Demonstration Plant SSC Testing Program

Presented to the US DOE

7 August 2003

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Demonstration Plant
SSC Testing Program

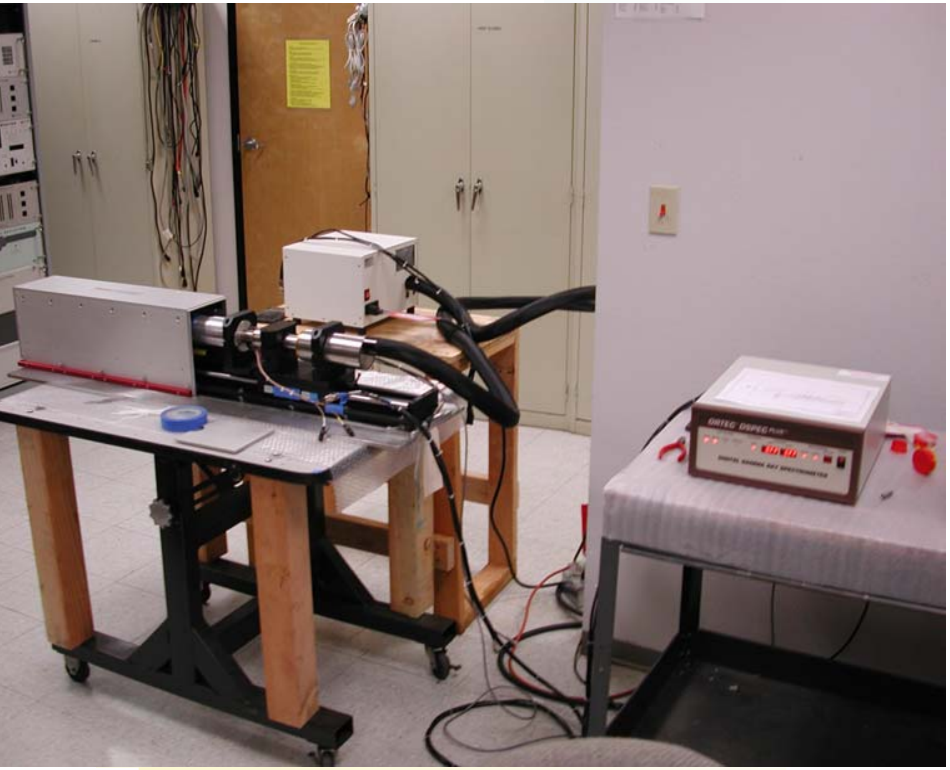
- Prototyping tests for Systems Structures and Components (SSC) design verification
- Helium Test Facility (HTF)
- Testing of turbo machines
- Validation testing

Prototyping Tests for SSC Design Verification

P B M

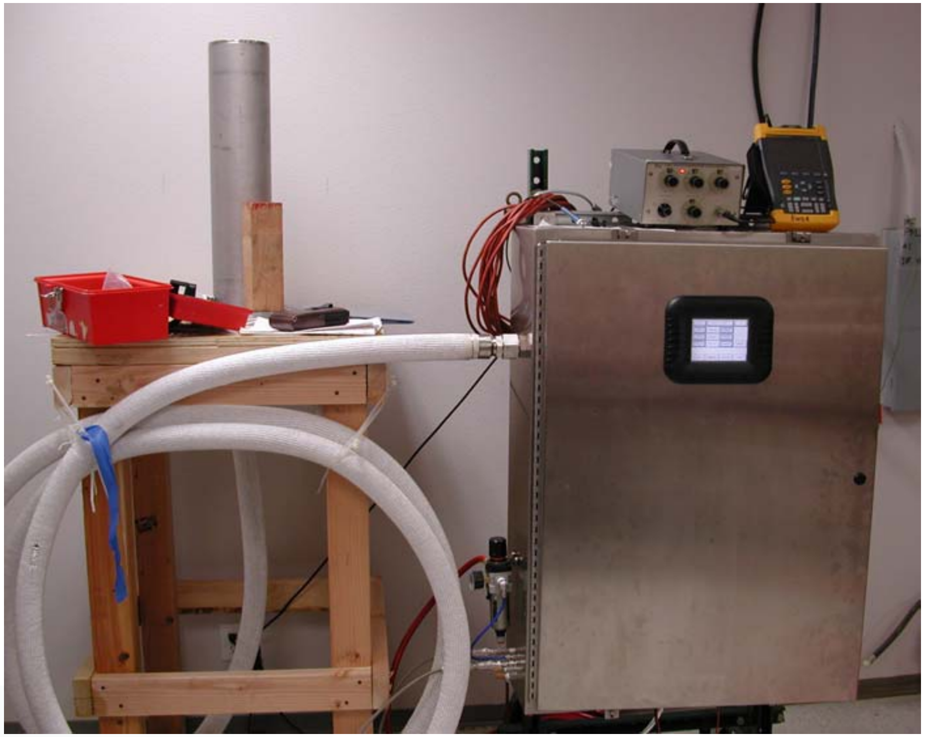
- The purpose of the tests is to evaluate:
  - The applicability of the technology in meeting the design requirement of the SSC
  - To test the functionality of the SSC
  - To evaluate the manufacturability of the SSC

Burn-up measurement



BUMS test set-up

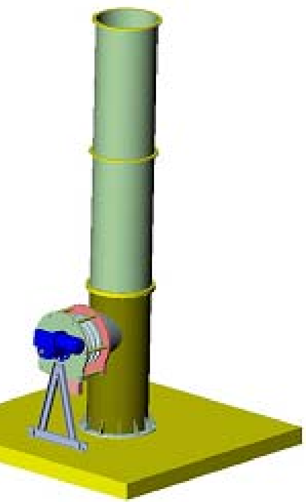
Activity measurement system (AMS)

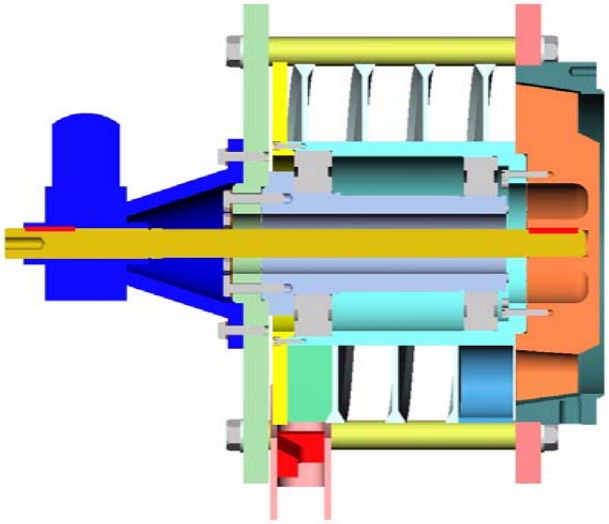


Fuel Handling:
Air Test Loop

P B M

Fuel Handling:

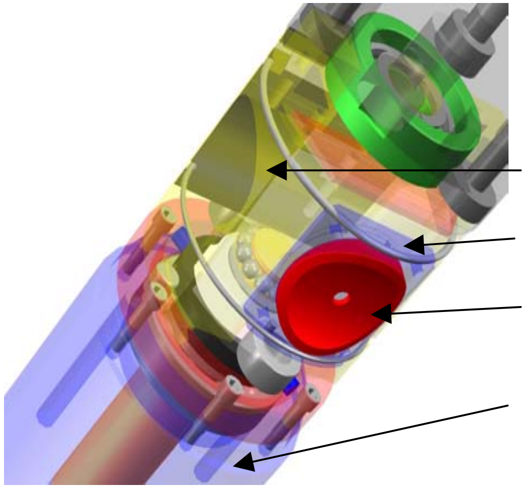


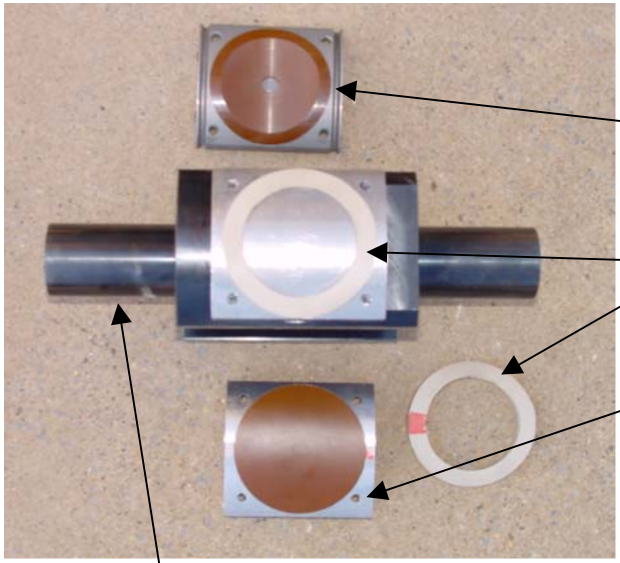


Core Unloading Device

Fuel Handling:

Double Seat Isolation Valve Verification Testing

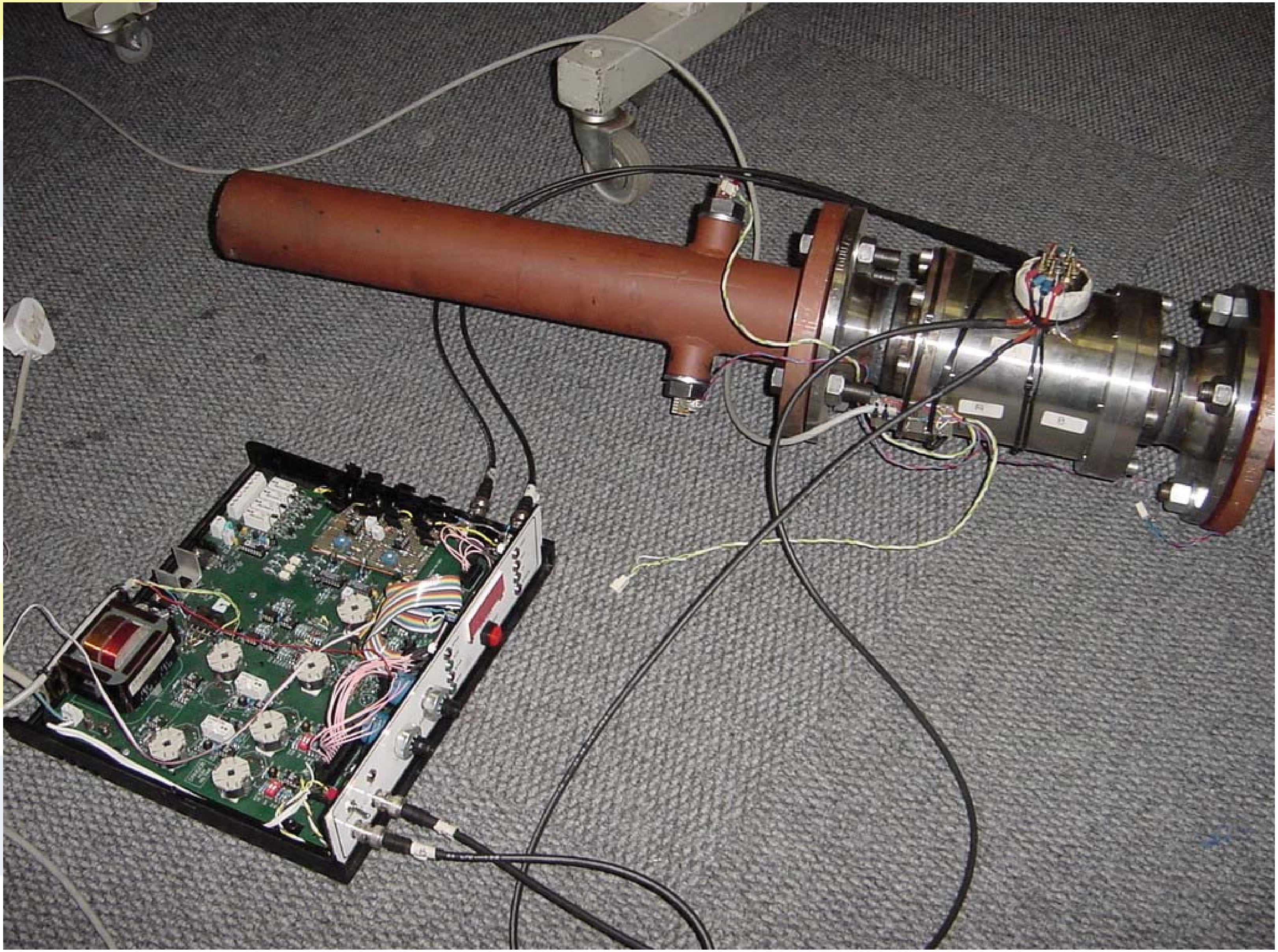




- Ring Type (Peak)
- Solid Disk (Vespel)
- Original German Design

Note: Ring Seat still mounted on grinding jig for surface finishing operation

Fuel Handling:
Sphere Counter



Reserve Shutdown System (RSS) gas transport system test

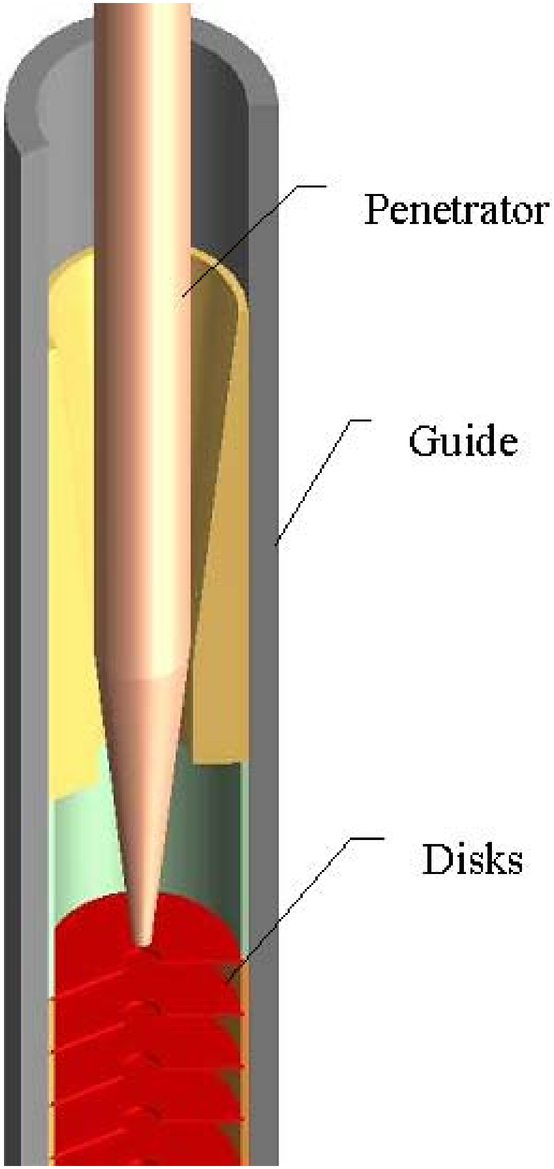
P B M

Top loading	Discharge vessel
	

Reactivity Control System:
Secondary Shock Absorber
Test Set-up

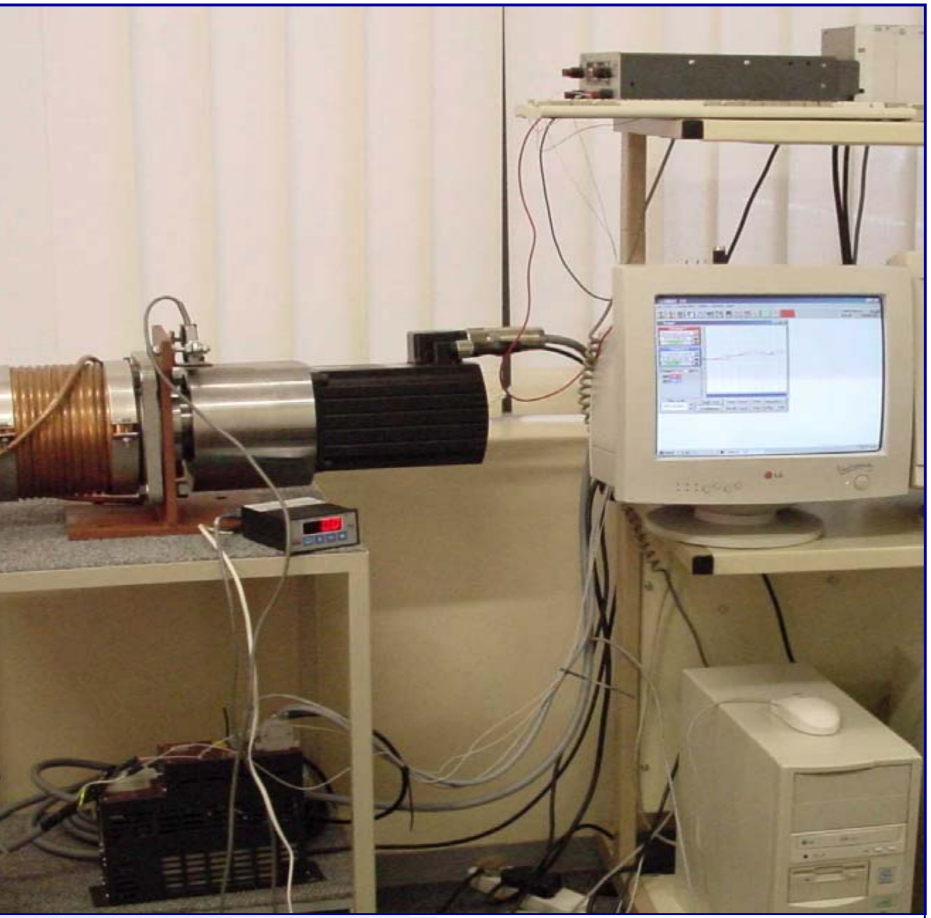
Reactivity Control System:

mproved 2nd Shock Absorber



Reactivity Control System (RCS)

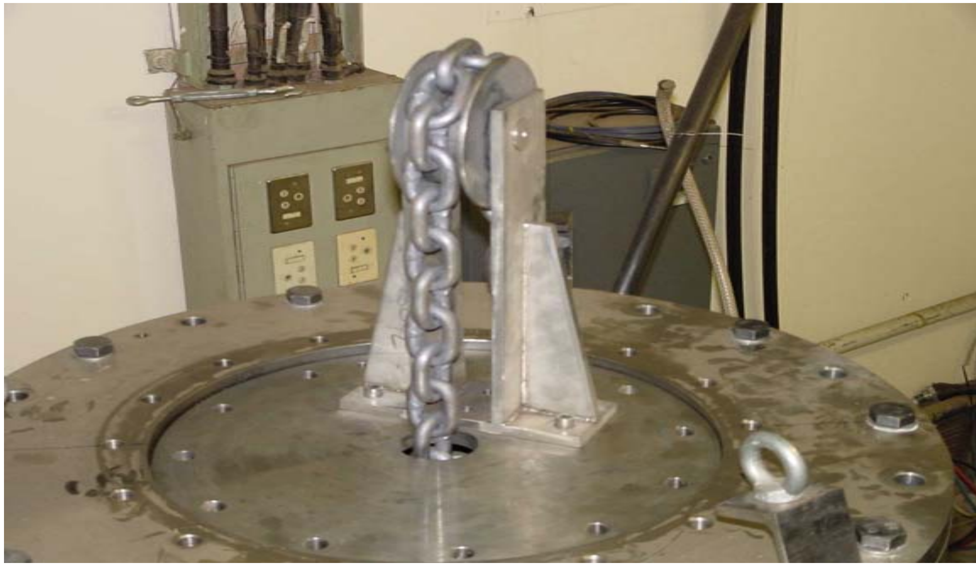
P B M



RCS Drive SCRAM Test set-up

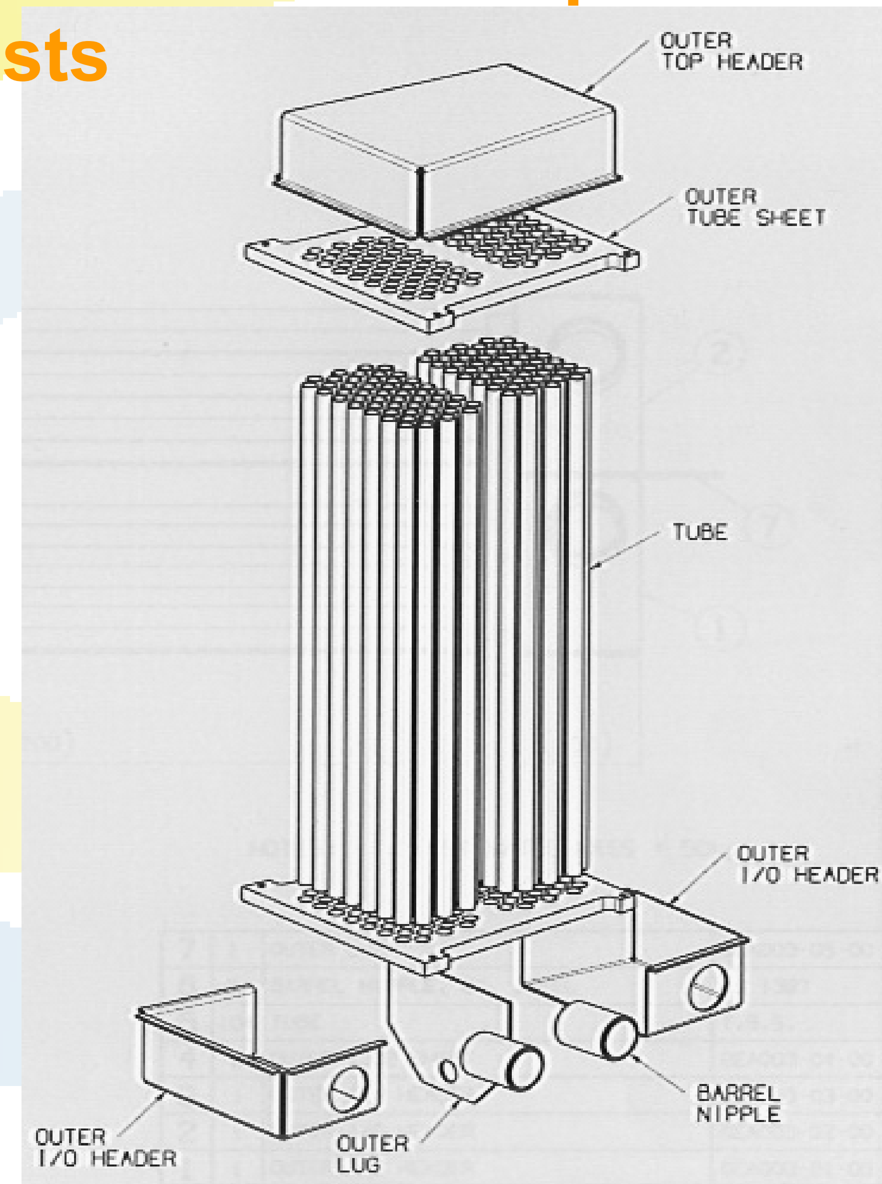
RCS Control Rod Drive Mechanism

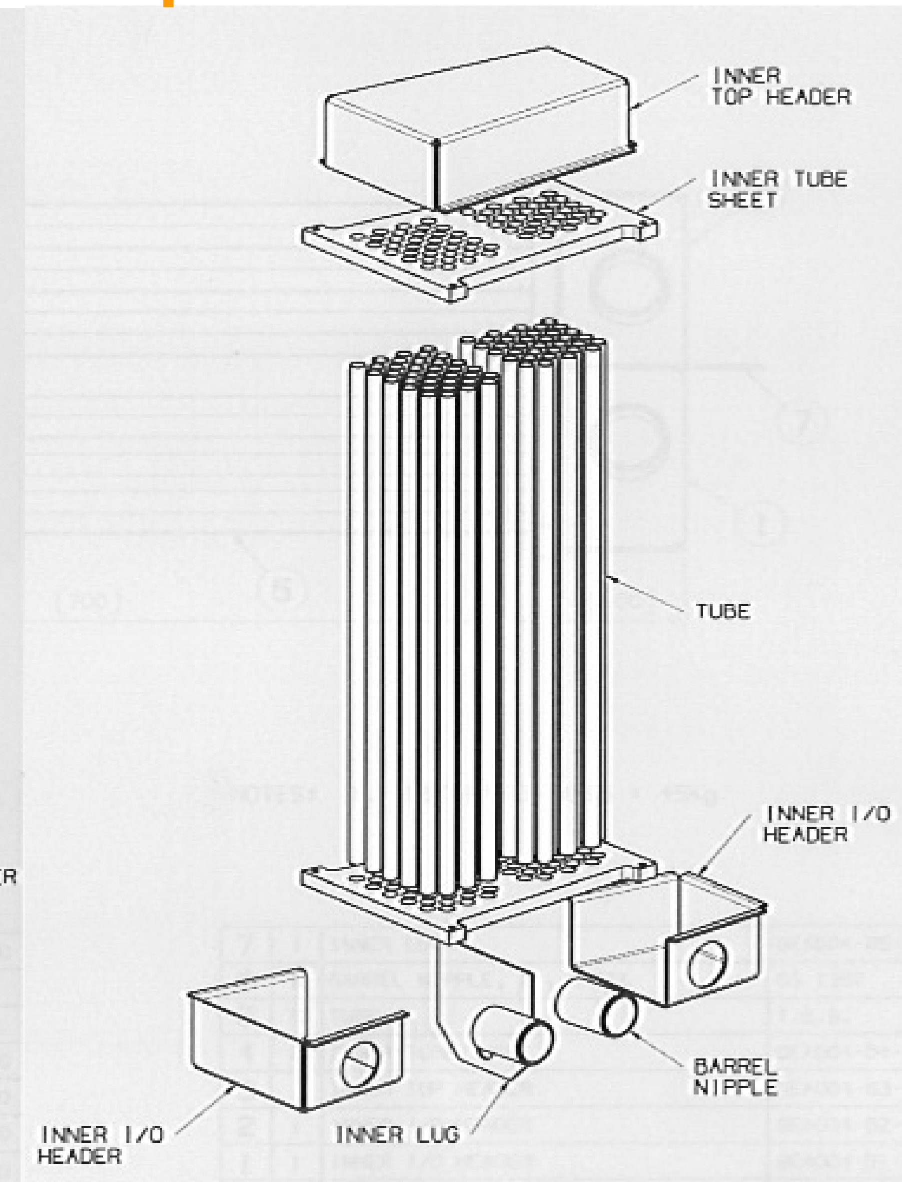
igh temperature SCRAM Shock test



Pre-cooler and Intercooler

heat transfer and pressure drop correlation tests





Pre-cooler and intercooler

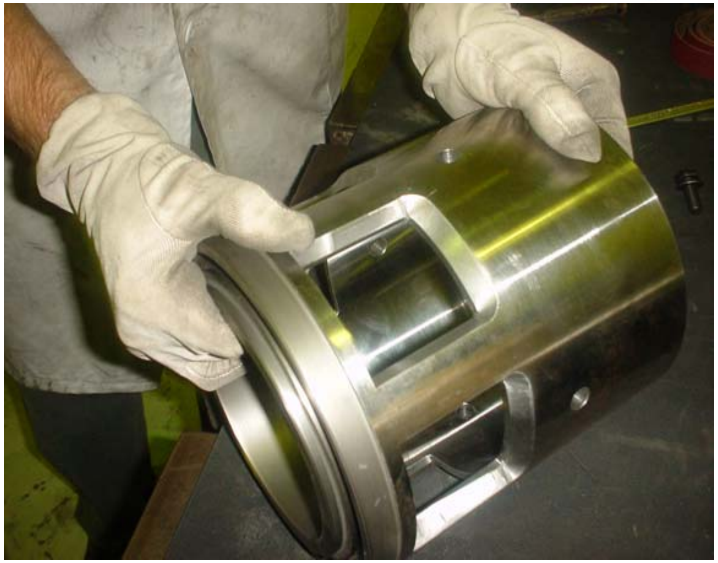
heat transfer and pressure drop correlation tests

Gas cycle valve tests

Gas cycle valve stiction test

Gas cycle valve actuator test

Gas cycle Valves:
Bypass Valve Manufacturing

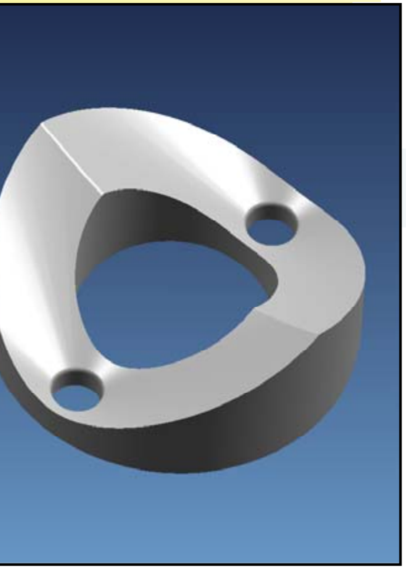



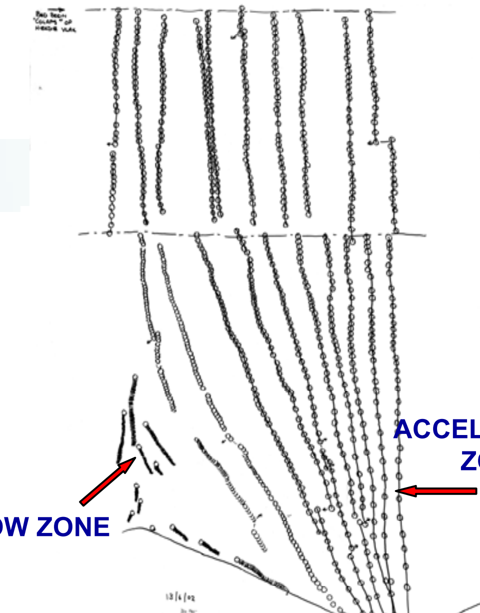
Spent Fuel Tank with rods

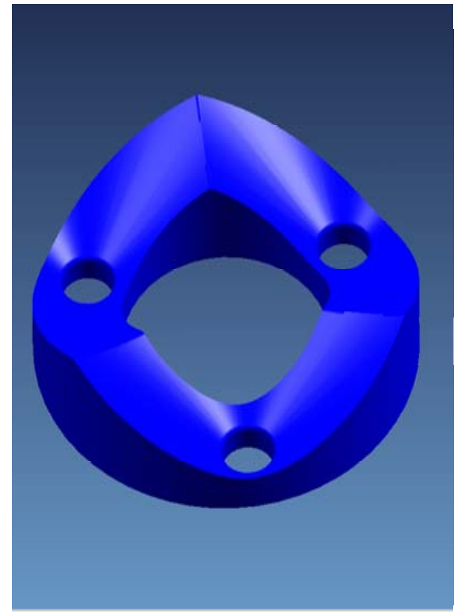
Test to measure loads on rods

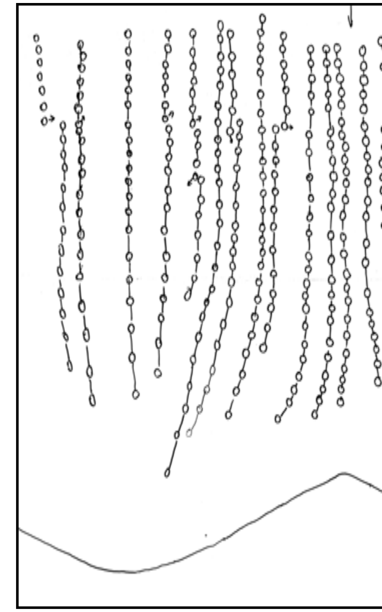
Fuel Spheres: 1/6 Scale solid centre sphere flow analysis

uel Spheres: Sphere flow tests
2&3 Outlet Core Base









2 Outlet Core Base

3 Outlet Core Base

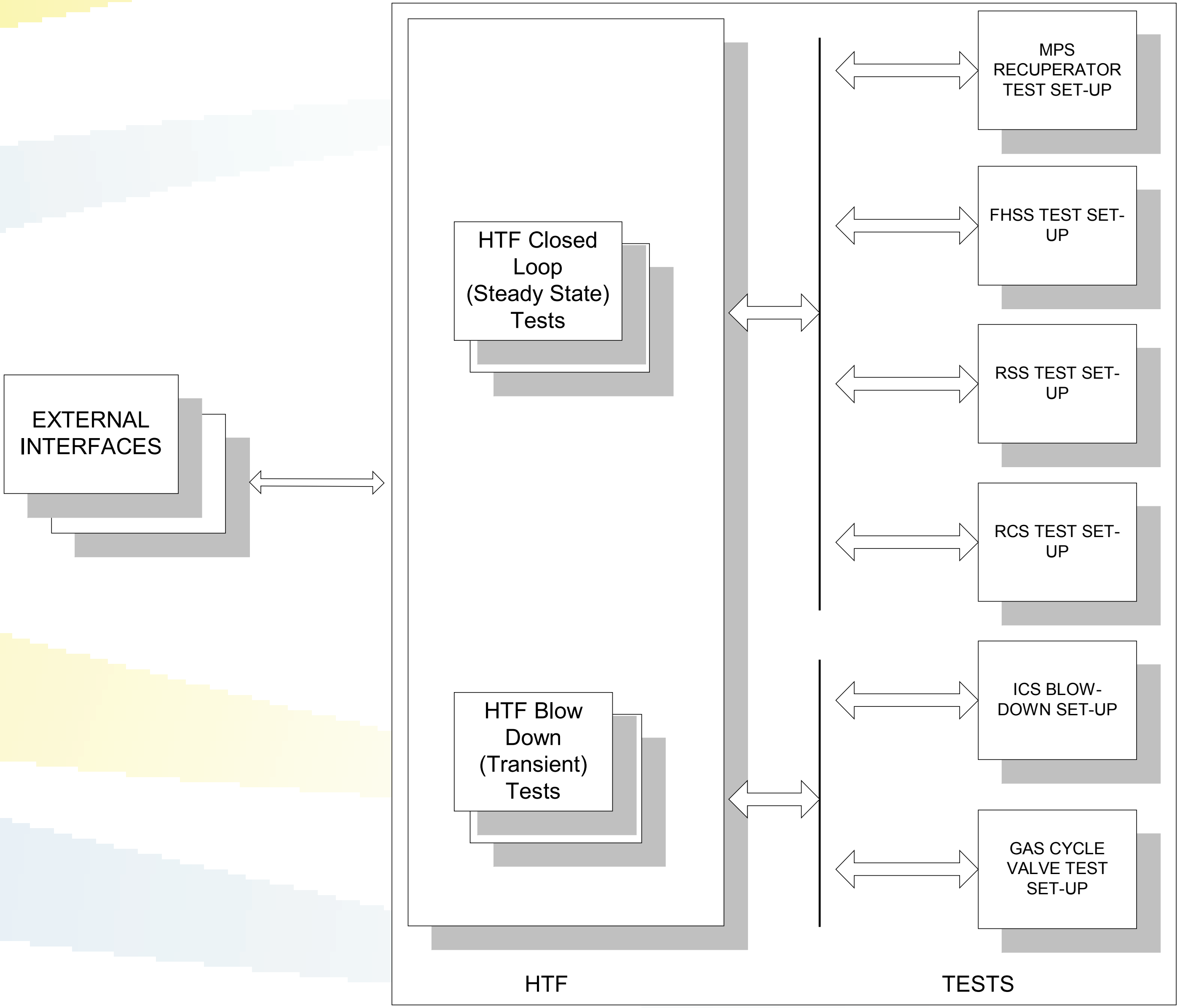
Helium Test Facility (HTF)

PBM

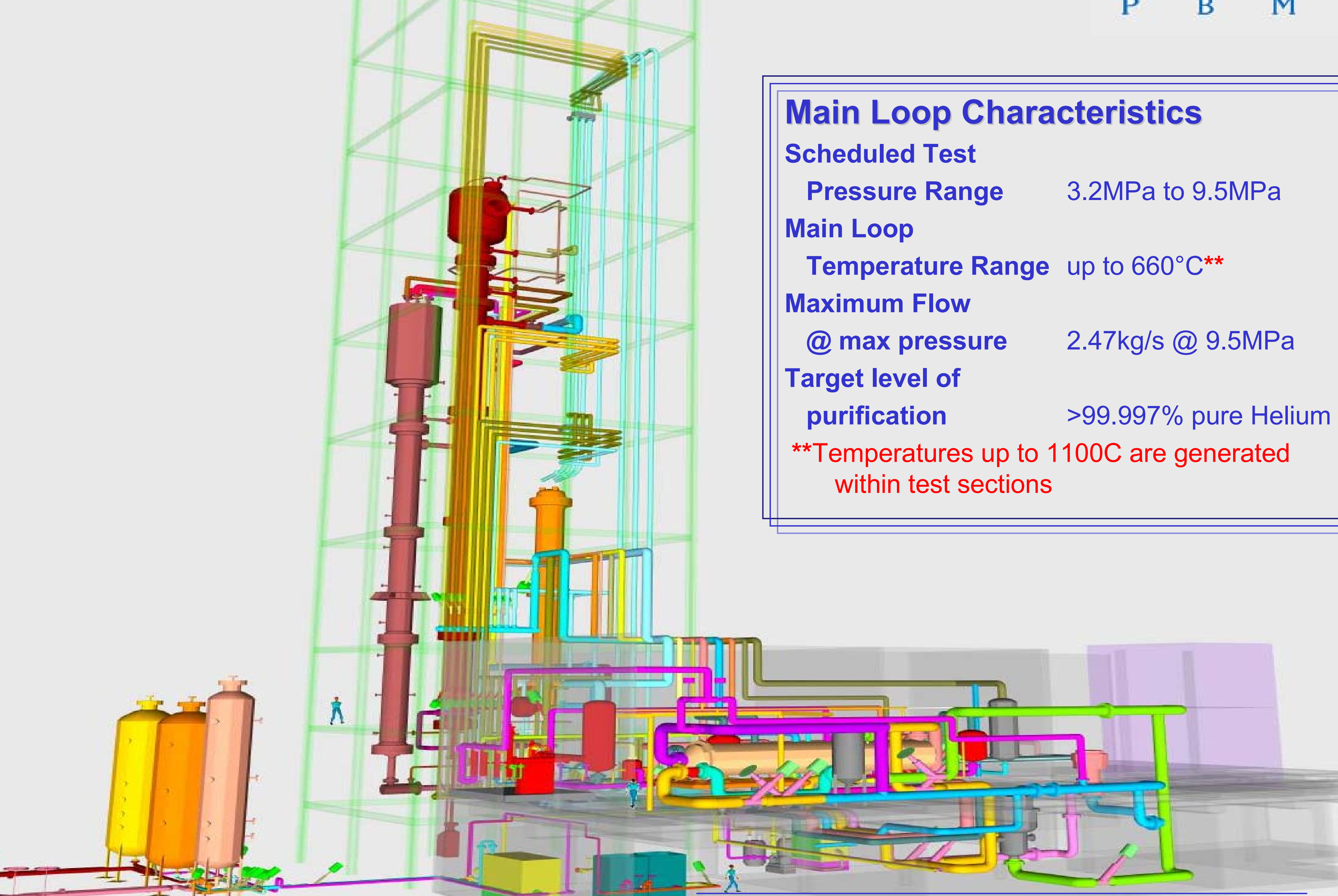
The Helium Test Facility is a facility in which full scale components could be tested under conditions which replicate full temperature and pressure operating conditions to which SSC will be exposed in the plant. The tests will include:

- Reliability tests
- Life cycle tests
- Steady state and transient tests of functionality in the operating environment

Helium Test Facility



Helium Test Facility

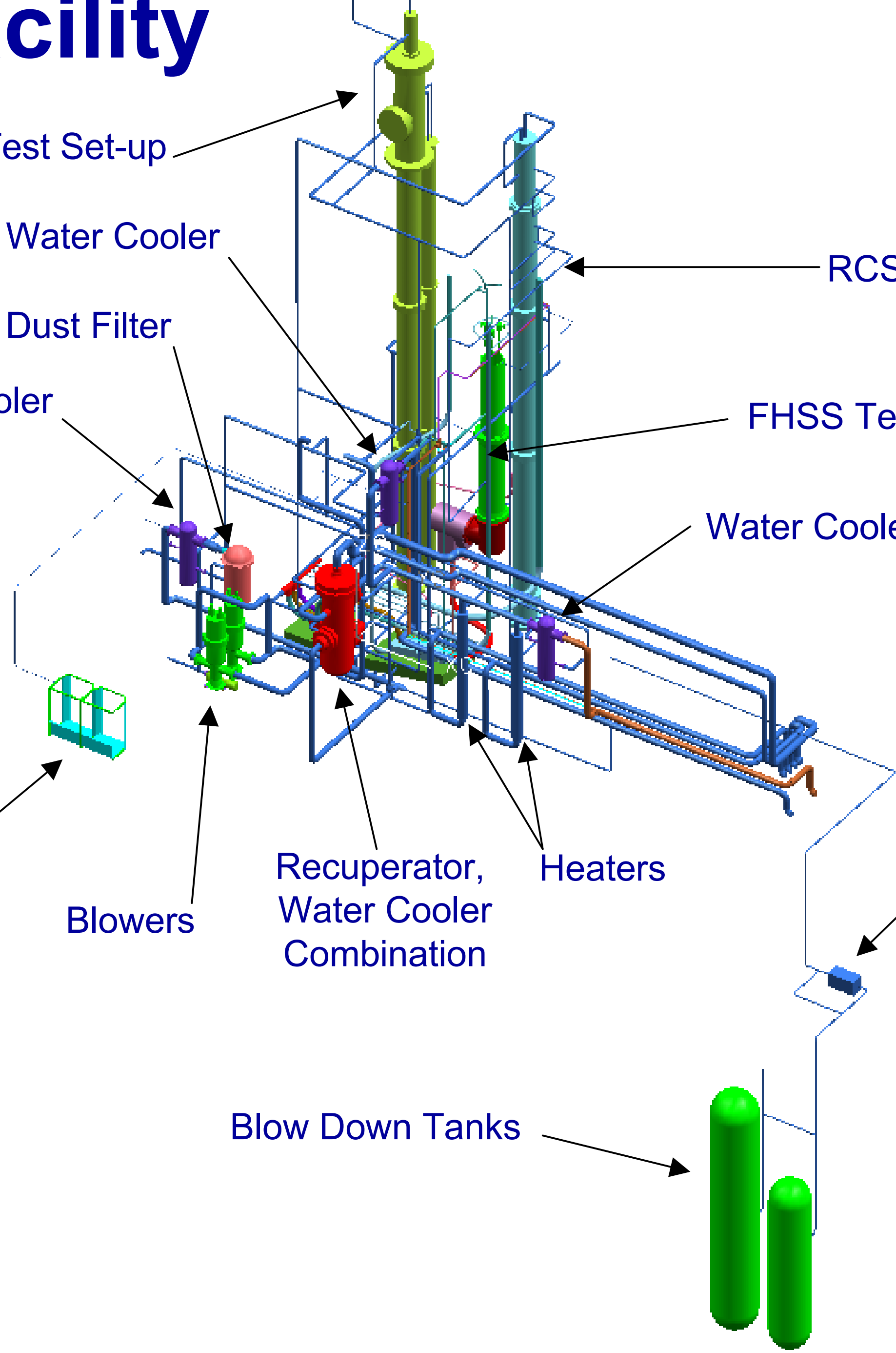


Main Loop Characteristics

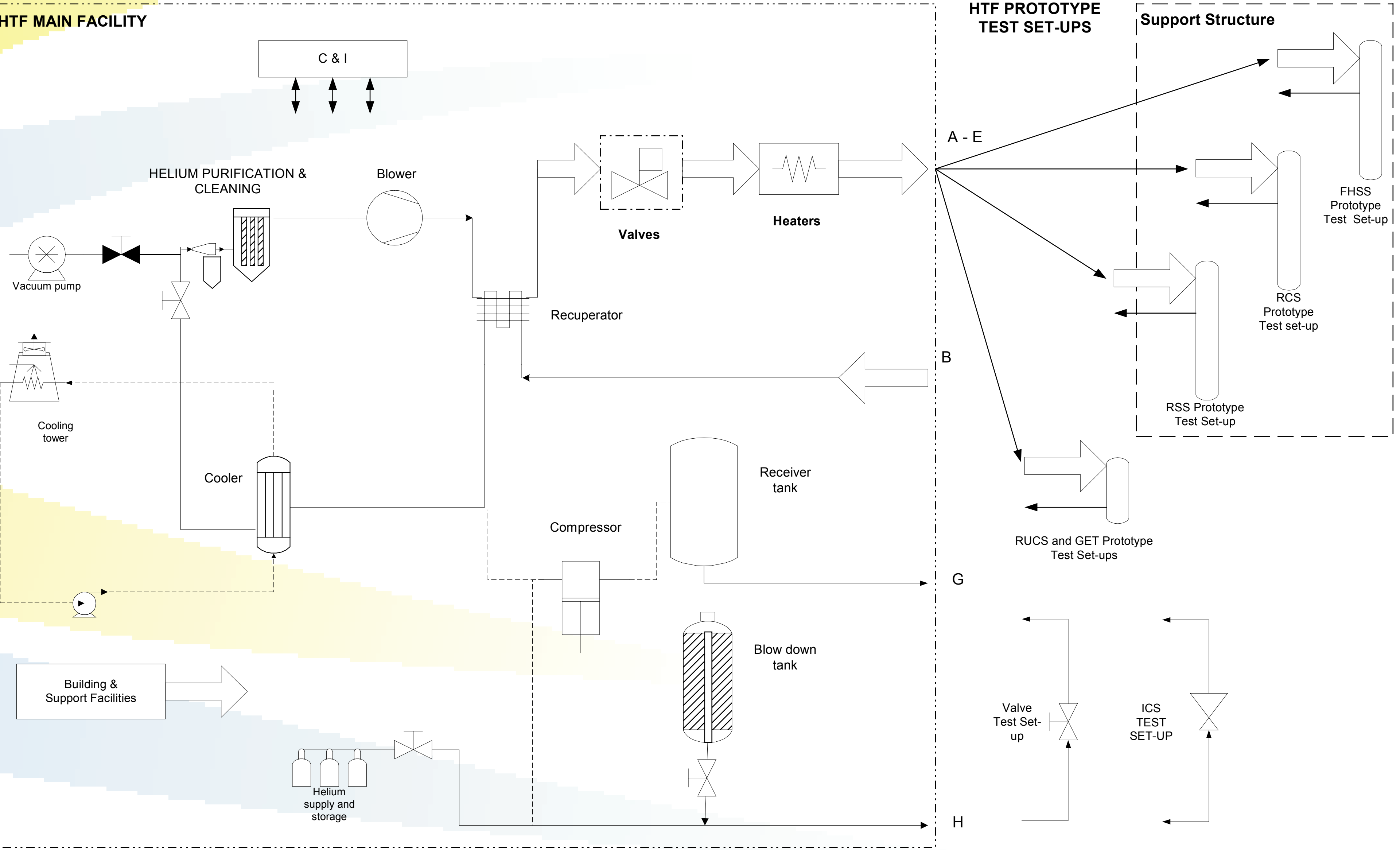
Scheduled Test	
Pressure Range	3.2MPa to 9.5MPa
Main Loop	
Temperature Range	up to 660°C**
Maximum Flow	
@ max pressure	2.47kg/s @ 9.5MPa
Target level of	
purification	>99.997% pure Helium

**Temperatures up to 1100C are generated within test sections

elium Test Facility
ayout

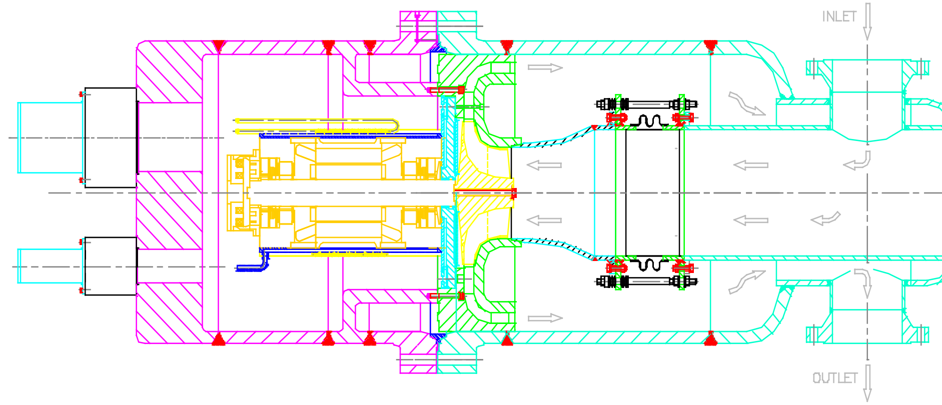


Helium Test Facility

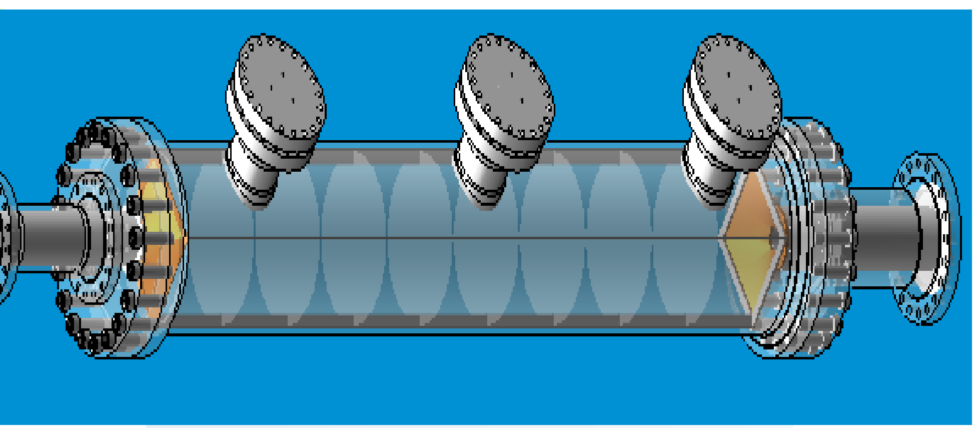


HTF Components

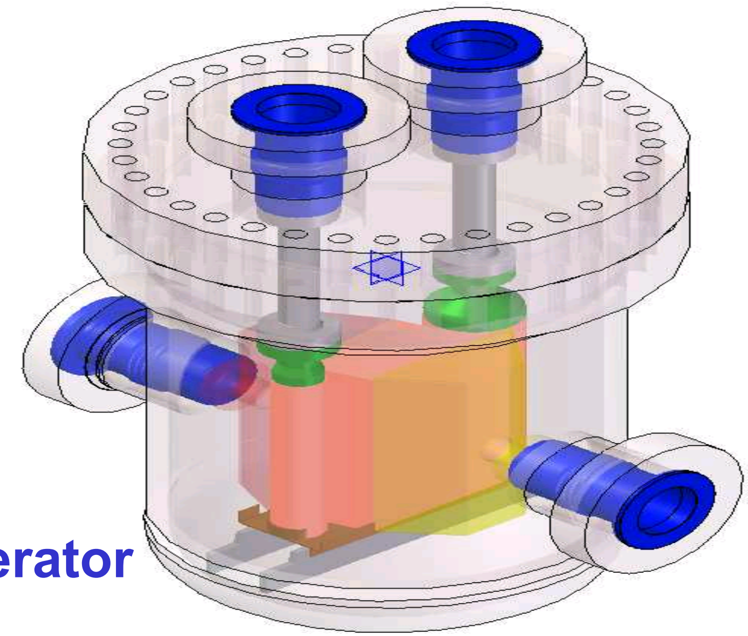
THTR Blower



Howden Blower



Heater Configuration

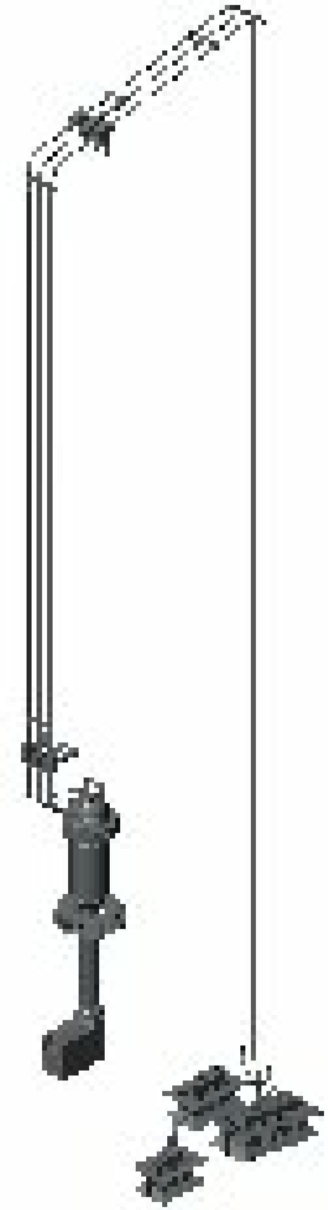


Recuperator

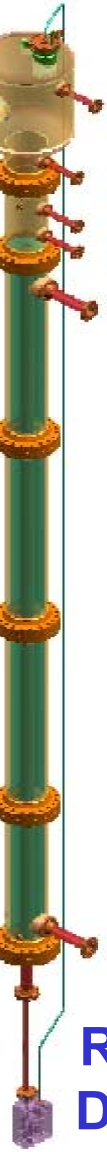
FHSS TEST PROGRAM

FHSS-HTF System has four test subsections, namely

- Sphere Conveying Test Section (SCTS)
- Block Insert Test Section (BITS)
- Storage Test Section (STS)
- Component Test Section (CTS) (In Laboratory)



Reactivity Control Systems Tests

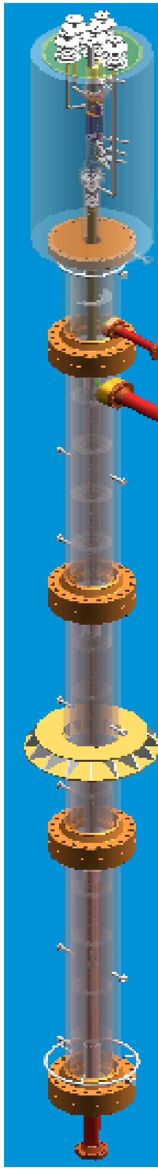


RCSS Component and System Qualification Tests.

- All extreme environmental conditions of RCS can be simulated. (Core channels up to 1100°C).
- All safety-related functions can be simulated.

Reserve Shut Down System

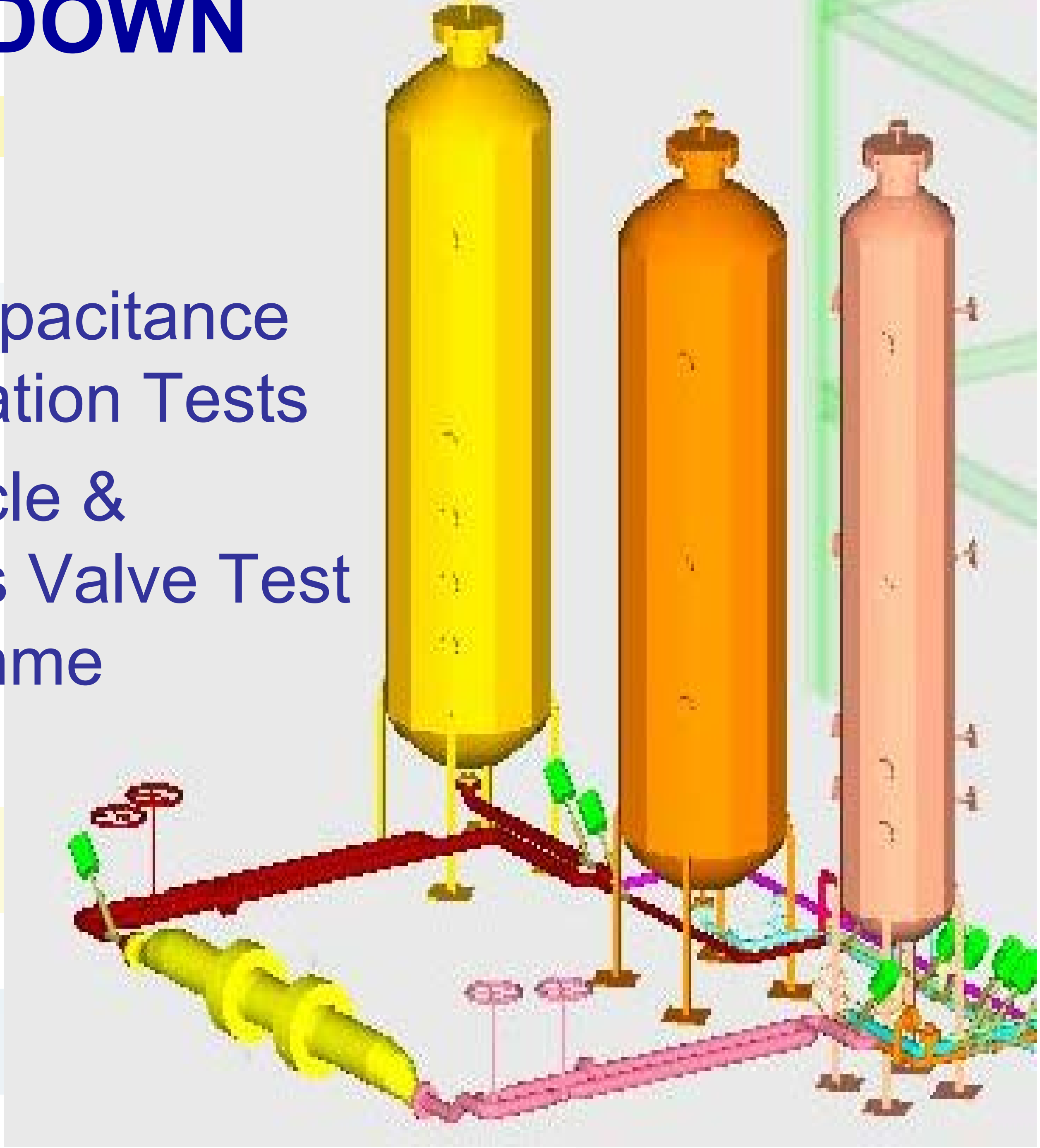
Reactivity Control System



BLOW DOWN TESTS

Heat Capacitance Qualification Tests

Gas Cycle & Systems Valve Test Programme



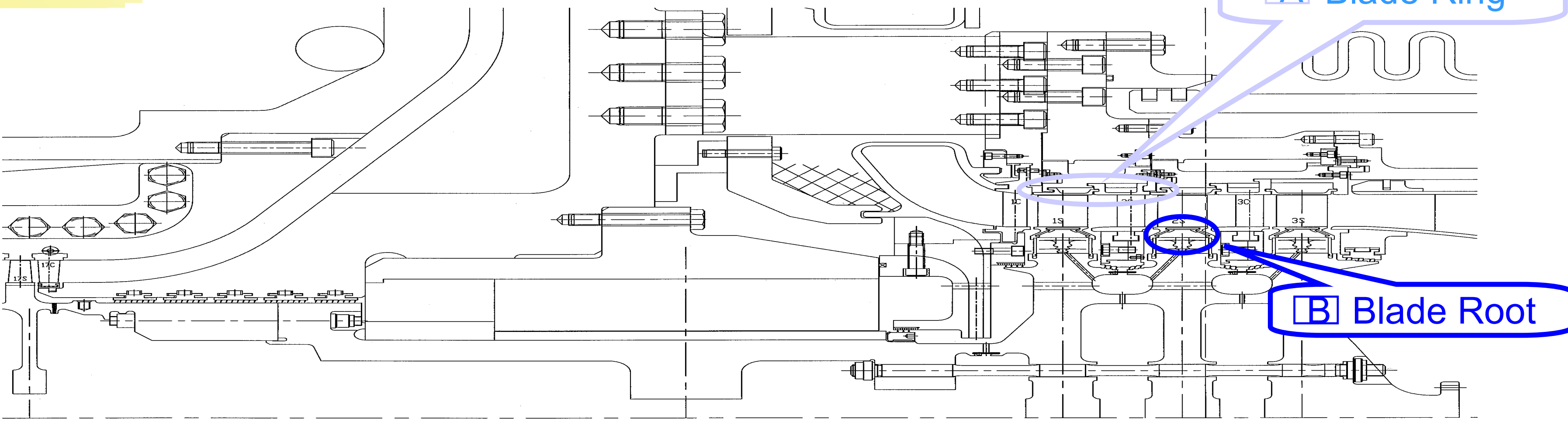
Testing of Turbomachines

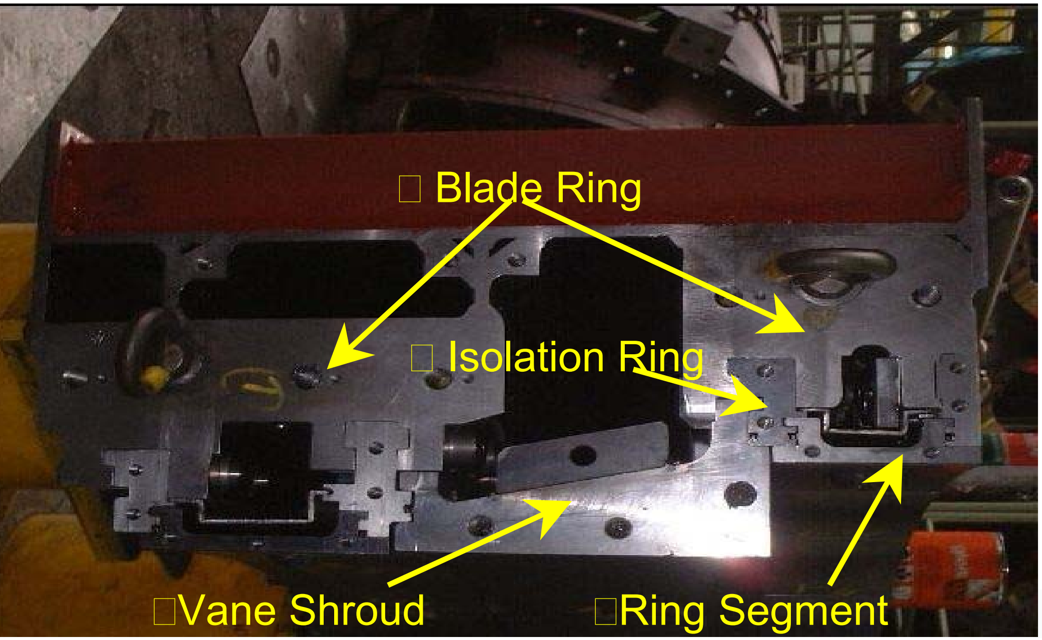
P B M

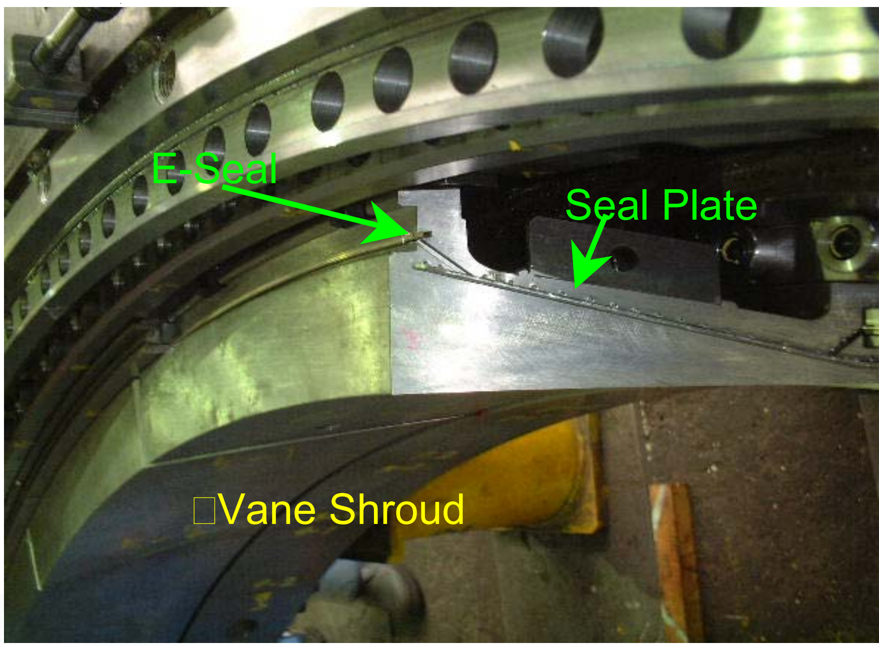
Objectives

– To perform tests to evaluate the performance of different turbo-machine components in a Helium environment as a risk reduction measure

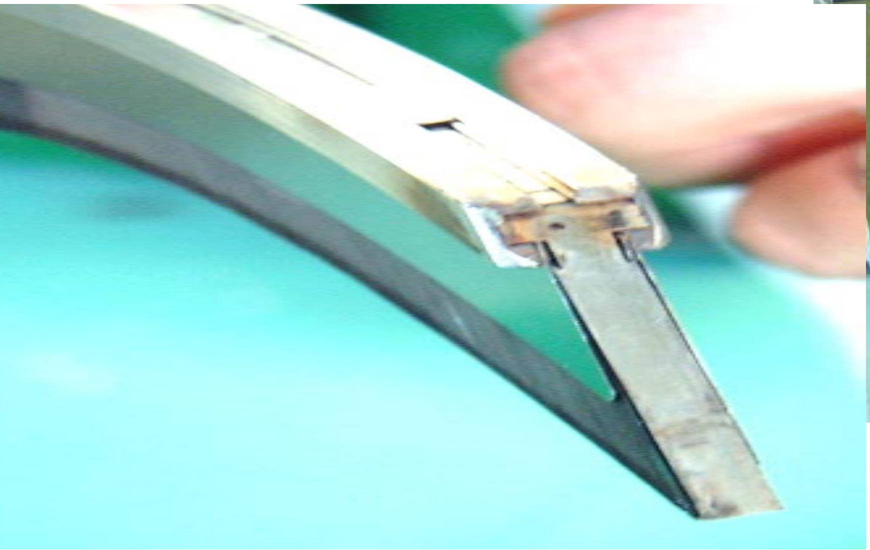
Turbines flow verification tests



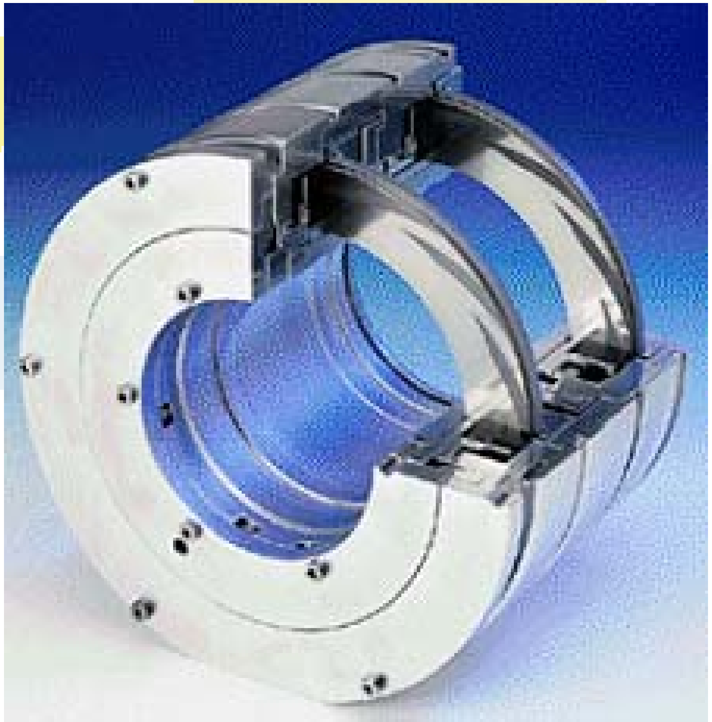


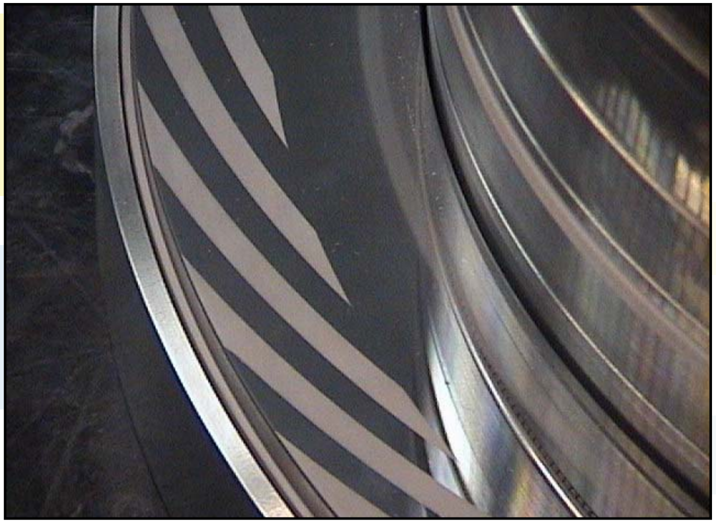


Turbines Leaf Seal Tests



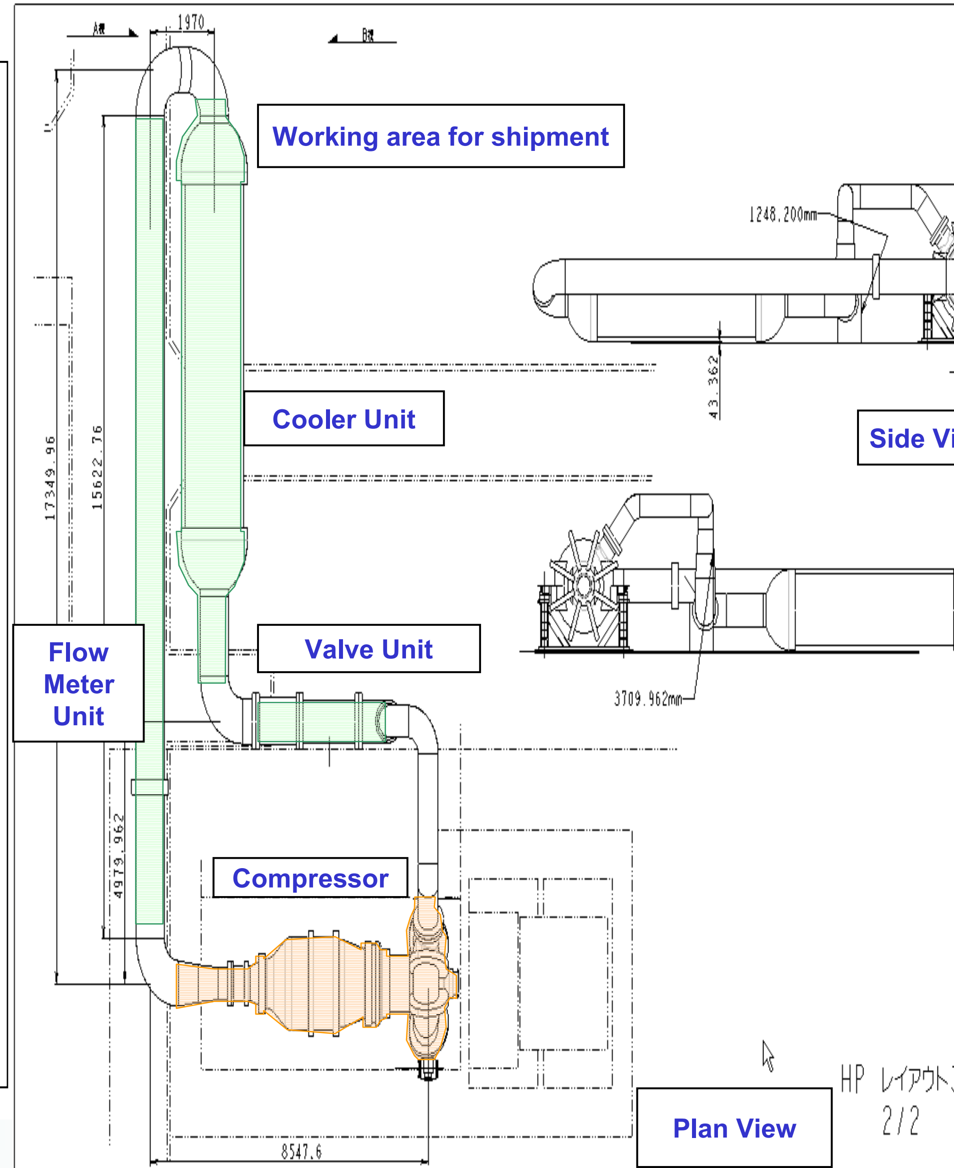
Power Turbine Dry Gas Seal Tests





	Leakage (l/min)			
	Ductile		Tungsten Carbide	
	IB	OB	IB	OB
Air	137	9.0	102	3.0
He	208	12.4	146	6.7

Hiroshima Test Facility:
PBMR Compressor tests



Layout for LP & HP compressor tests

PBMR Validation Testing

The objectives of the validation testing is to:

- Experimentally validate First-of-a-Kind design assumptions
- To experimentally benchmark difficult to analyse design calculations
- To experimentally determine unknown data required for First-of-a-Kind analyses

PBMR Validation Testing

The facilities used are the:

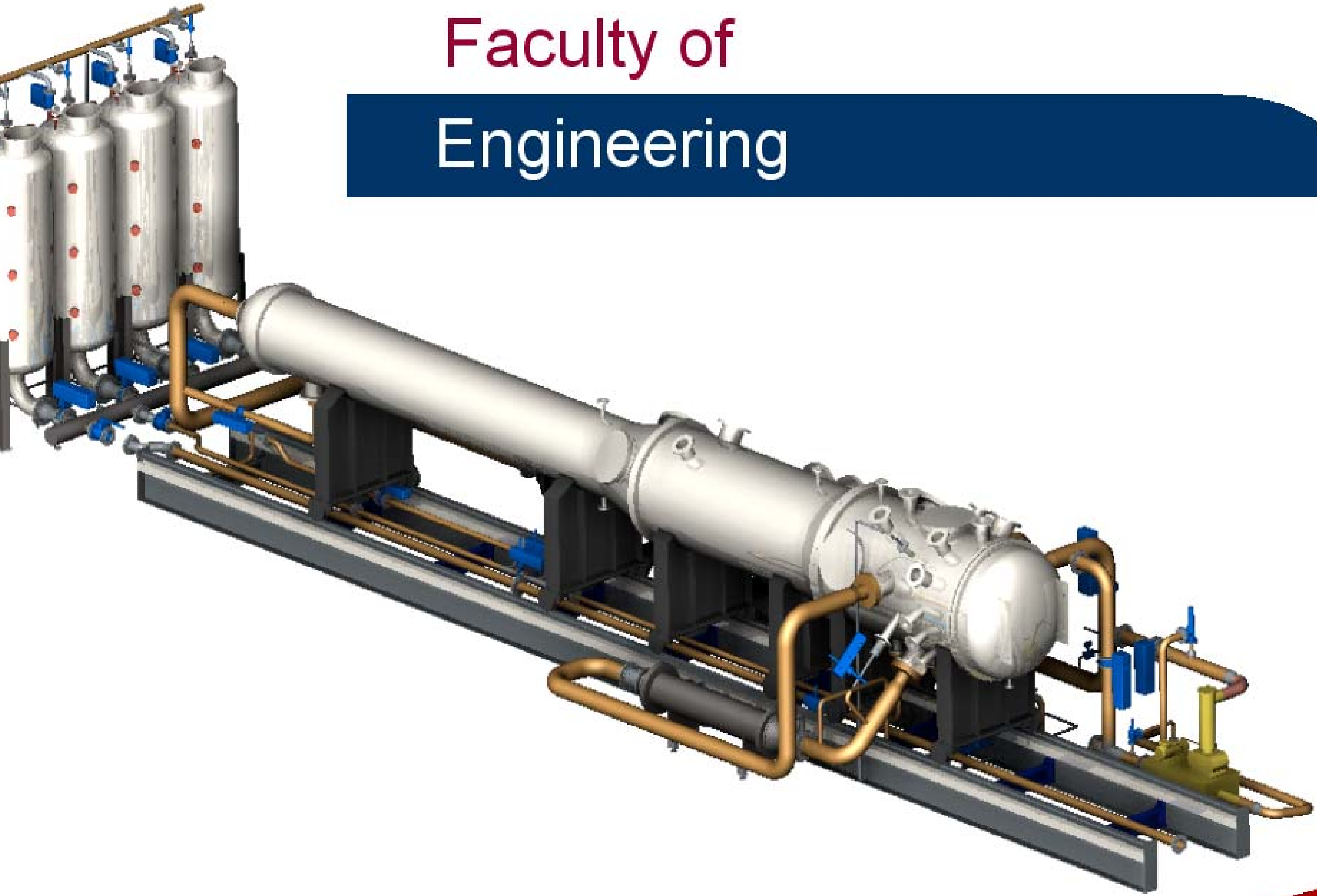
- PBMR Micro Model (PBMM)
- Heat Transfer Test Facility (HTTF)
- ASTRA Critical Facility
- Natural Convection Oxidation Facility (NACOK)
- Fourth Quadrant Turbine Testing

PBMR Micro Model

P B M

Faculty of

Engineering



M - T e c h
industrial

Potchefstroomse Universiteit
vir Christelike Hoër Onderwys

Objectives

P B M

- Demonstrate the operation of a closed cycle, three-shaft, pre- and inter-cooled, recuperative Brayton cycle in order to gain a better understanding of its dynamic behavior.
- Demonstrate the control strategies of the PBMR including:
  - Startup.
  - Load following.
  - Load rejection.
- Demonstrate the ability of Flownet to simulate the integrated performance of the cycle.

Design constraints

The dynamic behavior of the PBMM must display the same trends as that of the PBMR, but not necessarily with comparable time constants.

The PBMM plant layout must have the same topology and representative major components as that of the PBMR.

The control system of the PBMM must have the same topology and degrees of freedom as that of the PBMR.

Must use off-the-shelf turbo chargers as opposed to purpose designed machines.

Must use conventional heat source.

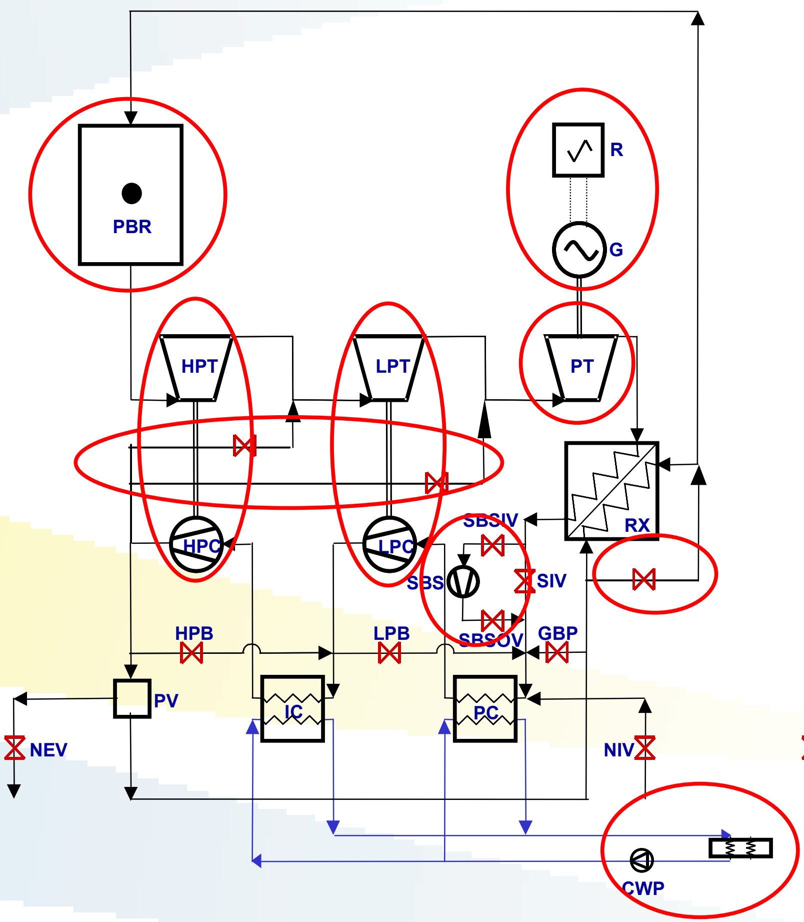
Thermal-flow design process

- Determine overall cycle layout.
- Determine major cycle parameters at nominal operating conditions.
  - Pressure level.
  - Maximum temperature.
  - Pressure ratio.
  - Power level.
- Component selection.
- System integration.
- Detailed hardware design.

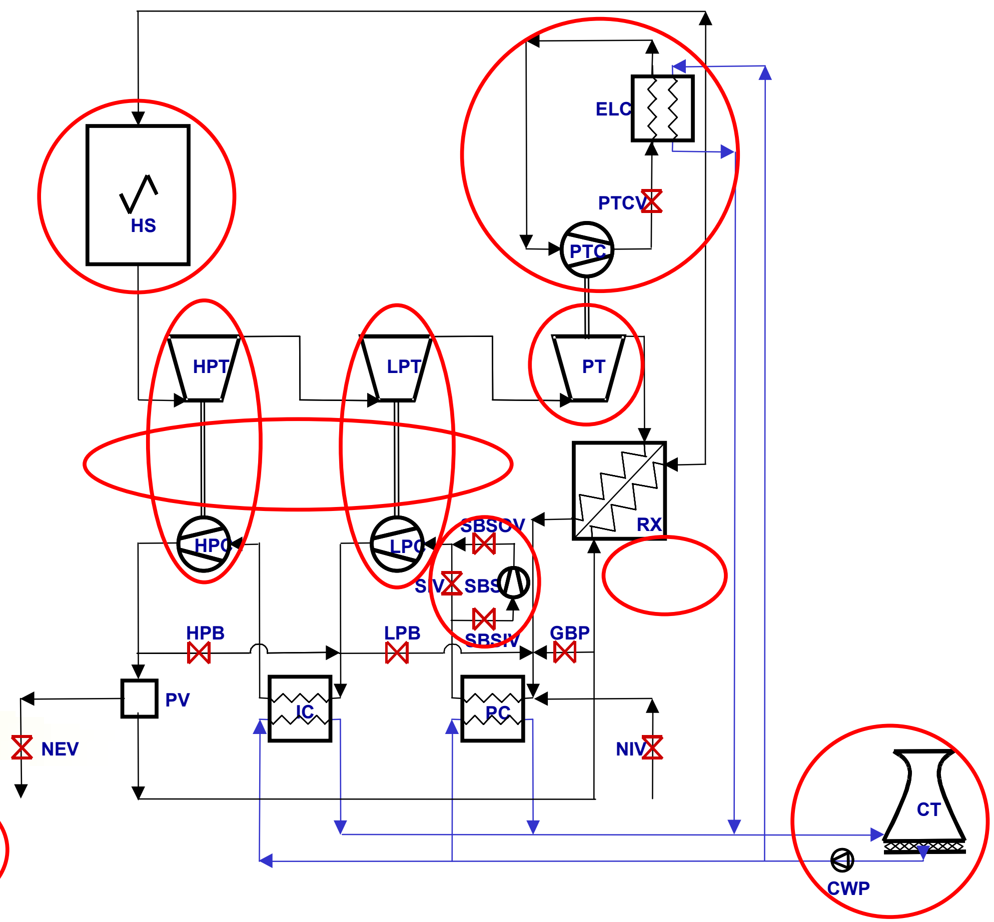
Cycle layout

7 Click
comp

PBMR



PBMM



Summary of differences

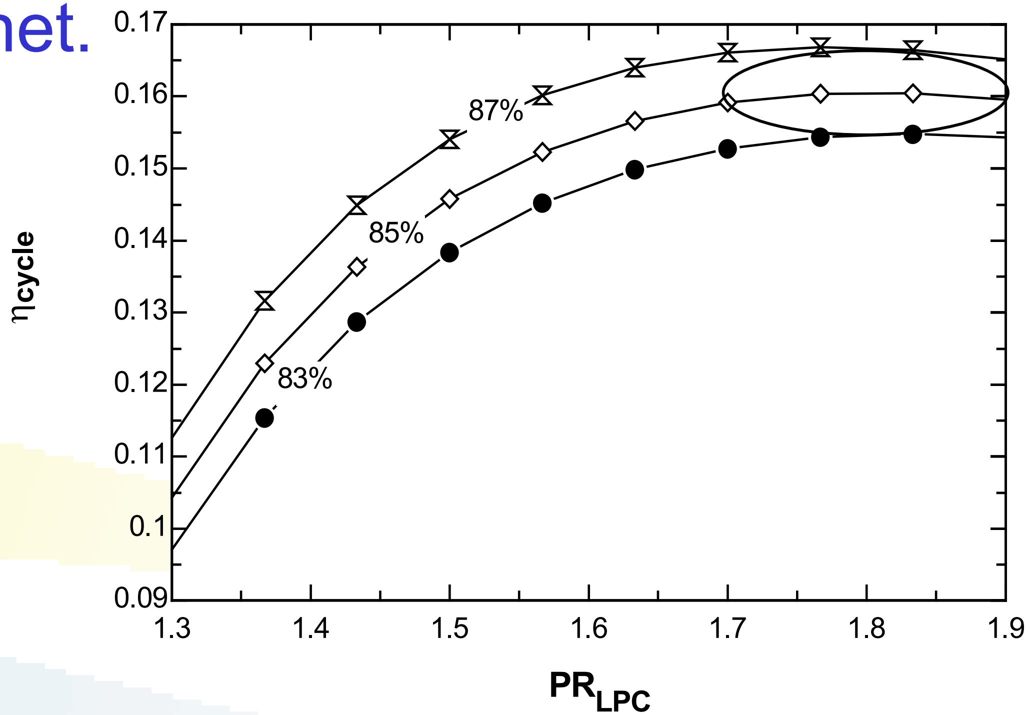
- Heat source is electrical resistance heater instead of nuclear reactor.
- Use of single stage centrifugal turbo-chargers instead of purpose designed multistage axial flow turbo machines.
- Load on power turbine is compressor with external load cooler instead of generator with resistor bank.
- Heat rejection via cooling tower instead of intermediate heat exchanger.
- SBS positioned differently.
- Does not contain LPT and PT cooling flows of recuperator by-pass flow.
- Use of Nitrogen instead of Helium as the working fluid.

Major cycle parameters

- Pressure level
  - Require inventory control variation between 100% and 40%.
  - Minimum cycle pressure at 40% power set at 100kPa.
  - Therefore minimum cycle pressure at 100% set at 250kPa.
- Maximum cycle temperature
  - Off-the-shelf turbo chargers allow maximum turbine inlet temperature of 700°C.
  - Therefore heater outlet temperature set at 700°C.

Major cycle parameters

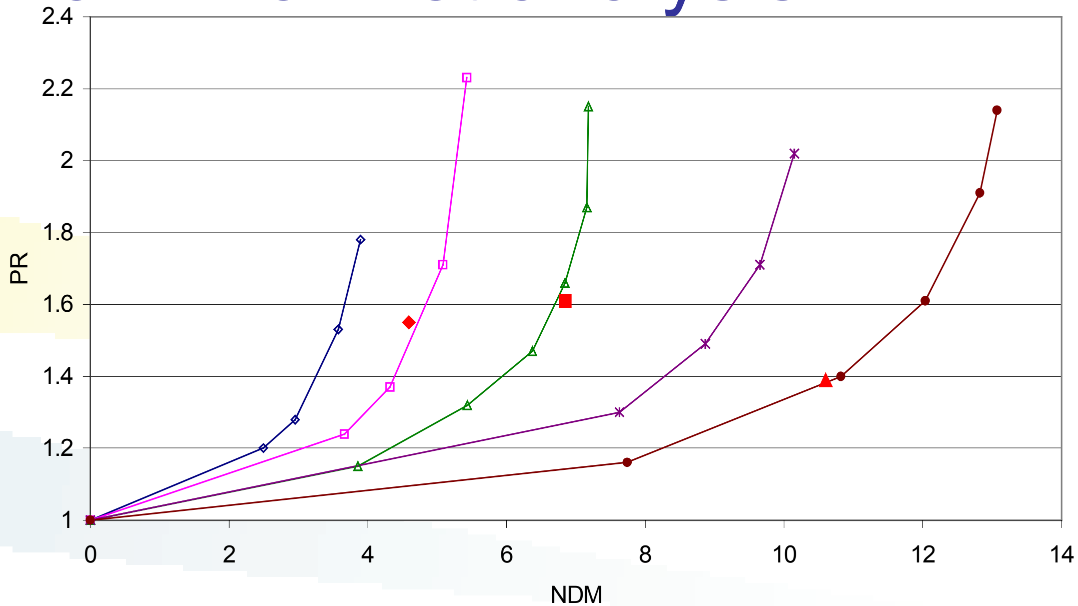
- Pressure ratio
  - LPC and HPC must have equal pressure ratios.
  - Optimize cycle thermal efficiency in terms of pressure ratio and recuperator effectiveness using Flownet.



  - Overall pressure ratio set to 1.9 x 1.9 = 3.6

Major cycle parameters

- Power level
  - Largest turbine in cycle is PT.
  - Use results from Flownet analysis to select largest commercially available off-the-shelf turbo charger for PT.
- Selection of LP and HP turbo chargers using results from Flownet analysis.



Summary of nominal operating conditions

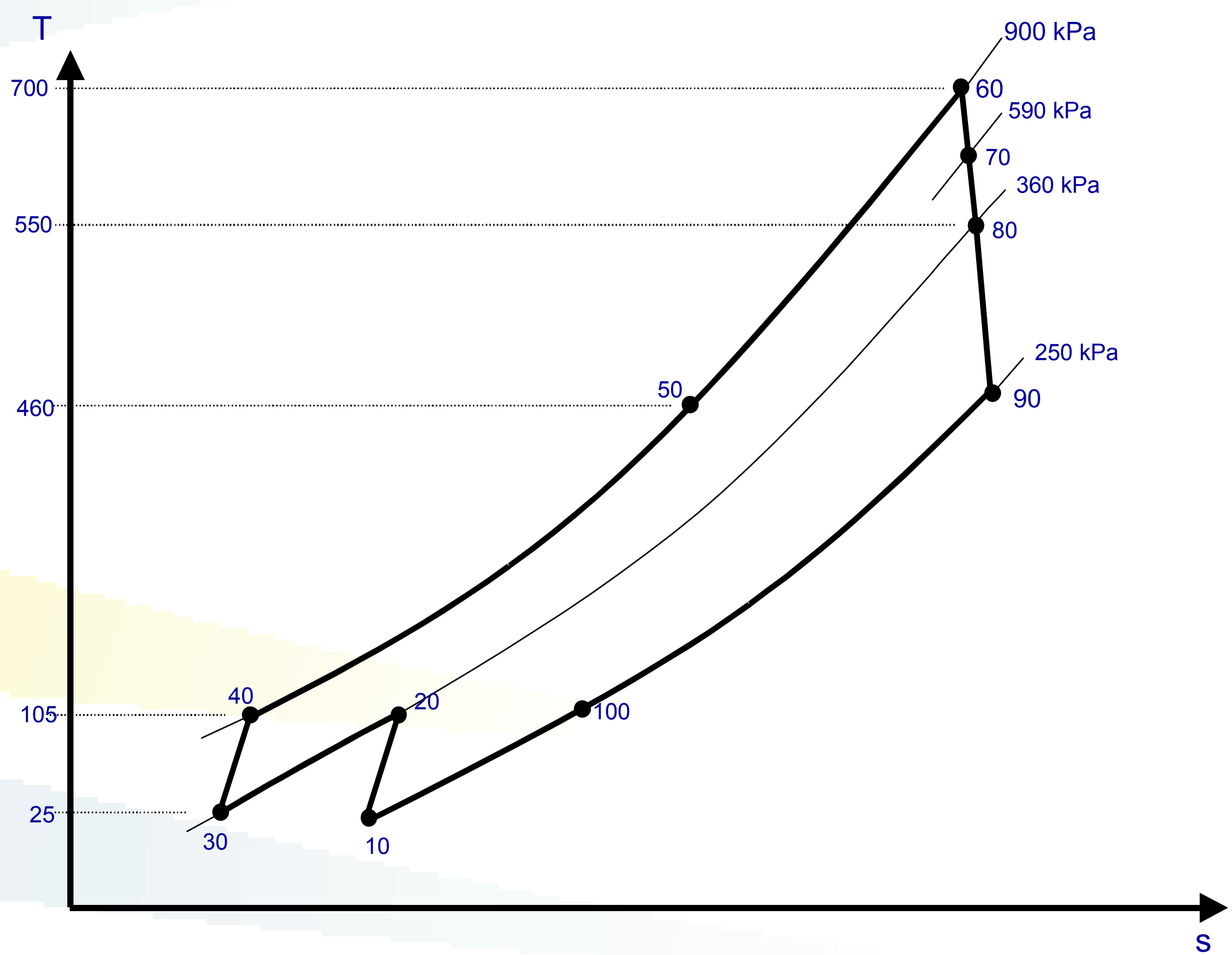
P B M

- Maximum cycle temperature of 700 °C.
- Minimum cycle pressure 250 kPa.
- Pressure ratio 3.6.
- Maximum cycle pressure 900 kPa.
- Power output ↔ 70 kW.
- Power input ↔ 365 kW.
- Cycle efficiency ↔ 19%.

Nominal operating conditions

P B M

Temperature-entropy diagram.



Project plan

P B M

Conceptual design phase

Preliminary and Detail design phase

Procurement

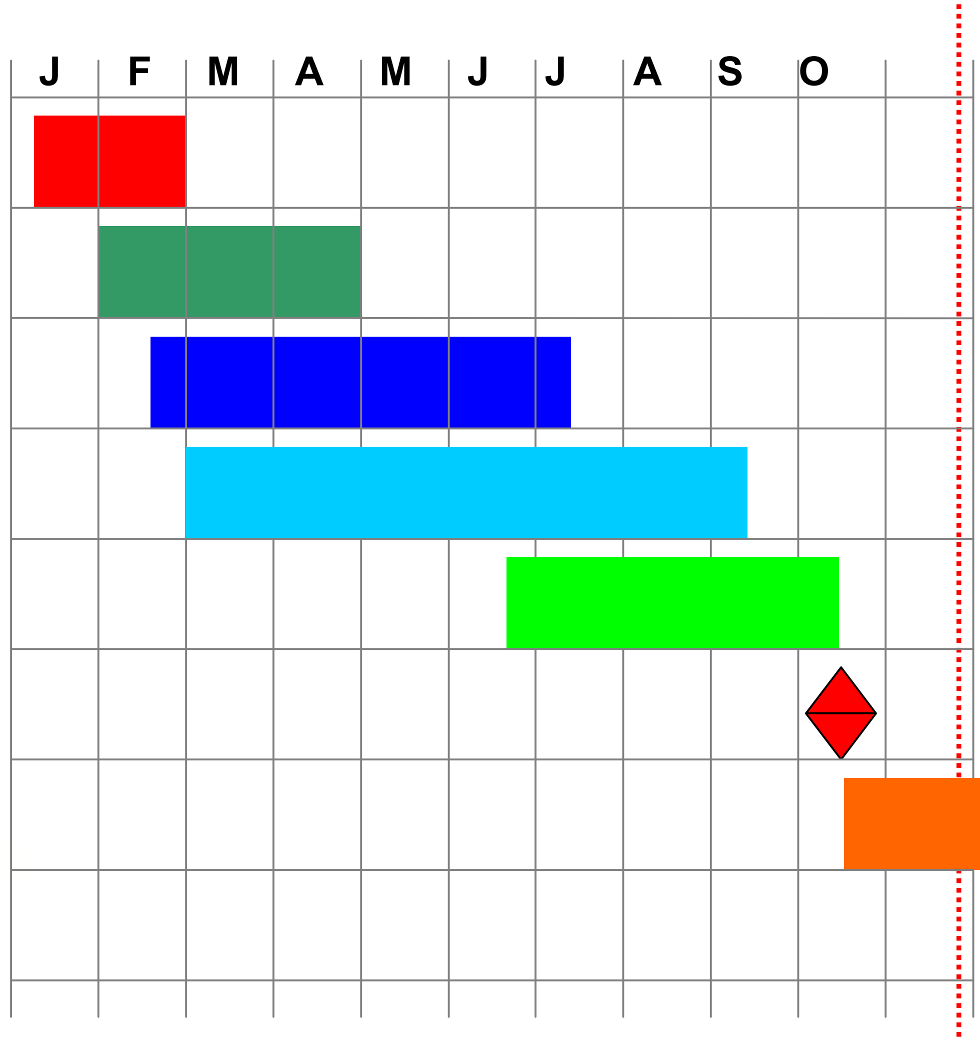
Construction

Commissioning

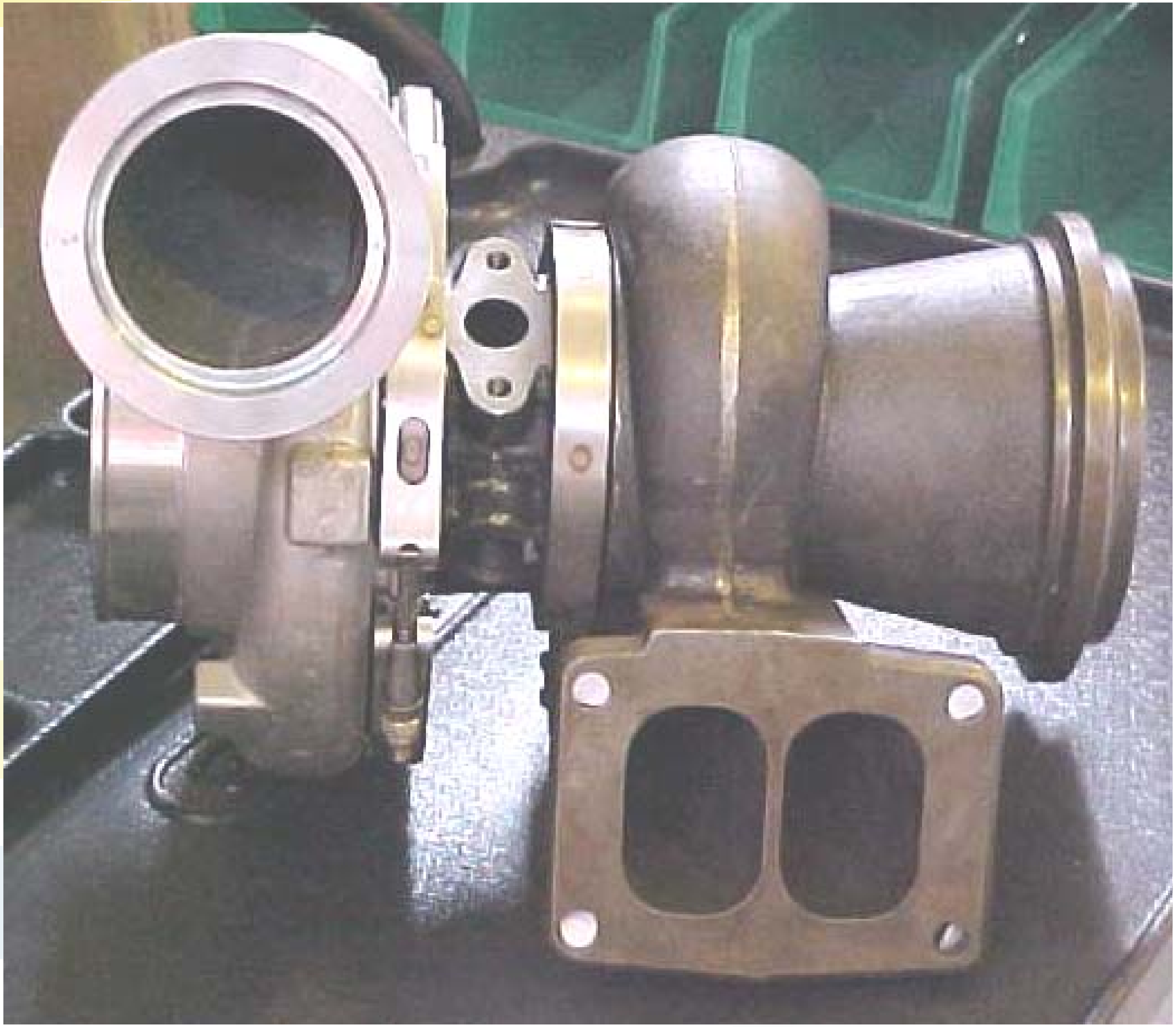
Demonstration

Utilization

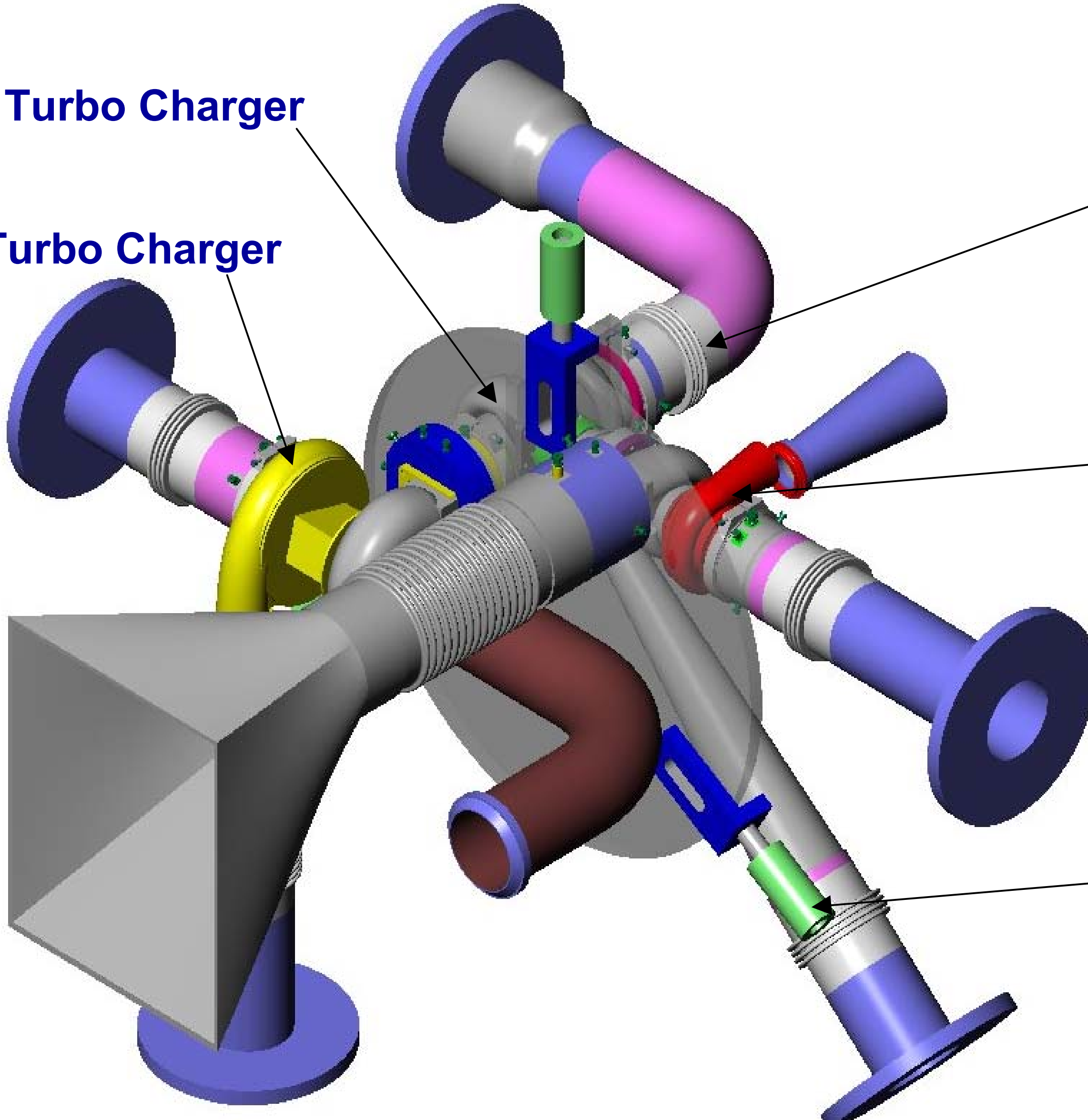
Phase Out (Future)



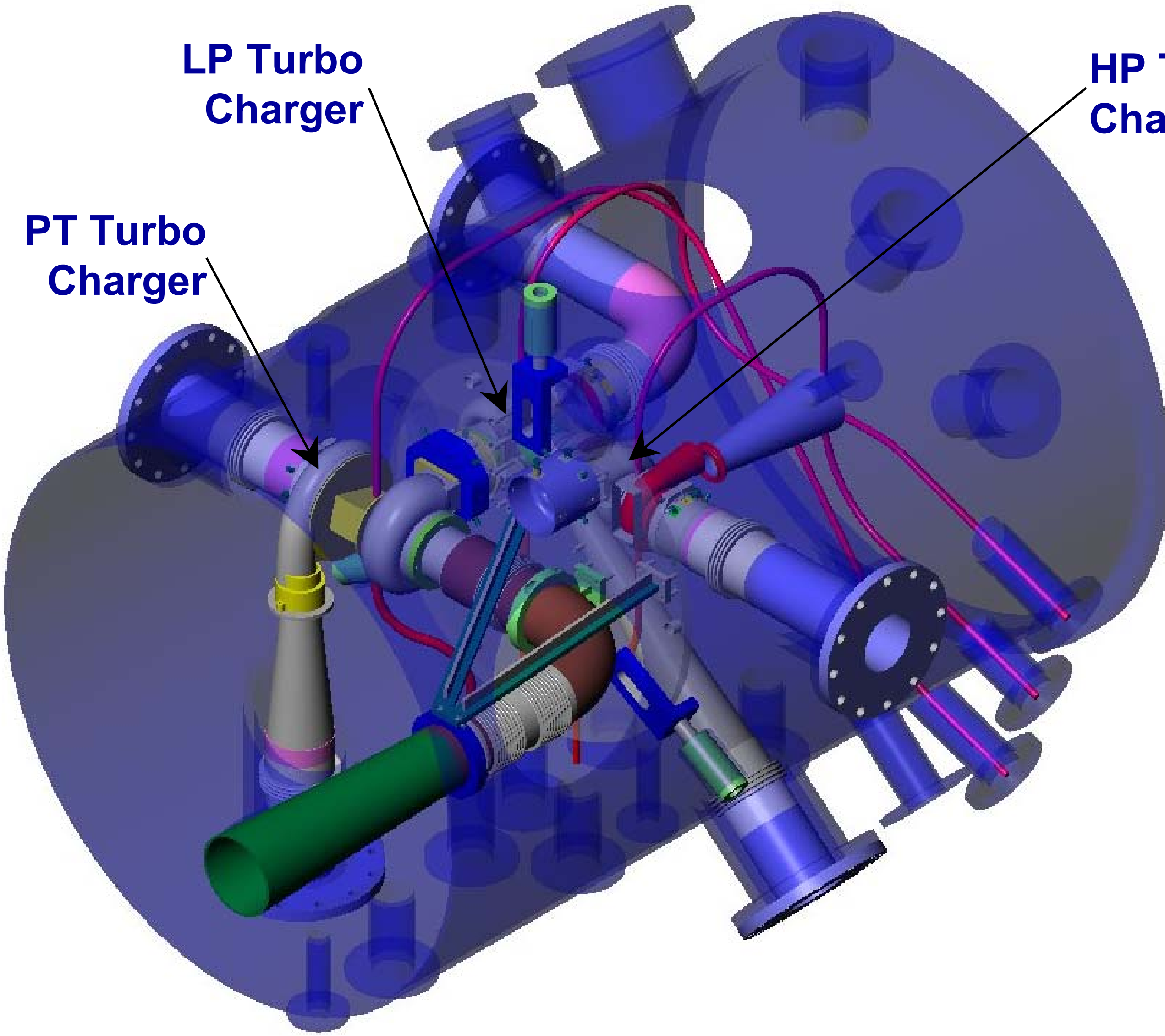
Turbocharger



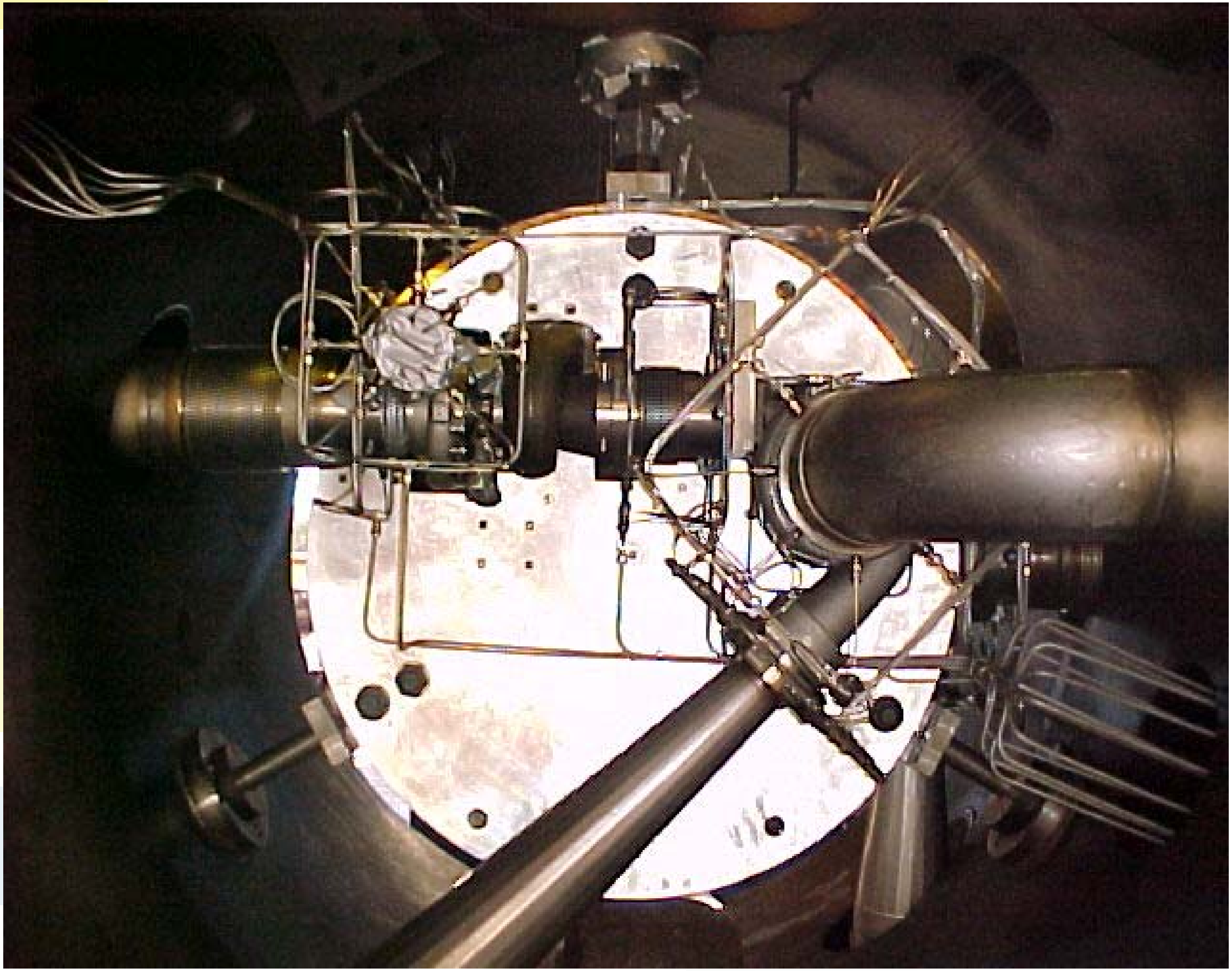
Turbo Charger Layout



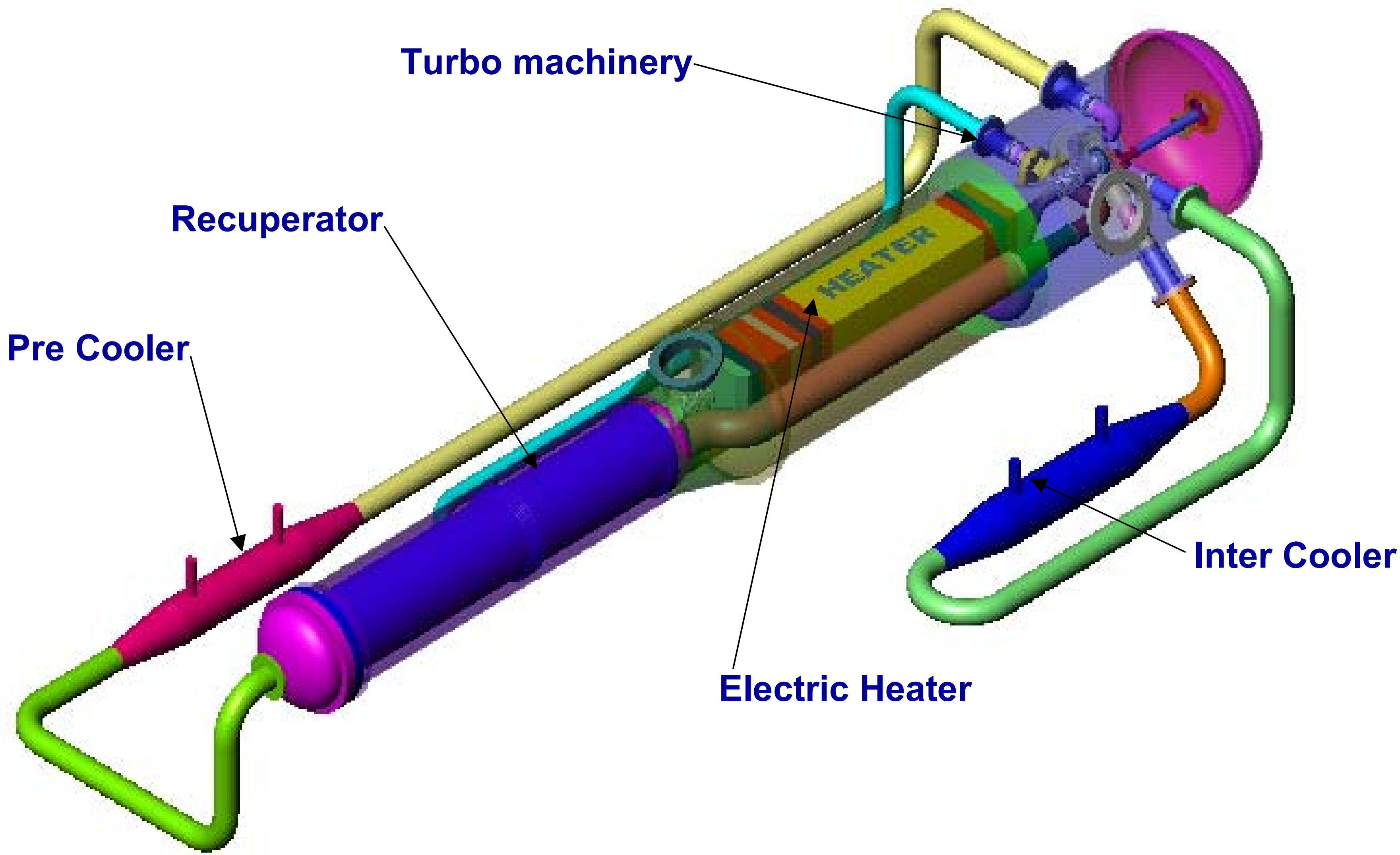
Turbo Charger Layout



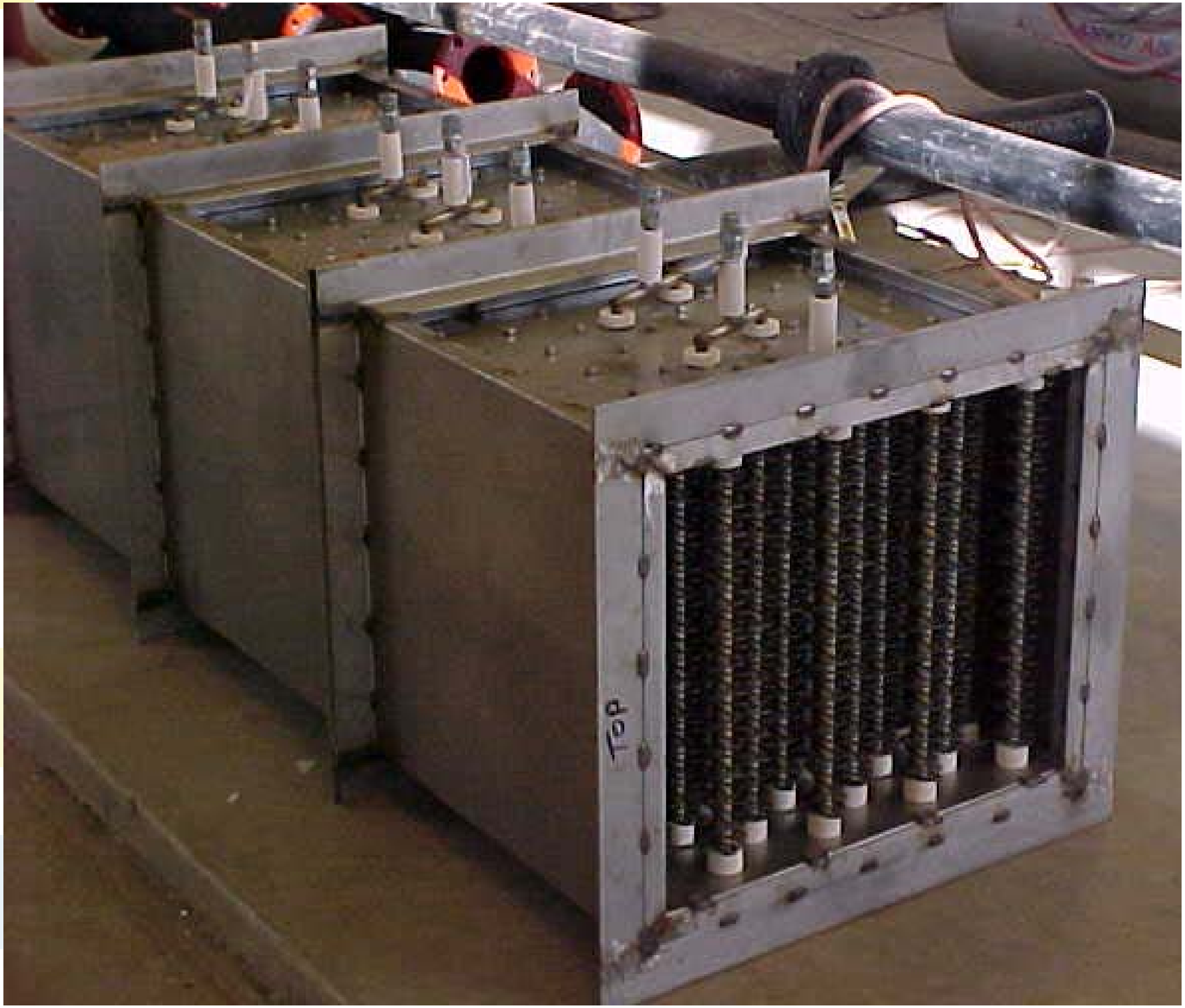
Turbocharger plate



Pressure Vessel Layout



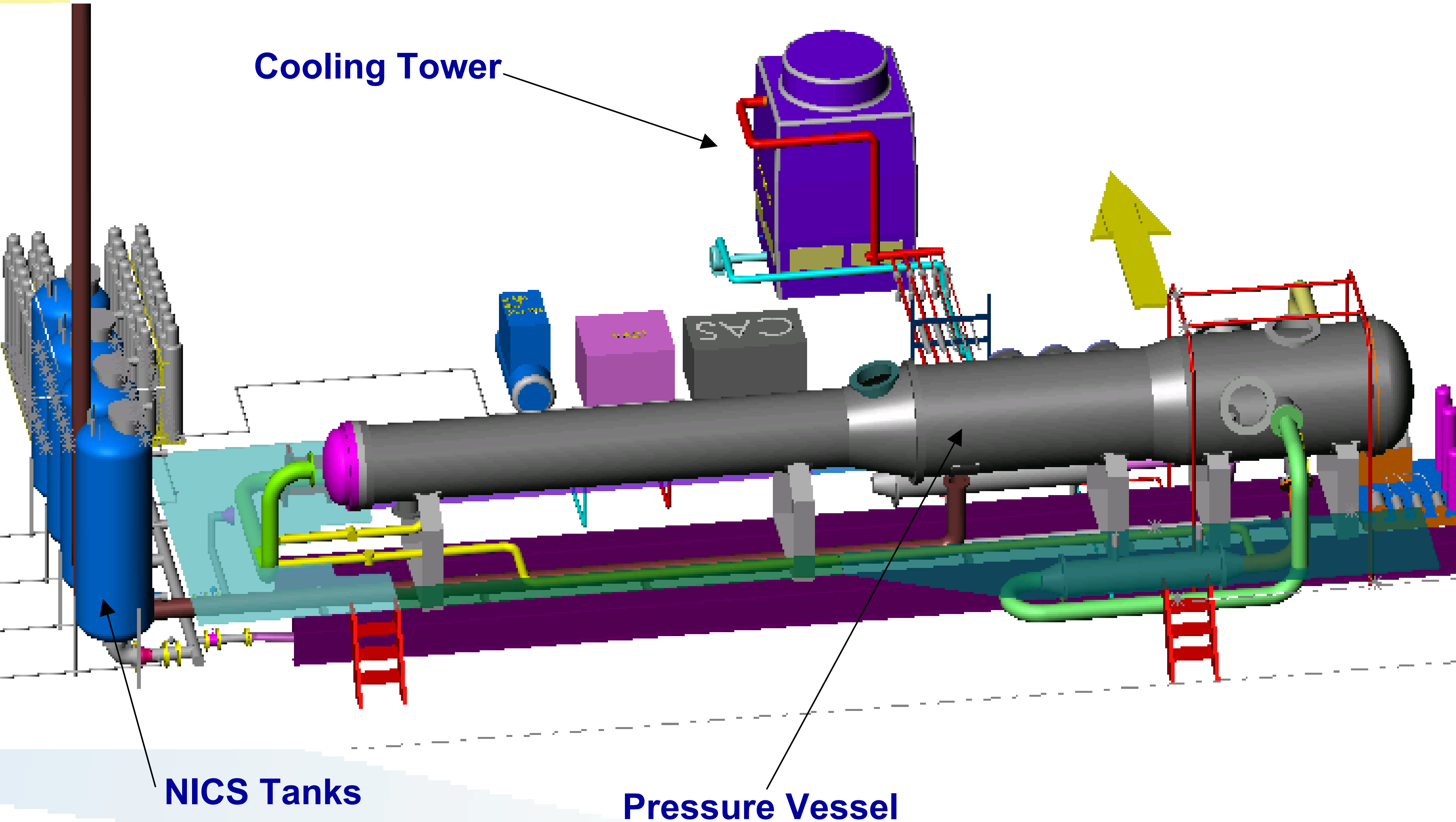
Electrical Heaters…



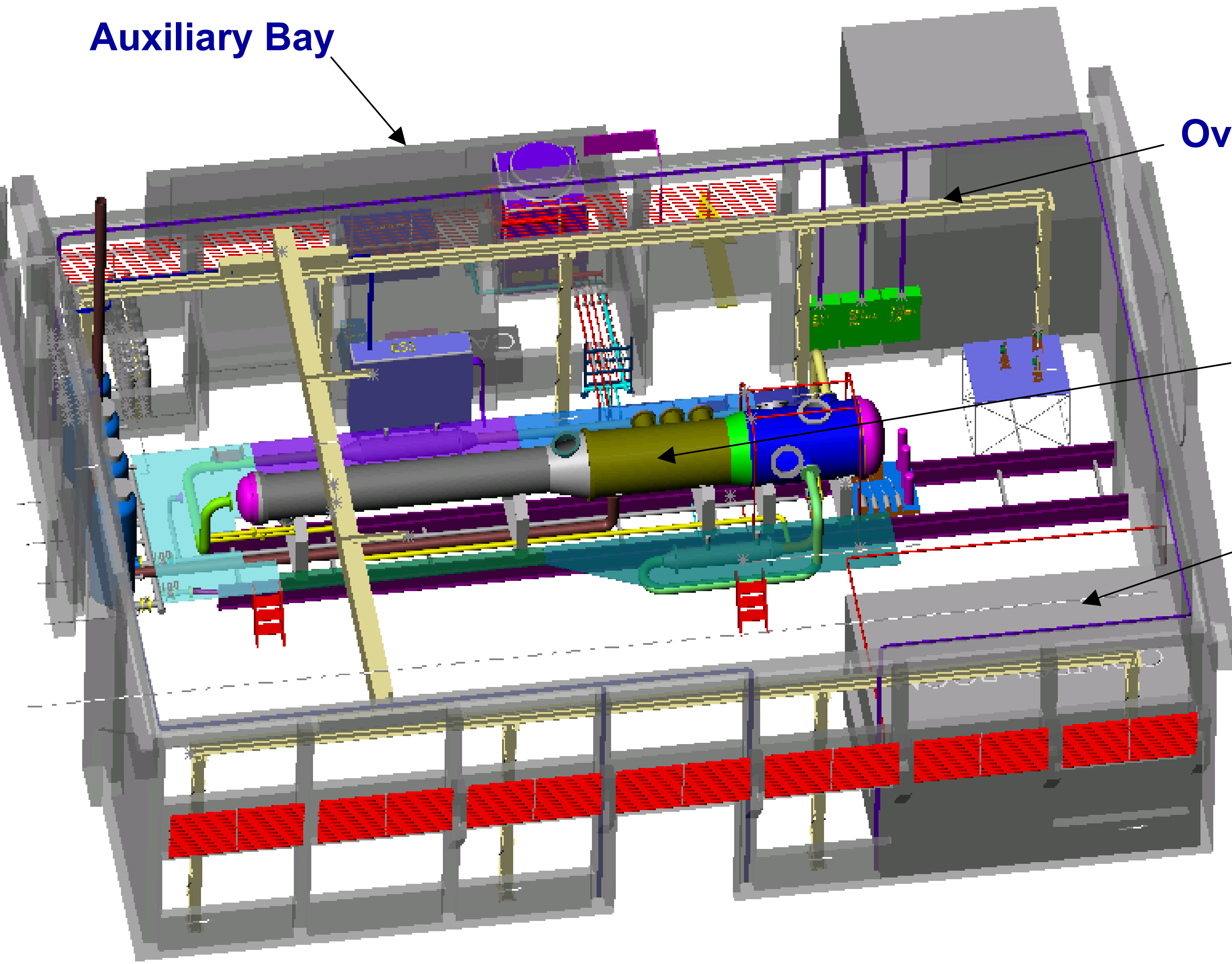
Recuperator

P B M

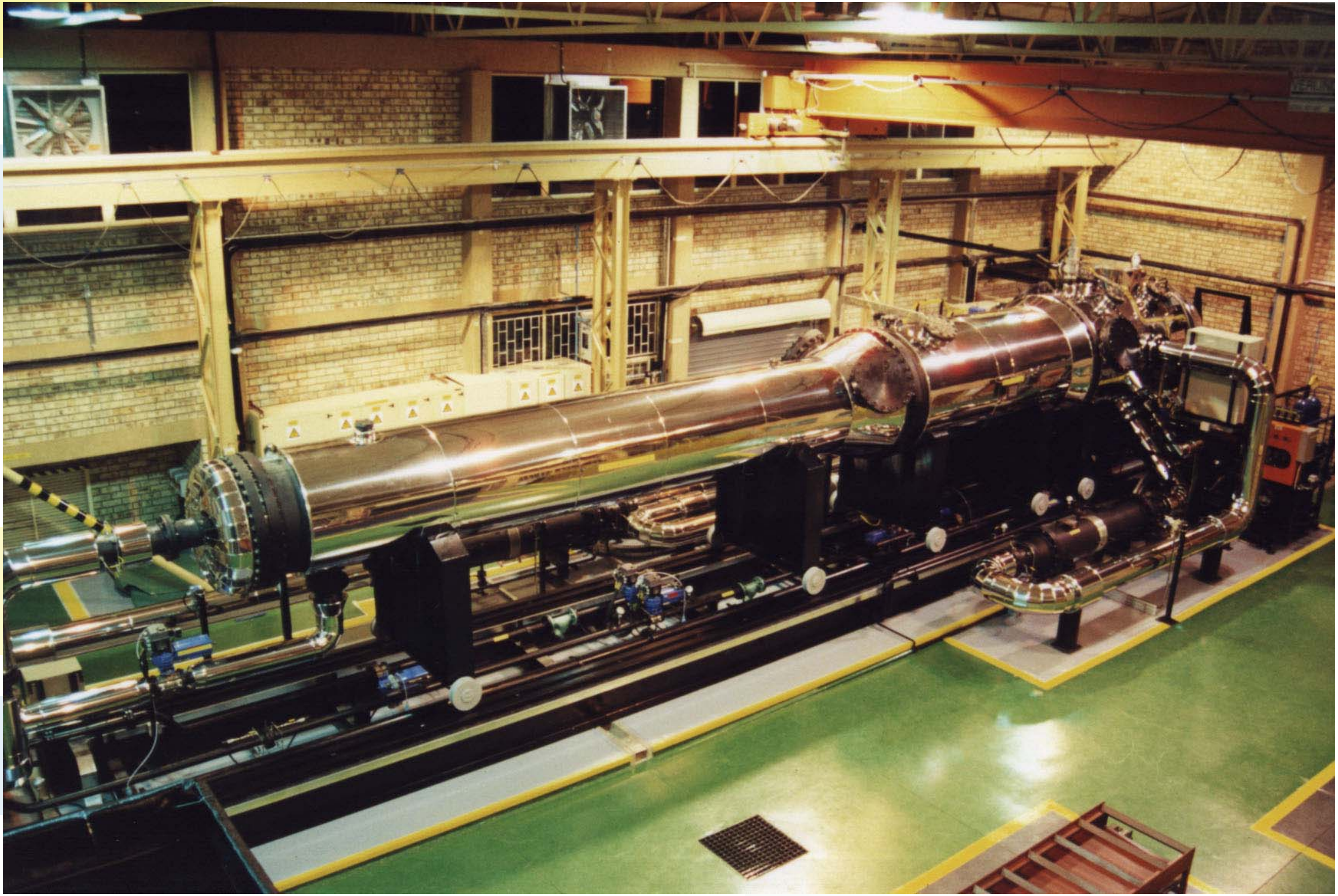
System Layout…



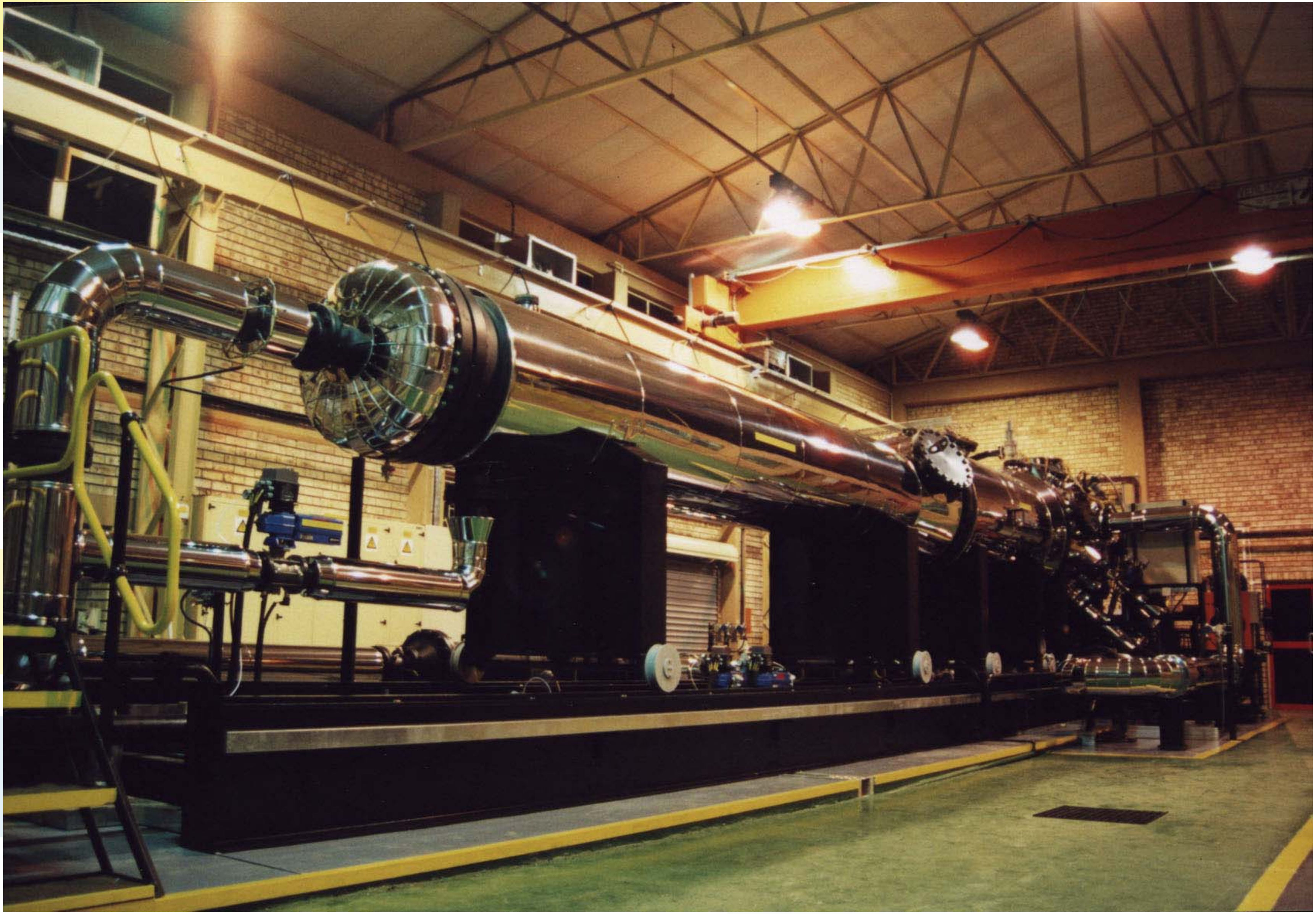
Building Layout



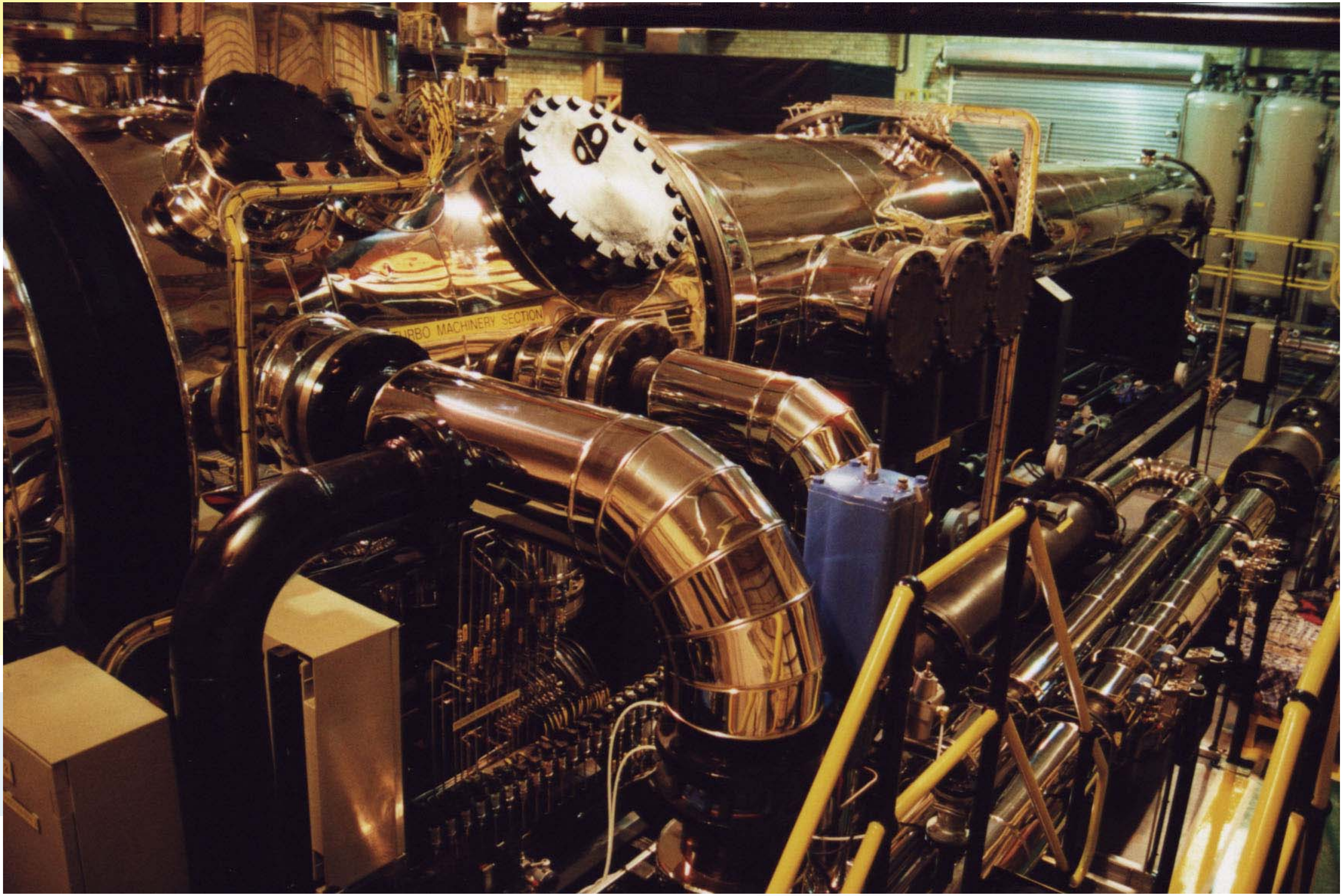
Final plant (1)



Final plant (2)

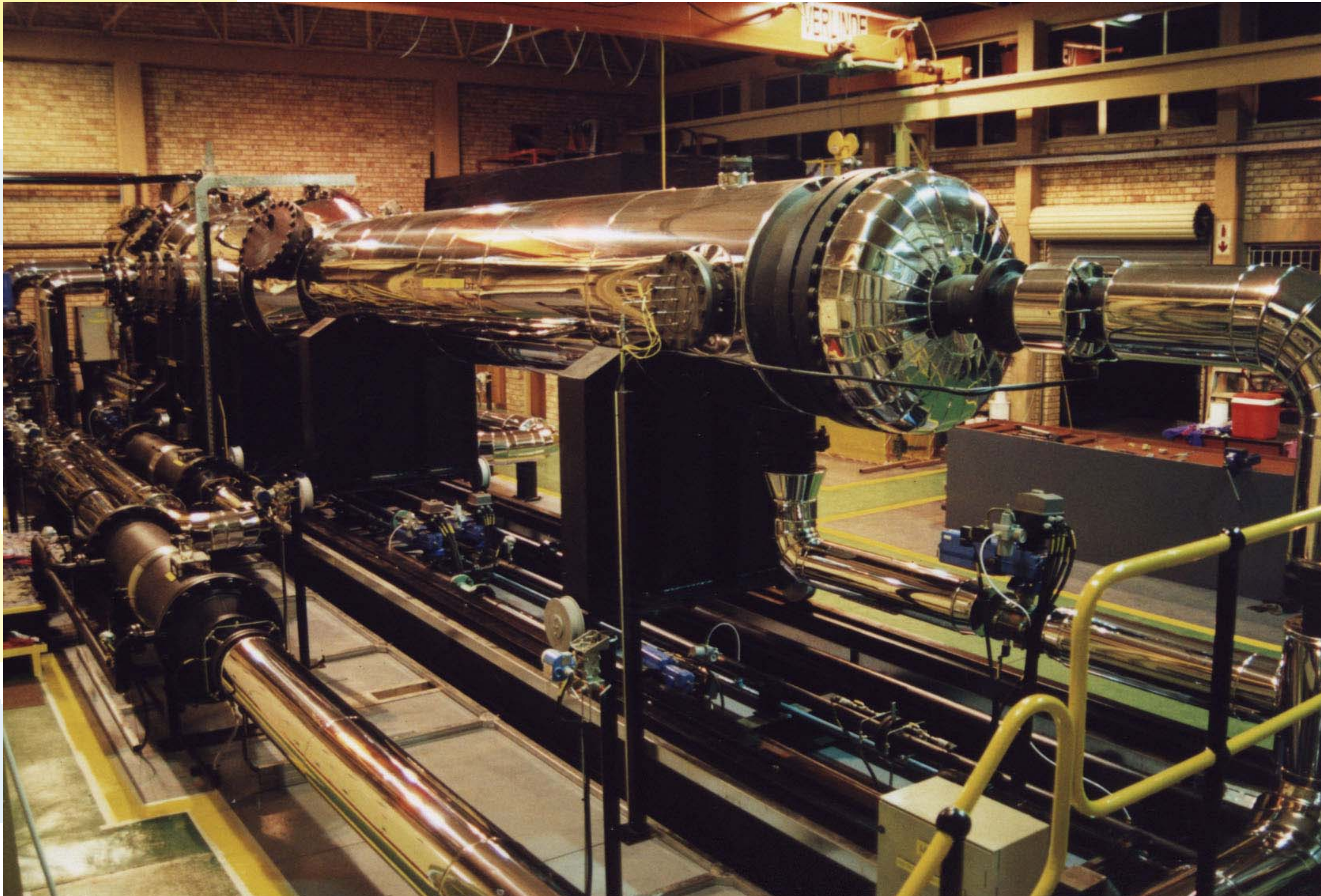


Final plant (3)



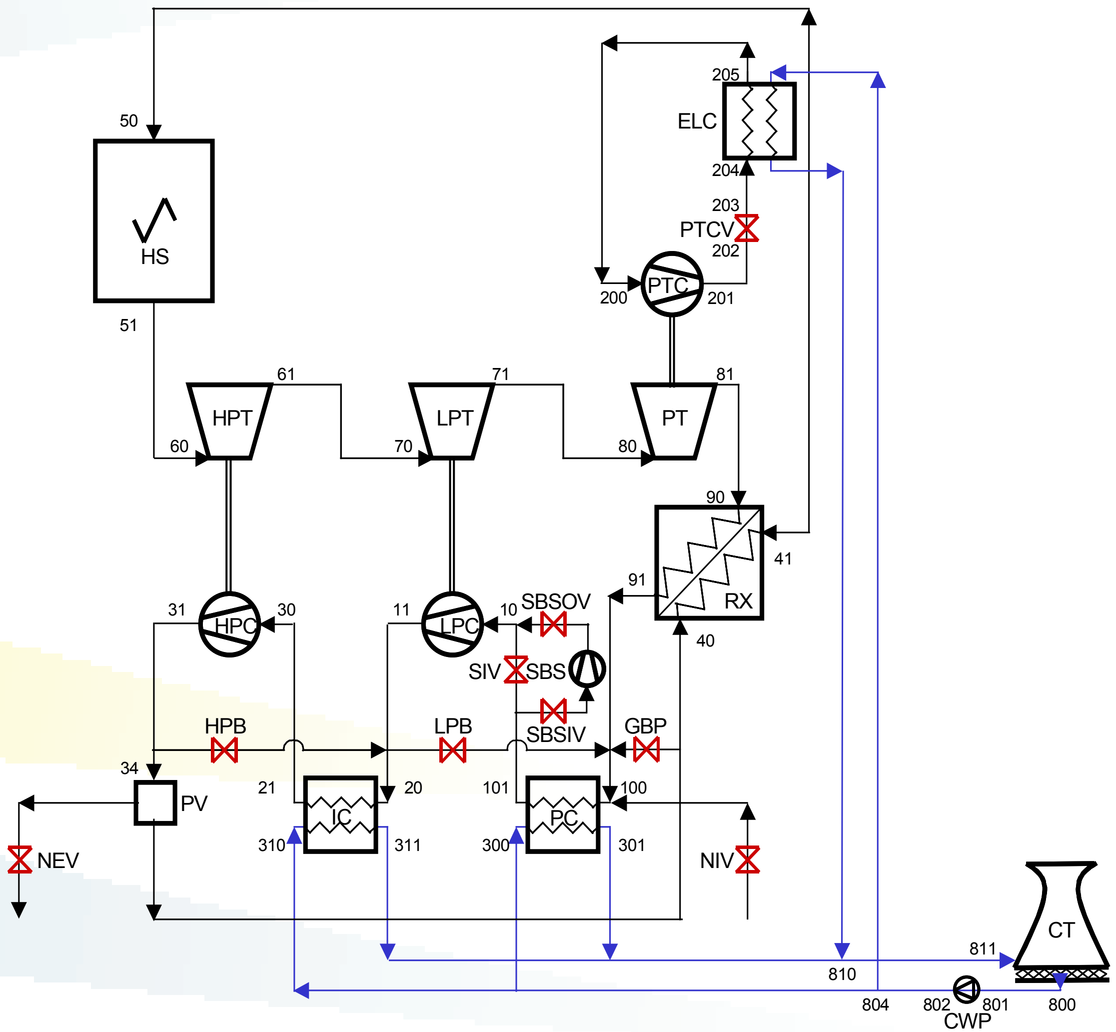
Final plant (4)

P B M



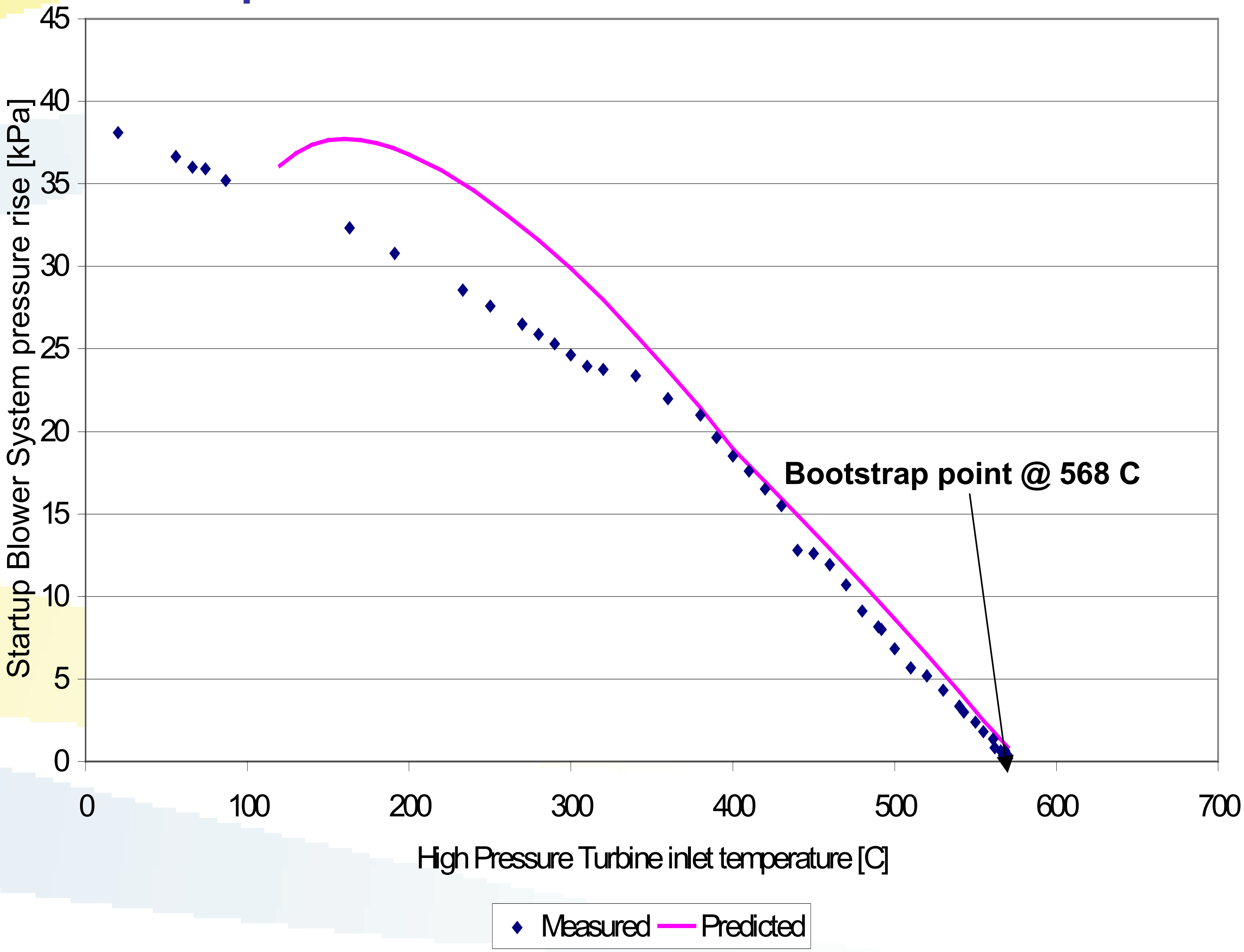
Start-up

Start-up sequence



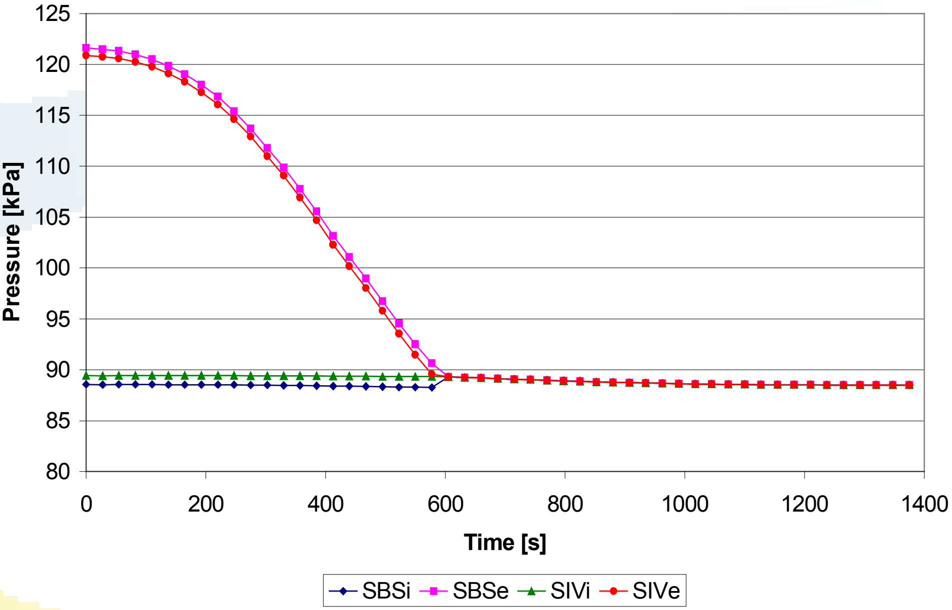
Start-up

Bootstrap

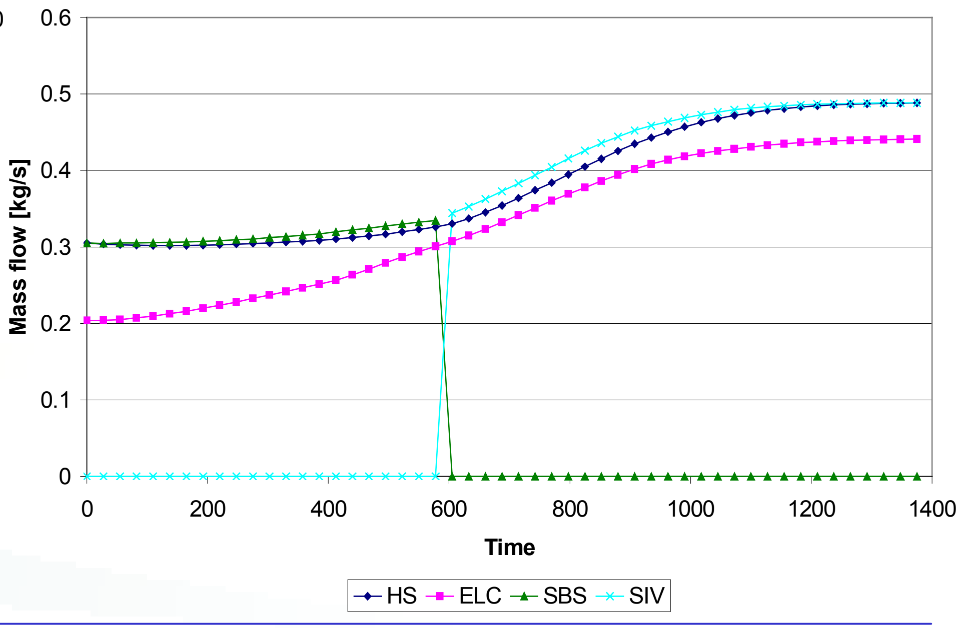


Start-up

SBS



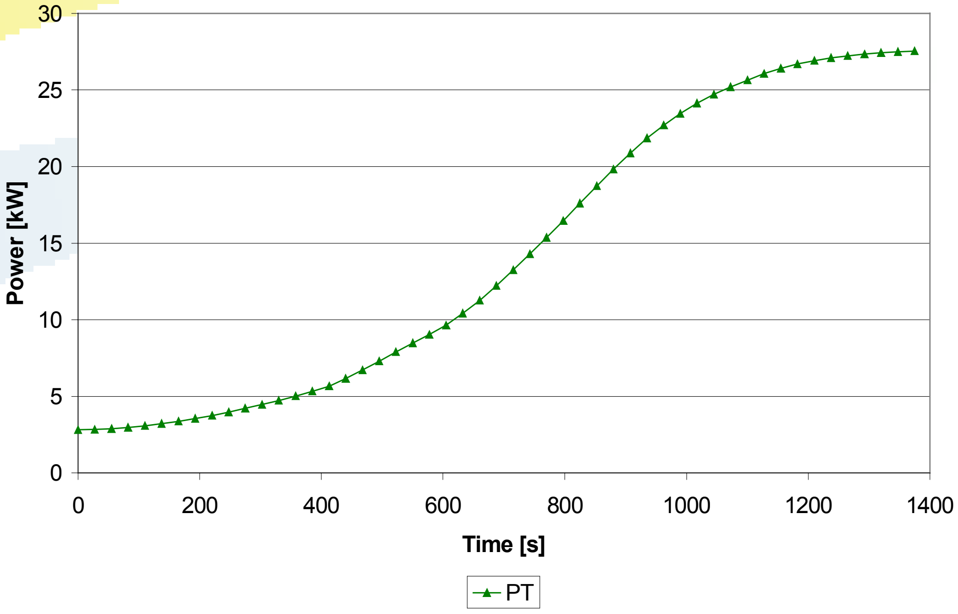
Pressure [kPa]
125
120
115
110
105
100
95
90
85
80
0
200
400
600
800
1000
1200
1400
Time [s]
SBSi
SBSe
SIVi
SIVe

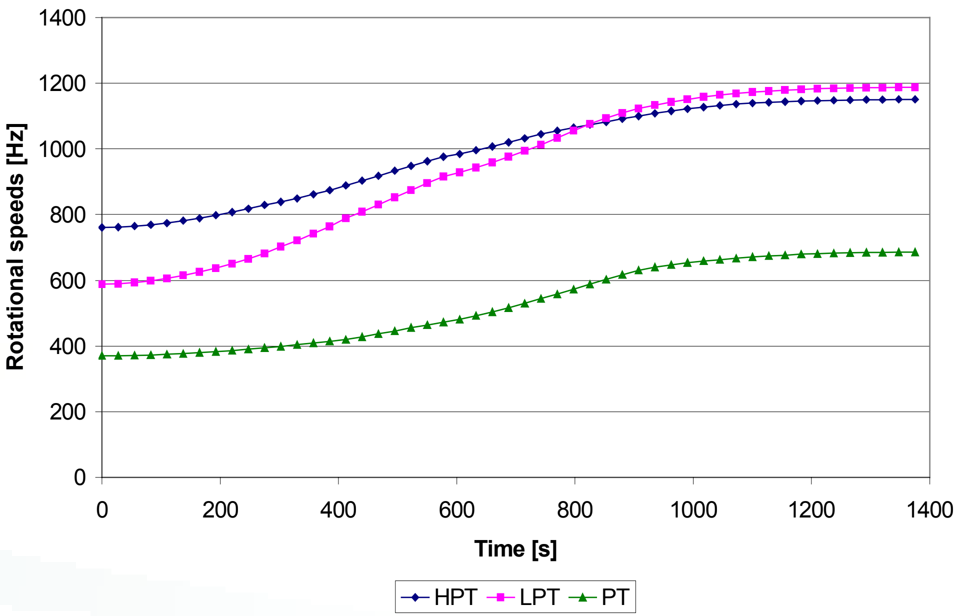


Mass flow [kg/s]
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
Time
HS
ELC
SBS
SIV

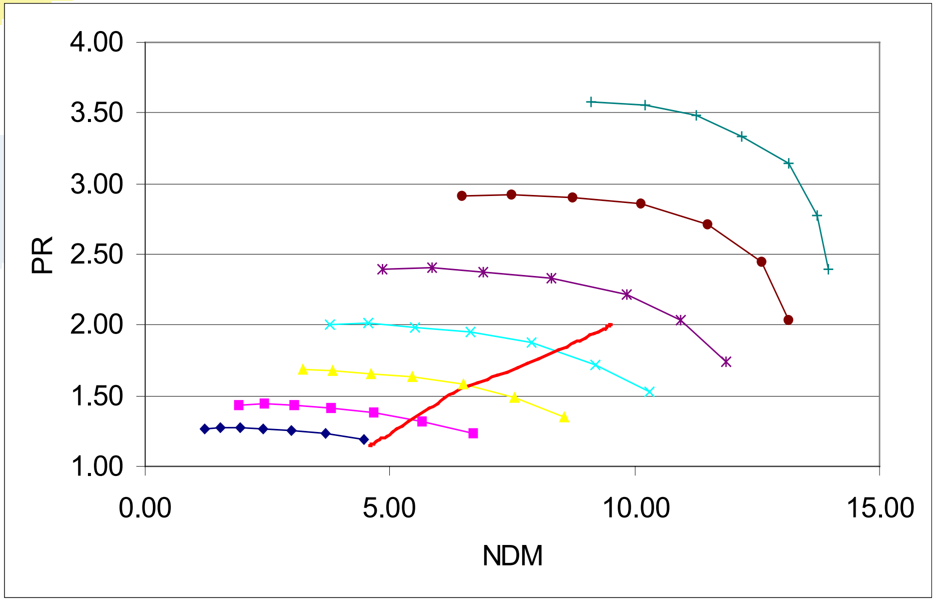
Start-up

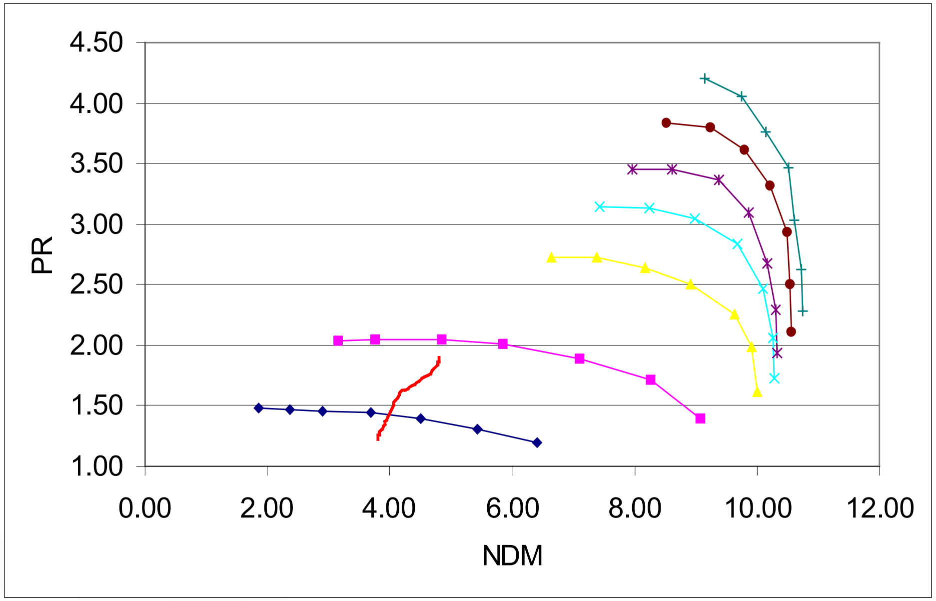
Turbines





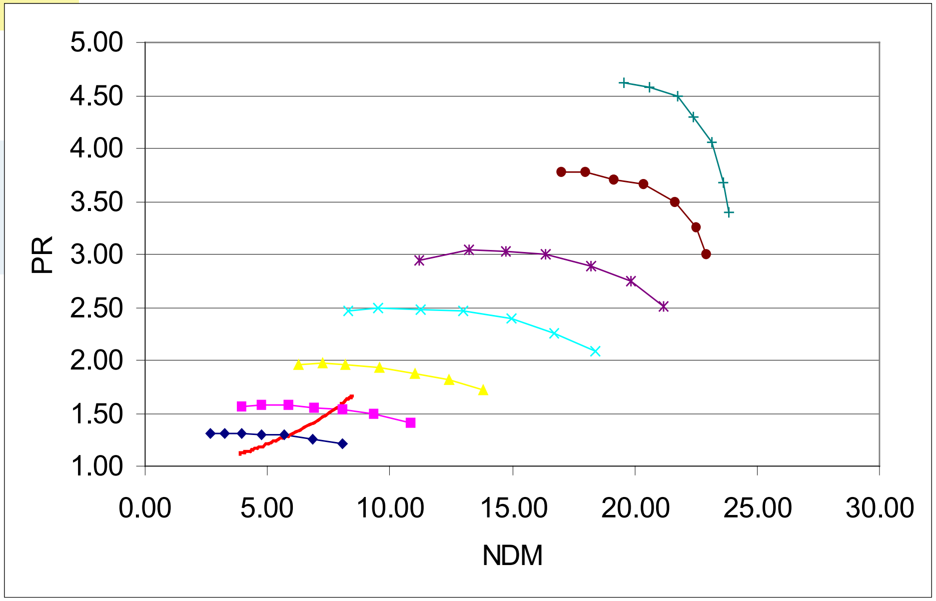
Start-up
LPC and HPC

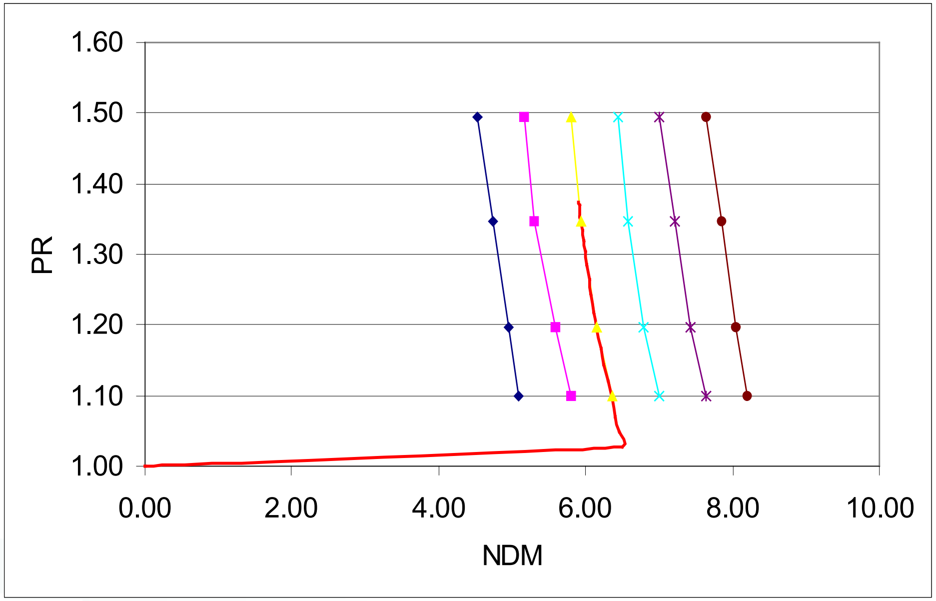




Start-up

PTC and SBS

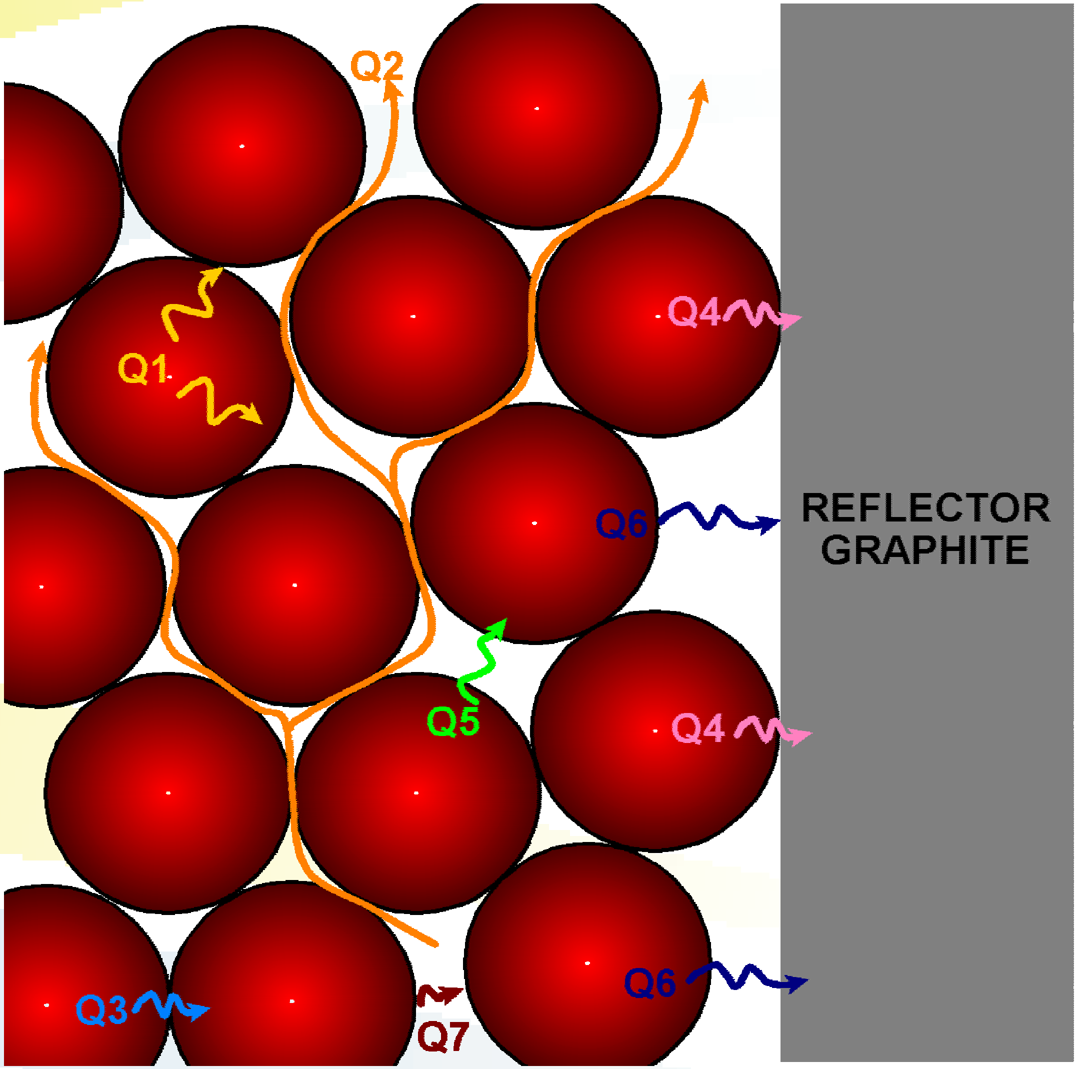




Heat Transfer Test Facility

The objective of this test is to determine the heat transfer properties of packed graphite pebble beds with heat generation under various cooling conditions.

Pebble Bed Heat Transfer Validation



Q1: Conduction from the centre of the pebble to the surface

Q2: Convection from the pebble surface to the gas

Q3: Point contact conduction between the pebble surfaces that are in contact with one another

Q4: Point contact conduction between the pebble surfaces that are in contact with the reflector

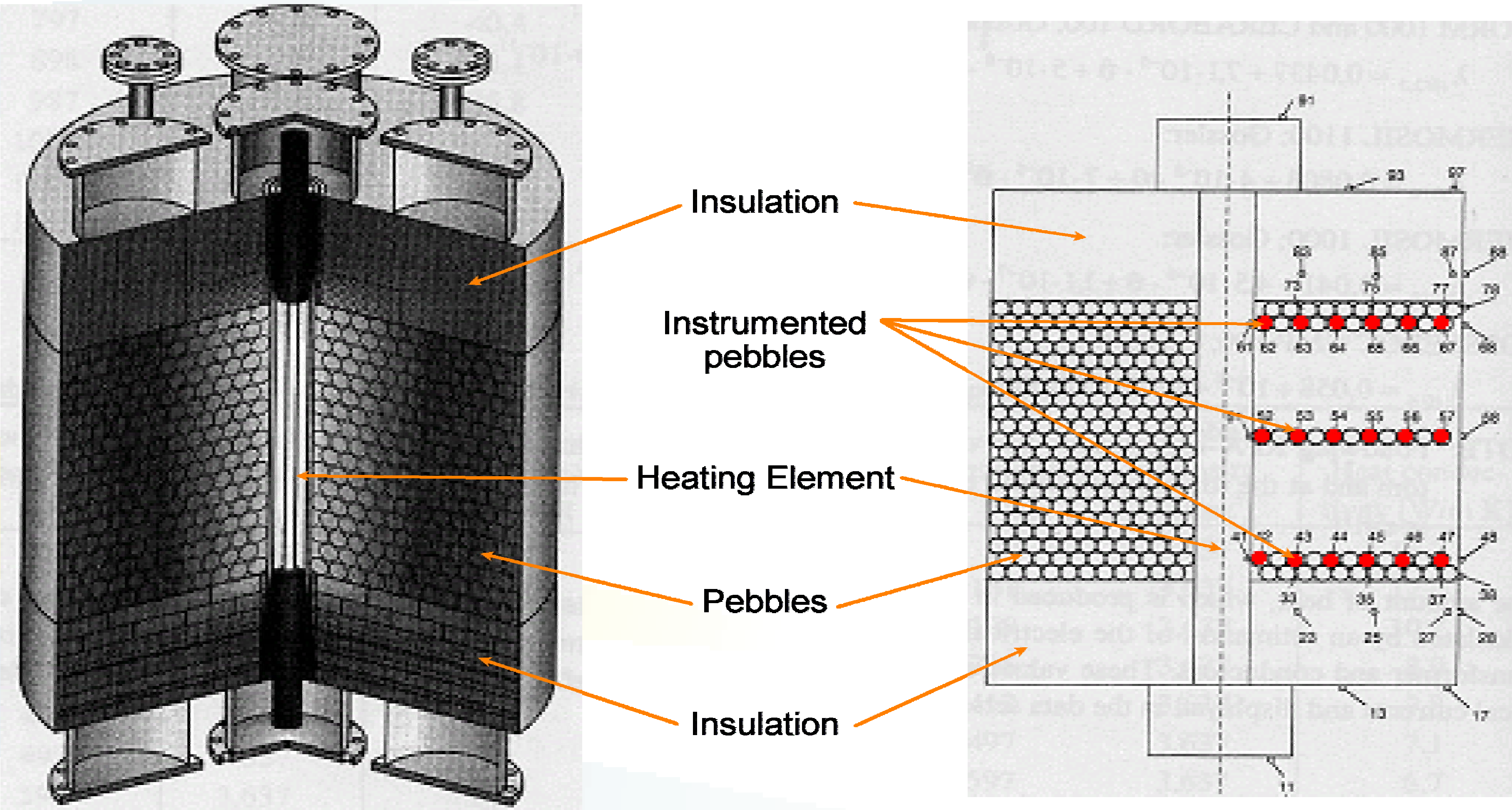
Q5: Thermal radiation between the pebble surfaces

Q6: Thermal radiation between the pebble surfaces and the reflector

Q7: Conduction in the gas

SANA Facility in Germany for Pebble Bed Heat Transfer Validation

SANA Facility Showing the Internals



Why can we not just use SANA experiment results ?

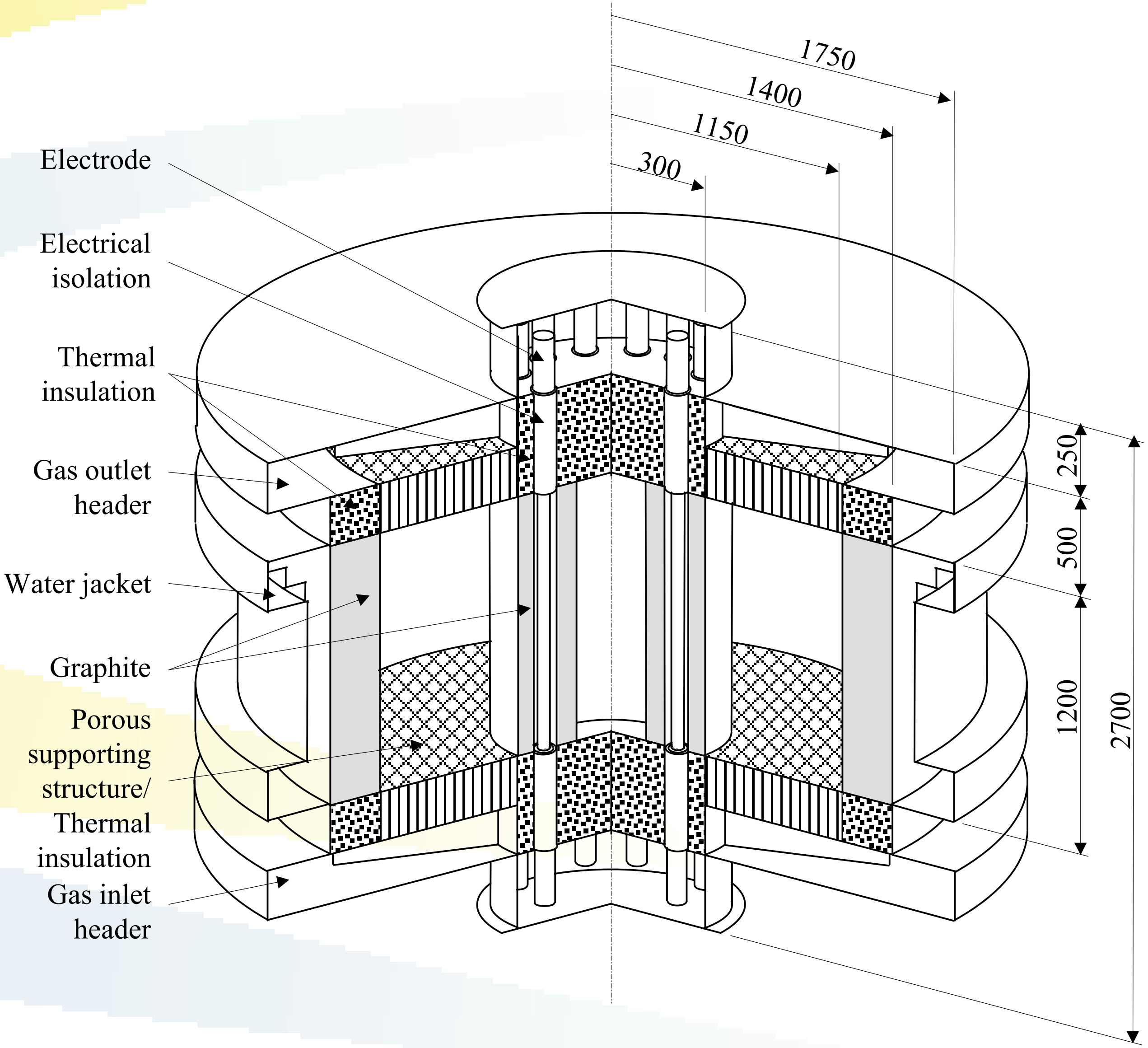
ndamentally SANA was designed based on the modeling data required for the des used at the time – this means that flow in the pebble bed is neglected or proximated using the correlations obtained form the tests. – PBMR use codes such CFD and Flownex that include the fundamental modeling of the gas flow effects or heat transport in the reactor.

BMR geometry is different and falls beyond the scope of the experimental geometry ed in SANA

Parameter	SANA	PBMR
Geometry	Cylindrical	Annulus
Core aspect ratio	1	12

Separate effects test were not performed with SANA, therefore calibration of certai fects/parameters that are modeled is very difficult if not impossible and could not b used for for code validation.

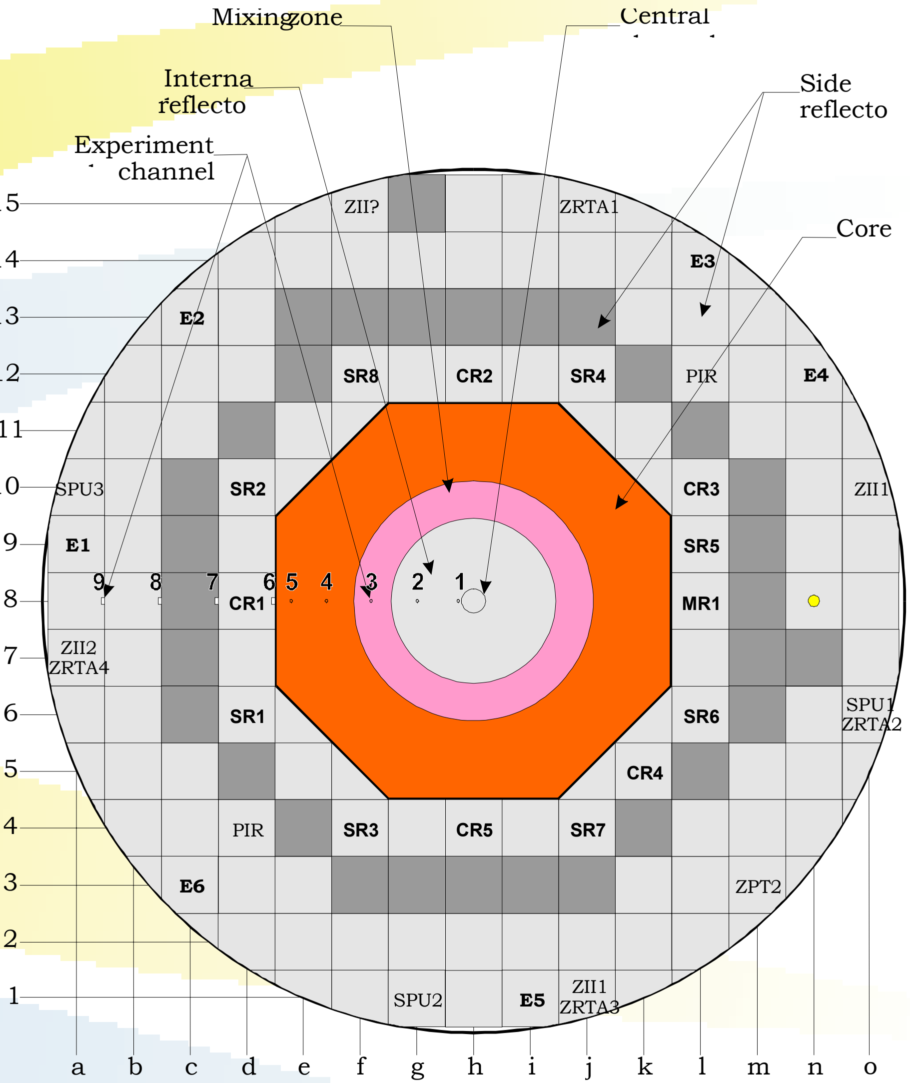
Proposed Integrated Effects Test Facility

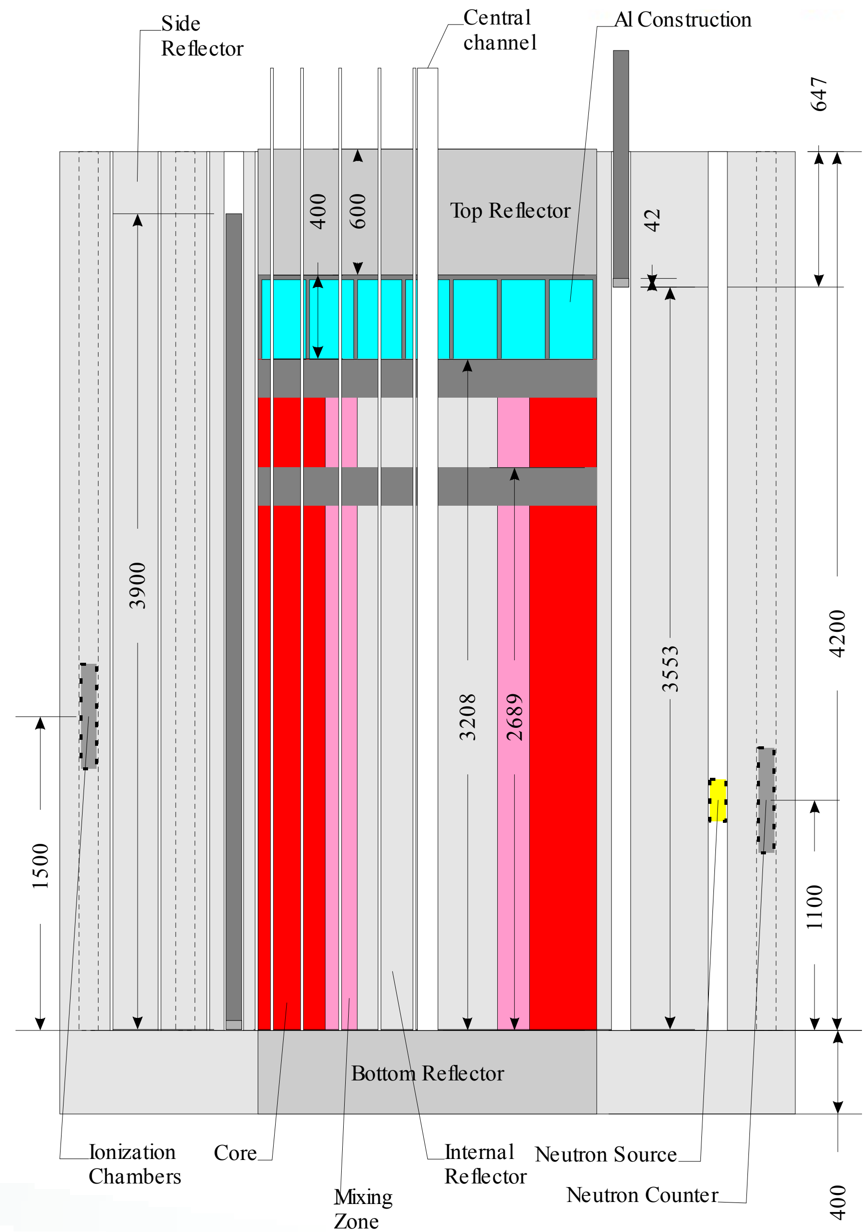


The ASTRA Critical Facility

- ASTRA Critical Facility at the Russian Research Centre – Kurchatov in Moscow
- Purpose is to perform benchmark experiments simulating specific characteristic features of the PBMR design
- The physical configuration of the ASTRA facility allowed for the possibility to carry out experiments simulating PBMR physics
- VSOP is the main core neutronics code used for the PBMR
- One important aim is to use the ASTRA Experiments to validate VSOP

The ASTRA Critical Facility





Filled Reflector Block

Unfilled Reflector Block

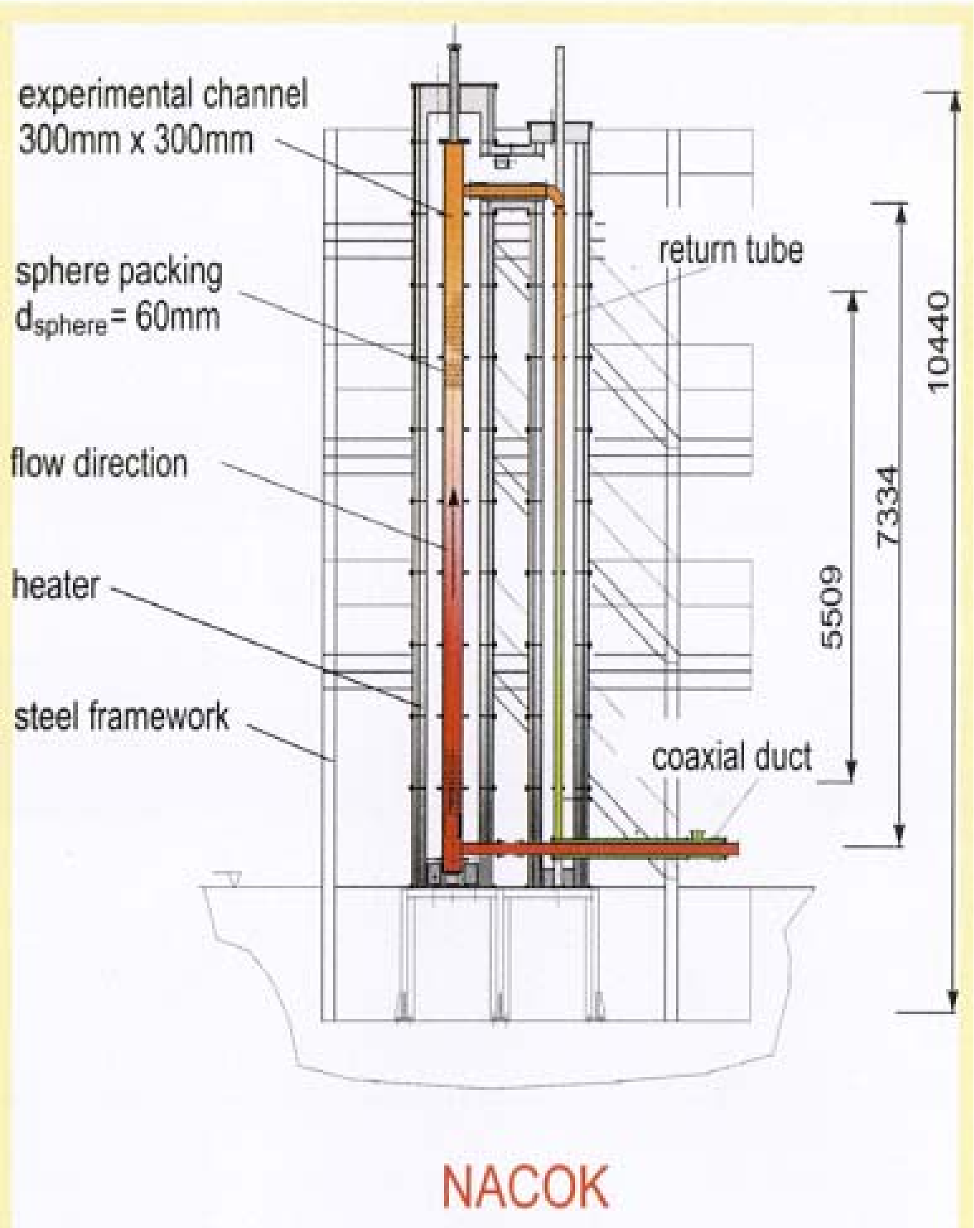
CR - Control
MR1 - Manual control
SR - Safety
E1-E6 - Experimental chambers
1-9 - Experimental channels for
PIR,ZPT,ZII,ZRTA - Ionization chambers and neutron

Neutron source

The NACOK Facility

- NACOK Natural Convection in Core with Corrosion
- The objective of this test facility is to investigate the oxidation (corrosion) of hot graphite cores by oxygen under natural circulation following an air ingress event

The NACOK Facility



The NACOK Facility

NACOC - MAIN DATA

Max. temp. in experimental channel	1200 °C
Max. temp. in return tube	800 °C
Max throughput of air	17 g/s
Total number of thermo-couples	82
Total number of gas measurement points	26
Number of points to measure gas velocity	2
Max. heating power	147 kW

The Multi-Quadrant Testing Facility

The primary objective of the multi-quadrant Turbo Machine Test Facility is to conduct various Separate Effects Tests on a relatively small scale to determine empirically the performance of compressors and turbines operating in quadrants other than the usual