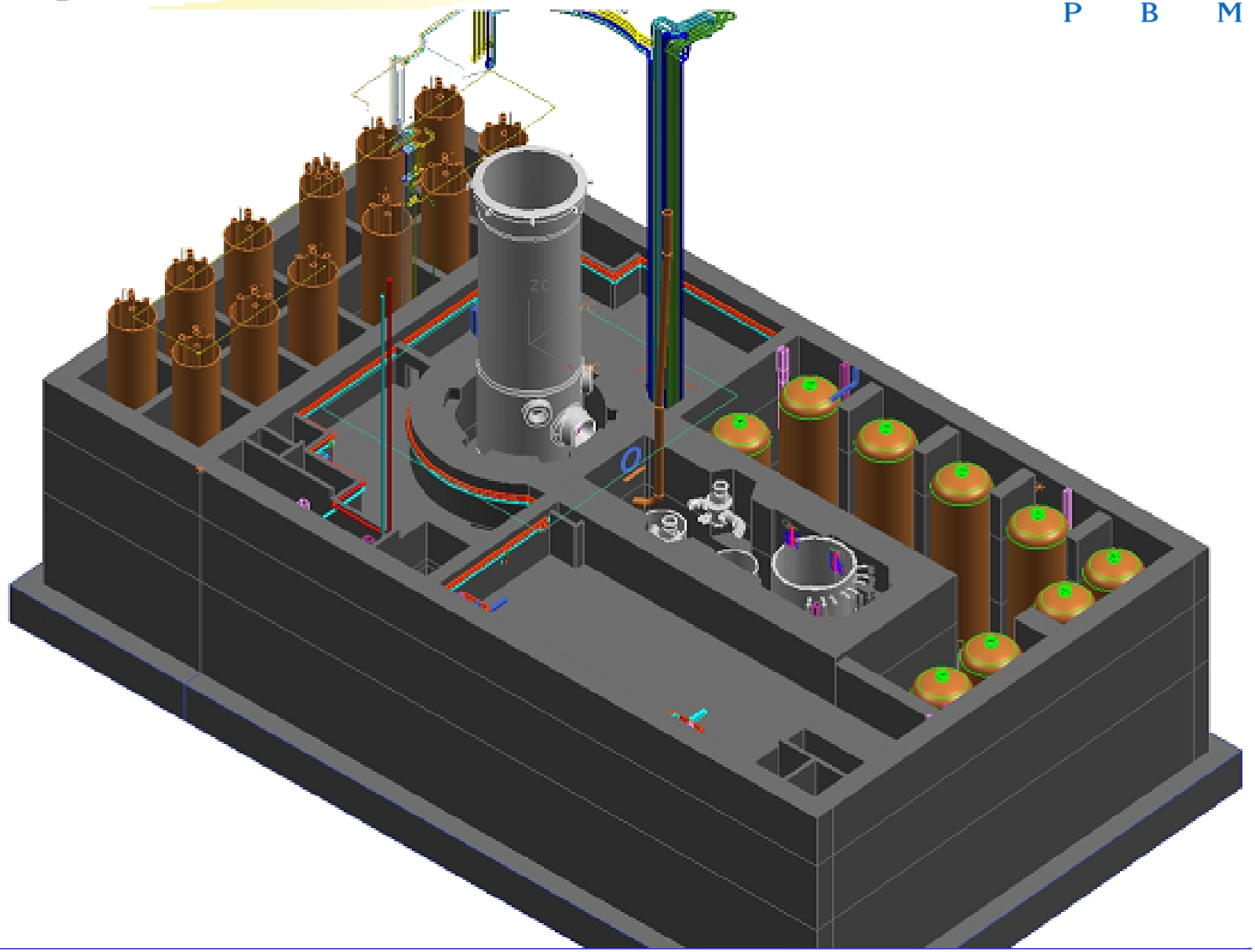
Equipment



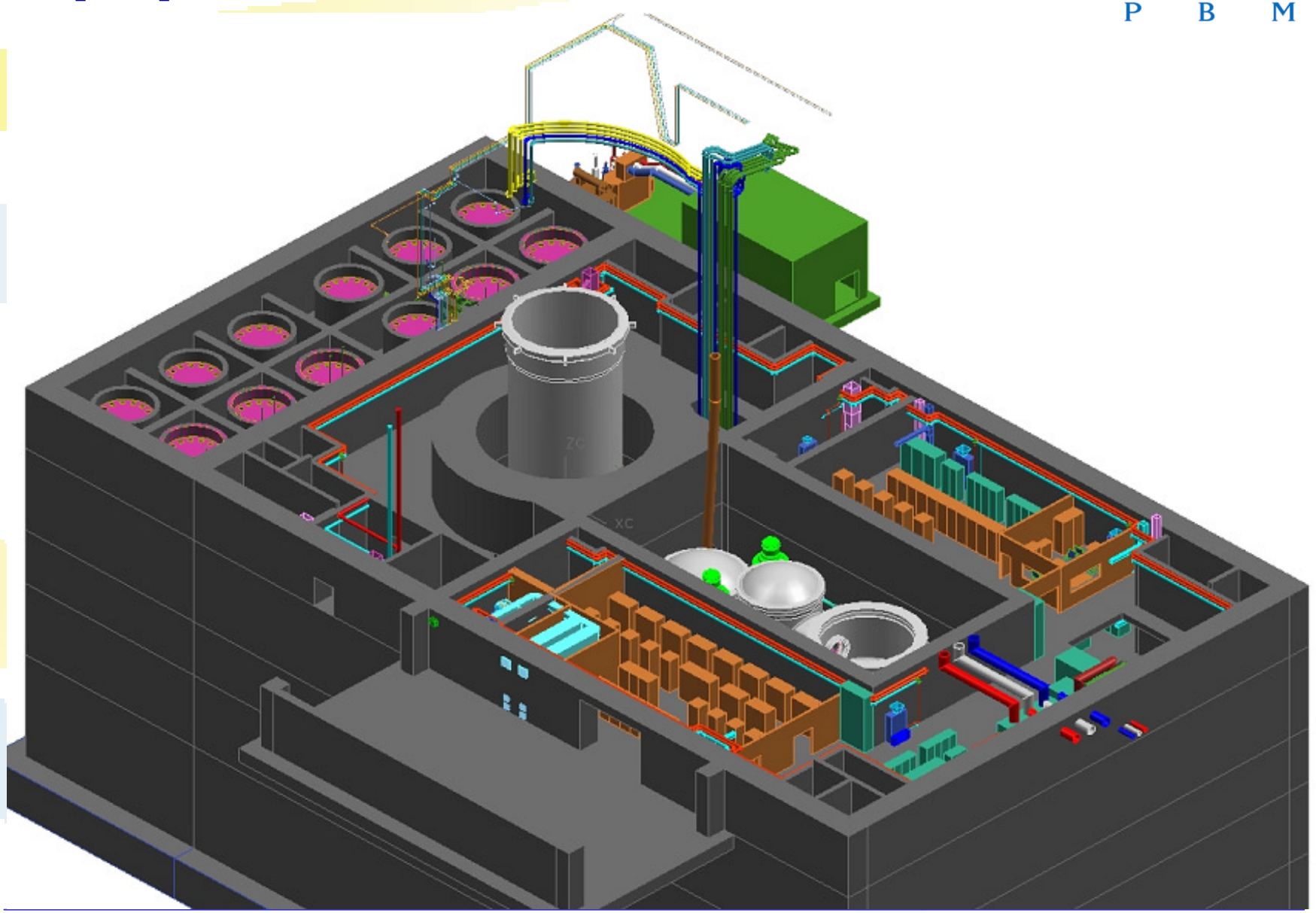
Equipment at –22 m



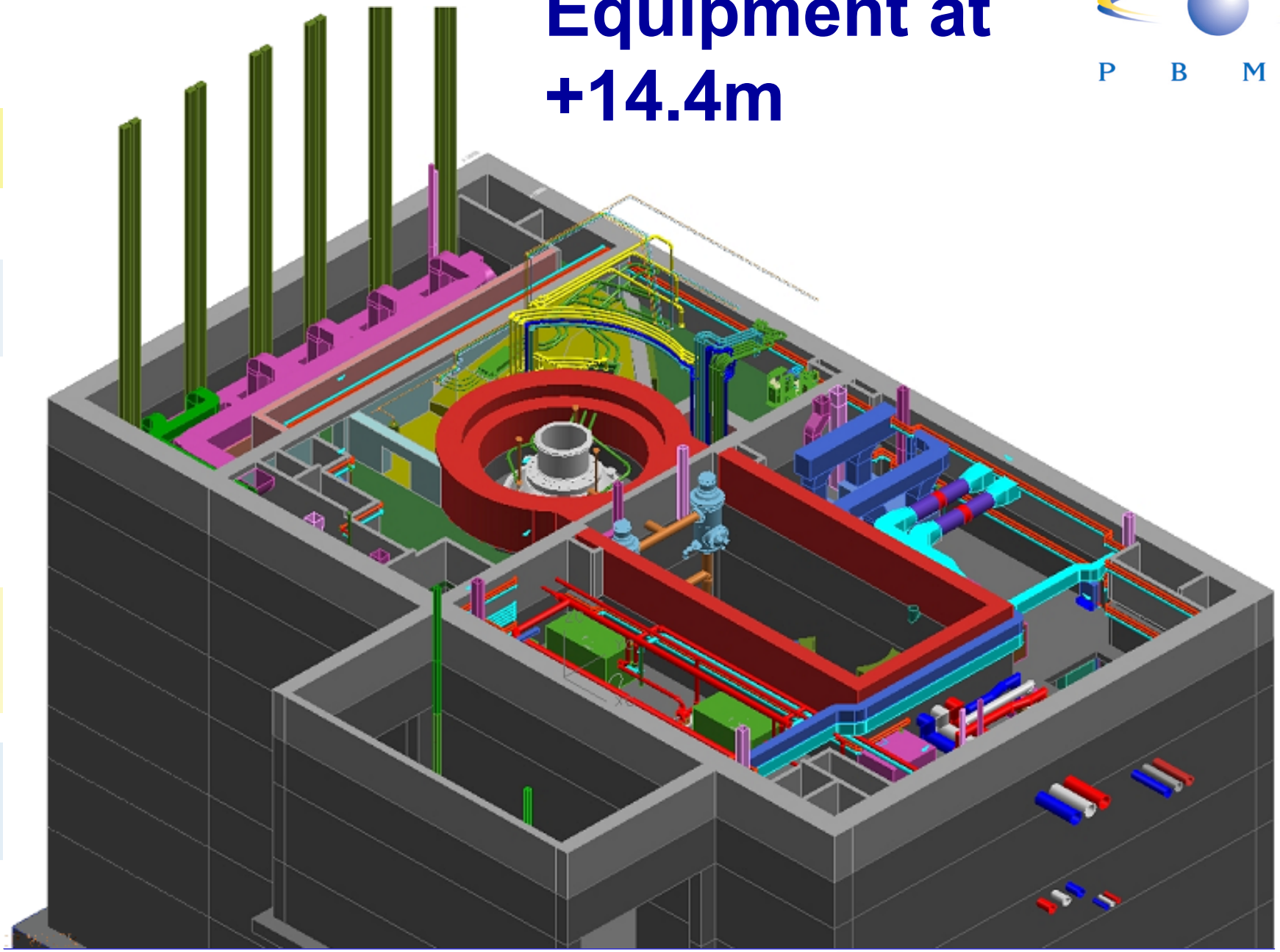
Equipment at –10 m



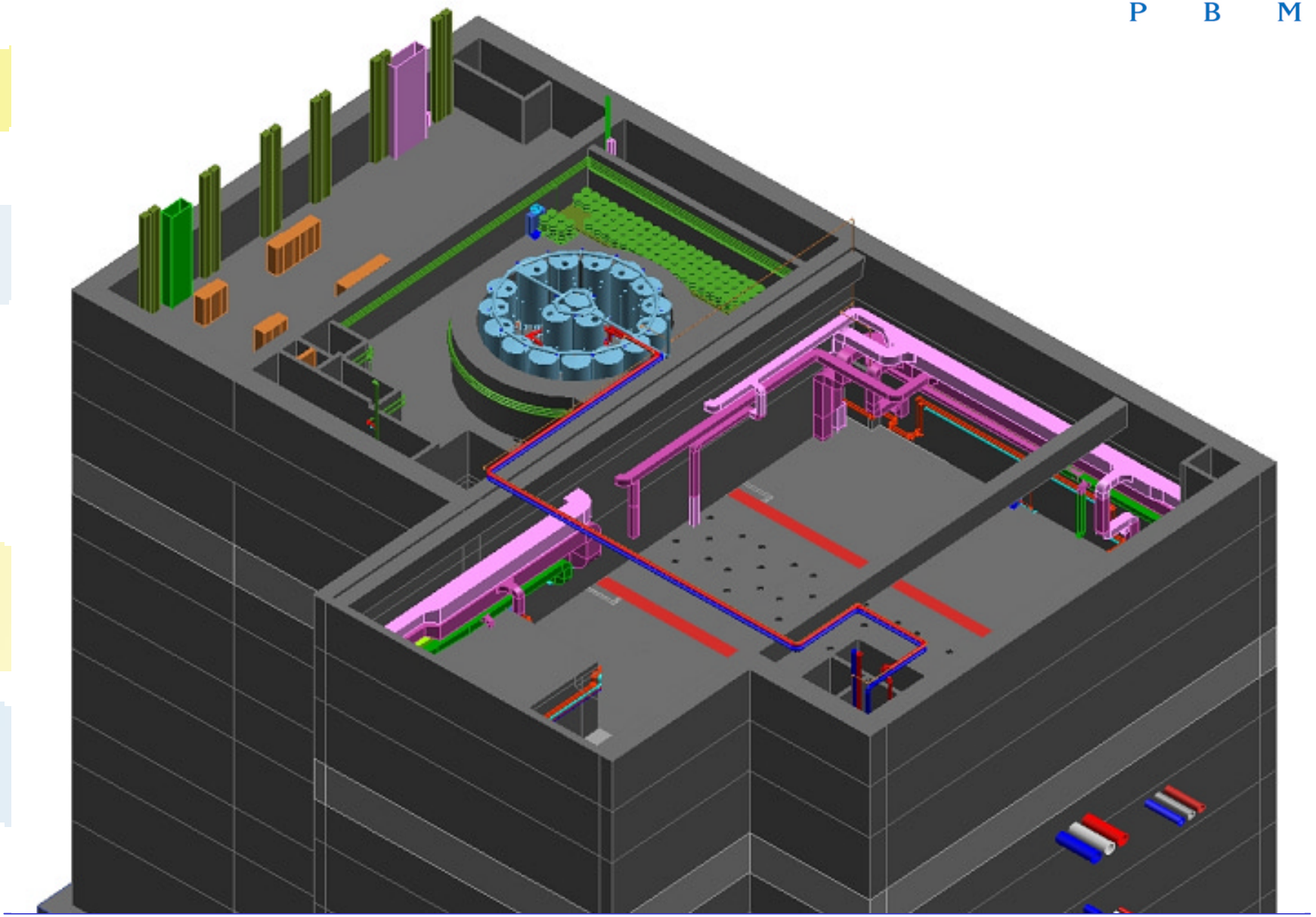
Equipment at +7m



Equipment at +14.4m



Equipment at +27.9m



Power Plant Design Overview

Purpose of the Multi Module Plant Conceptual Design and Layout

To estimate the cost of the MM Plant:

- Minimum cost configuration for a base load plant
- Technical reference for the Business Case
- Optimal sharing of components between modules
- Demonstration Plant components integrated into the MM Plant Layout

Power Plant Design Overview

Shared Plant - MM Plant

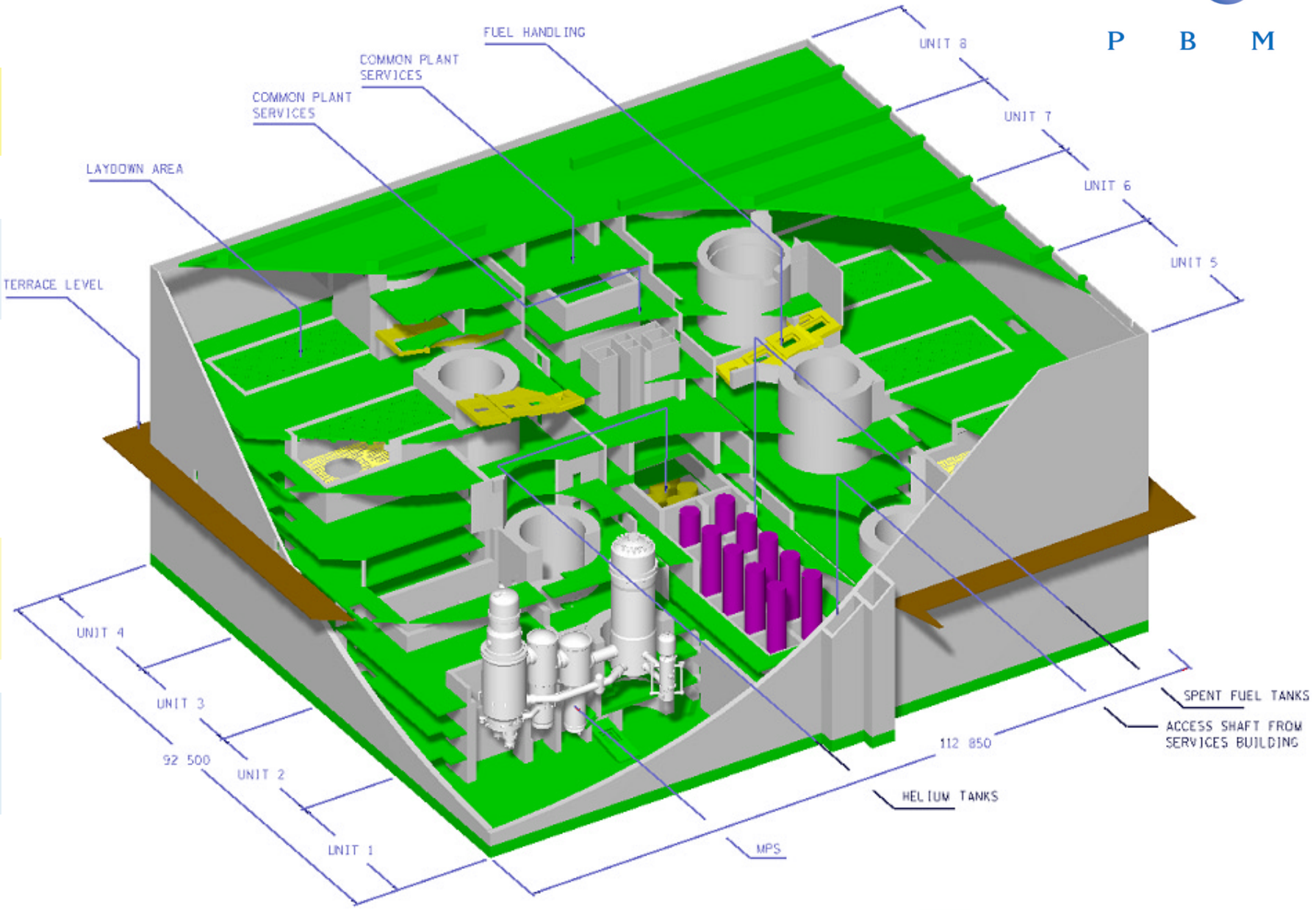
- Helium Inventory Storage: 1 x 200% capacity
- Helium Purification: 2 systems
- Helium Make-up: 2 stations
- Spent Fuel Storage: 10 years capacity
- Used Fuel Storage: 2 x 100% capacity tanks
- Graphite Storage: 2 x 100% capacity tanks
- HVAC blowers and chillers
- One Remote Shutdown Room
- One set of Special Tools
- One Primary Loop Initial Clean-up System
- Selected Equipment Handling
- Fire Protection Reservoirs and Pumps
- Generator Lube Oil System & Transformer (shared per 2 modules)

Power Plant Design Overview

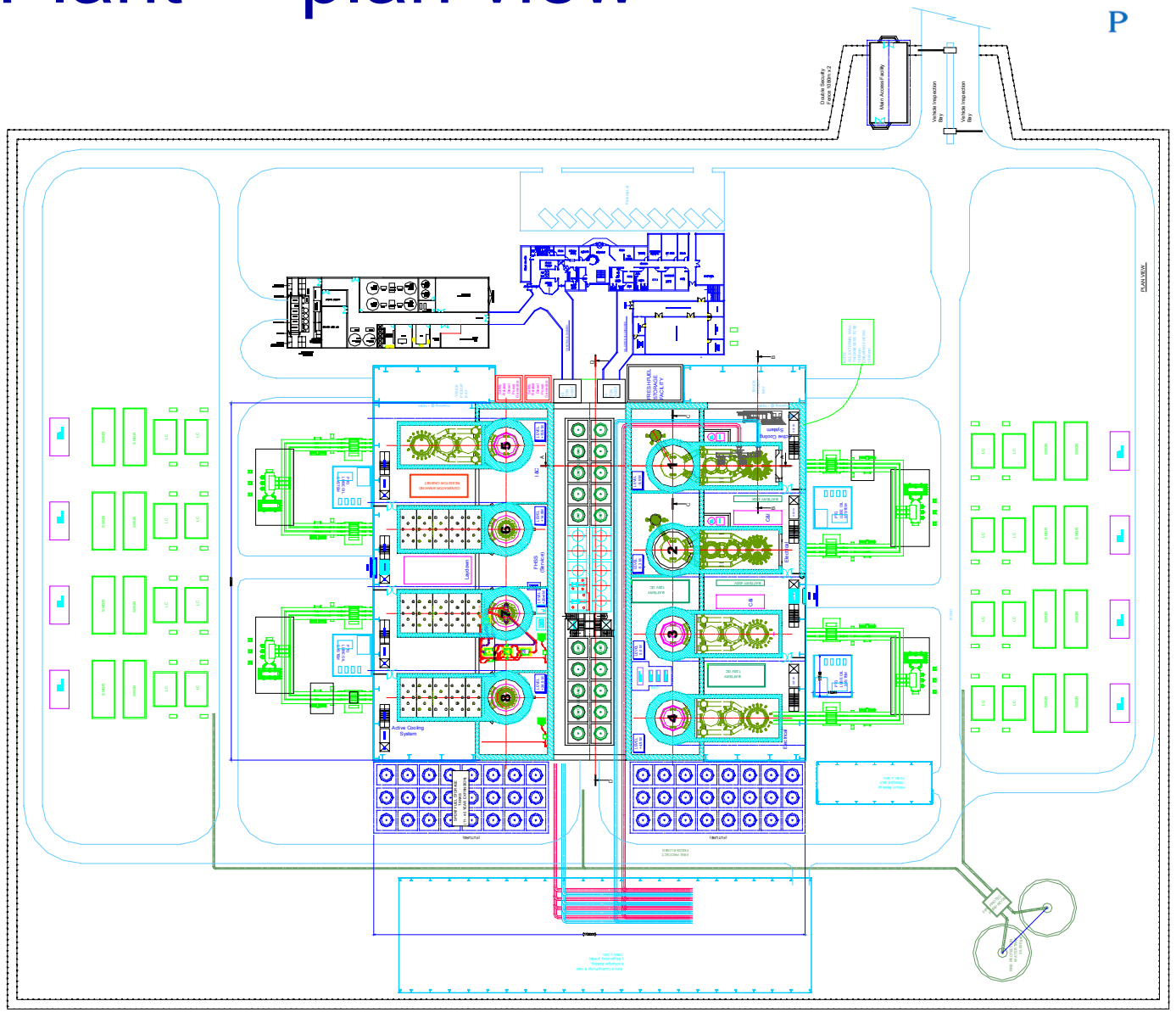
Non-Shared Plant - MM Plant

- Main Power System including Gas Conditioning Systems
- Fuel Handling (excluding storage systems)
- Reactor Cavity Cooling
- Active Cooling
- Control and Instrumentation (RPS, PEI, OCS,EPS)
- Helium Inventory Trim Tank
- Compressed Air – High & Low Pressure
- HVAC air circulation
- Fire Protection inside the Module
- Resistor Bank

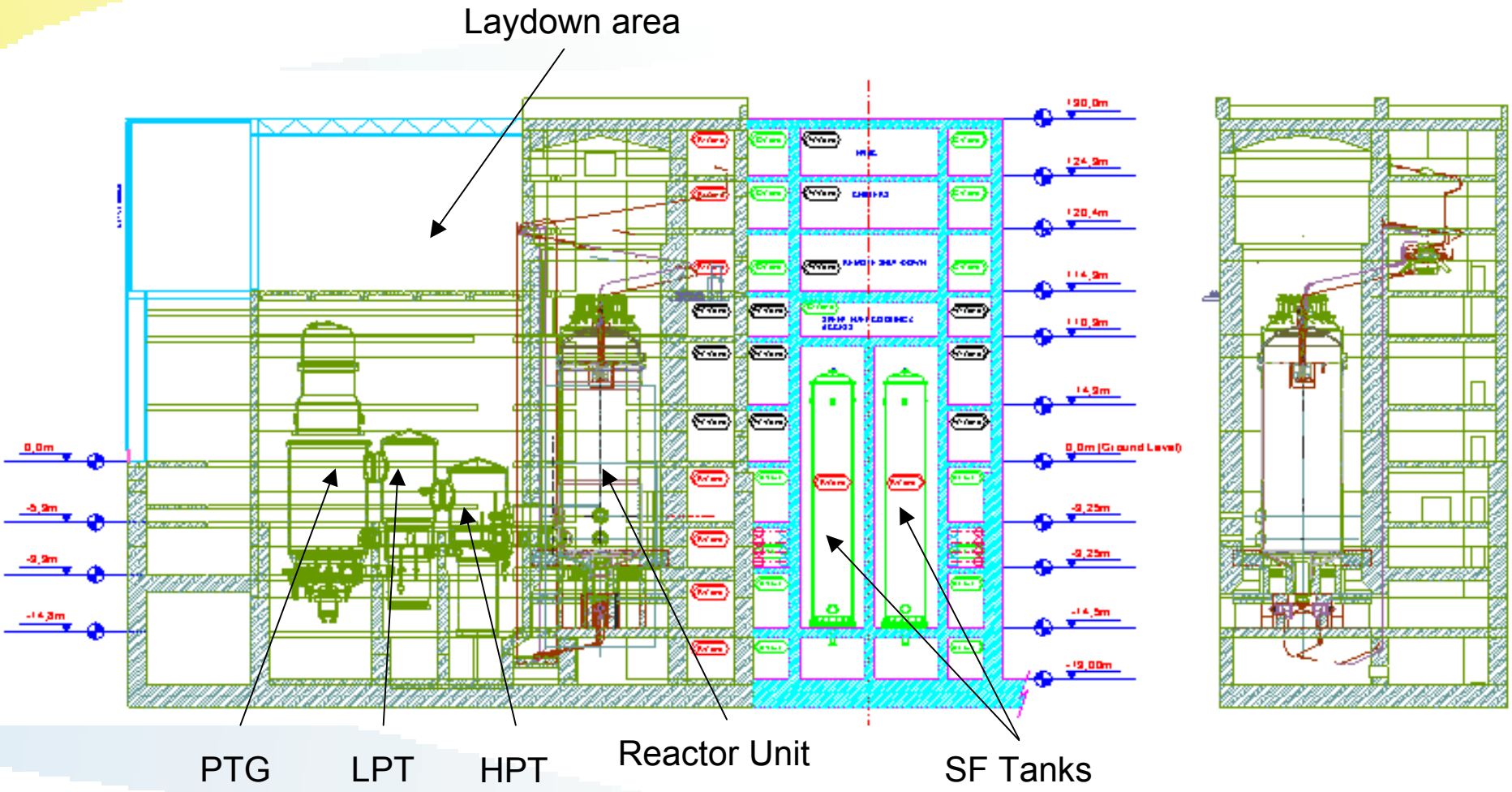
Cut away isometric of PBMR MULTI MODULE CONCEPT



MM Plant - plan view



MM Plant – side view



MM Plant Shared Area - side view