RHIC 56 MHz Cryomodule External Review

IP-4 (Interaction Point 4) Quiet Cryogenic Delivery Subsystem

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IP-4 Quiet Cryogenic Delivery Subsystem

- Cavity Design pressure: 1.38 bar [20 psia, 5 psig]
  - RHIC supply: “S” header, 3.5 bar, 5.3K
  - RHIC return: “R” header, 1.25 bar, 4.6K
  - RHIC return: “WR” header, 1.20 bar, 288K
- Quiet operating environment
  - Microphonics / Acoustic from helium system
    - Supply line from RHIC main cryolines
    - Return line, compressor suction
  - Mechanical vibrations

Noise and Vibration Isolation

- Condenser to isolate noise sources
- Bellows flexline between 1st separator and condenser cryostat
- Bellows flexline between condenser cryostat and cavity cryostat
- Actuated Valves on condenser cryostat, none on cavity cryostat, except relief valve

IP-4 Quiet Cryogenic Delivery Subsystem

- CONDENSER OPERATION
  - Condenser to Boiler Heat transfer Gradient → Condenser side Vapor Pressure
  - Condenser side operating pressure changes with heat load
  - Condenser side transient responds time constant depends vapor volume
- Tuner Operation
  - react to frequency shift from condenser pressure change
  - Order of: Max few mbar/sec → Hz/sec
- Other
  - Cooldown
  - Fill
  - Isolate
- Shield Cooling: from boiler side vapor flow

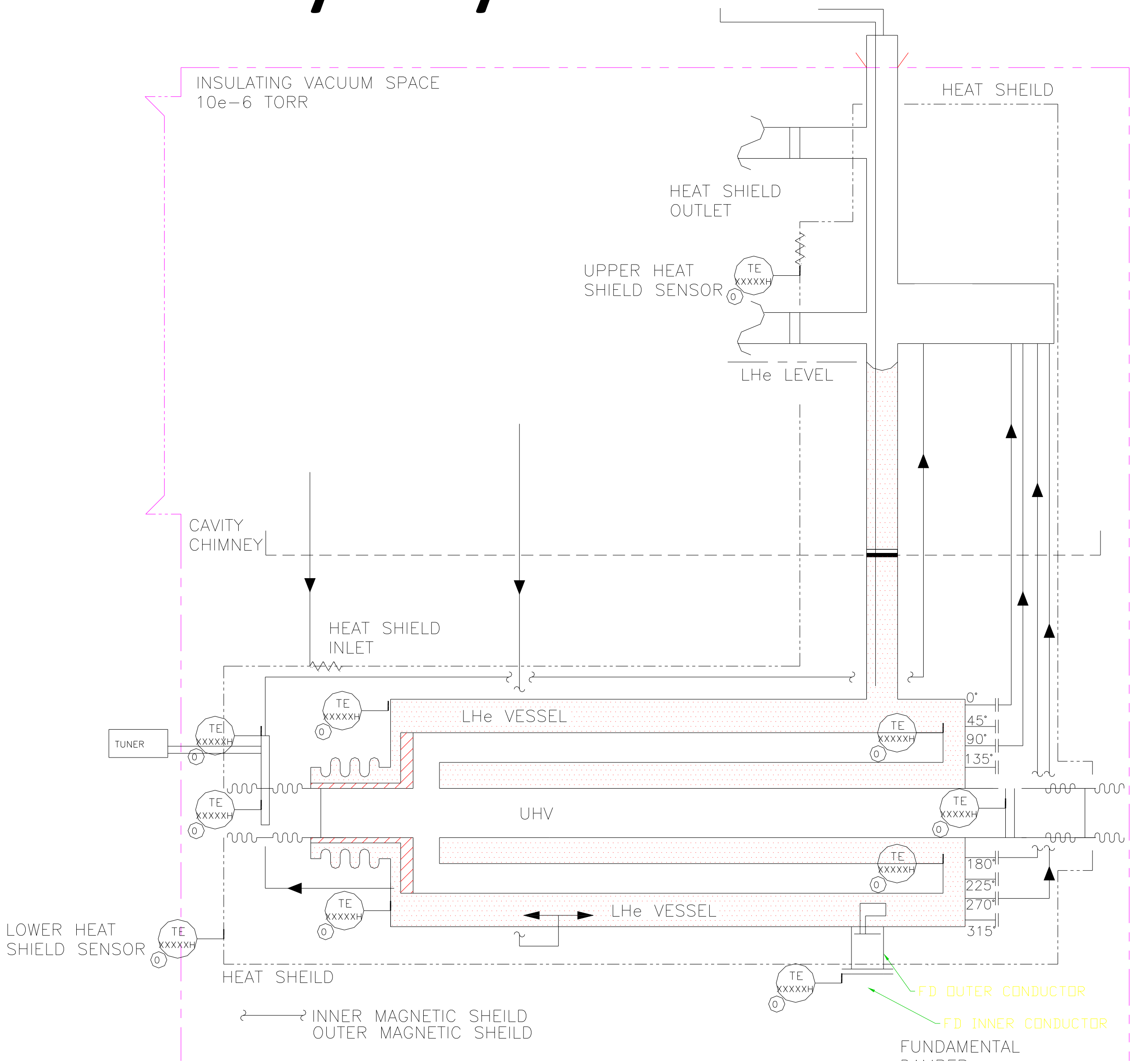
Cavity Cryo Loads

- Dynamic Load @ 2MeV: around 20W each cavity
- Static Load: ~ 20W each cavity
  - Nitronic Rod Supports: 4 W
  - Radiant load from heat shield: 1 W
  - Tuner Yoke: < 1W
  - HOM cables: < 1W
  - IR detector windows: < 1W
  - Fundamental damper: < 2 W?
  - Warm UHV beam tubes radiant load: <3 W
  - Warm UHV beam tubes conduction load: <1 W
  - Vapor space / Vent stack: 2W
  - Diode wires < 0.1W
  - SC level probe <0.1W

Dampers & Other Cooling

- HOM dampers flange cooling
  - Supply line from helium vessel, 2-phase independent return line to vapor space
- Tuner Yoke cooling
  - Supply from helium vessel, 2-phase independent return line to vapor space
- Fundamental Damper, from bath

Cavity Cryostat Interface



Condenser/Boiler

- Designed heat load →200 W (for two cavities)
- Proposed heat transfer surface area →40 m^2
- Average heat flux across heat transfer surface area →5 W/m^2
- Condenser side temperature → 4.4 K
- Boiler side temperature → 4.3 K
- Proposed heat exchanger type → Plate and fin
- Heat exchanger material → Al 3003
- Condenser vapor volume → 100 Liters

Condenser/Boiler

- DT_1 , Condenser side condensed liquid helium film → **10** mK
- DT_2 , Fin on condenser side → **6** mK
- DT_3 , Parting plate wall → **0.2** mK
- DT_4 , Boiler side, natural convection → **59** mK
- DT_5 , Fin on condenser side → **6** mK
- DT_6 , Helium column at bottom of the heat exchanger → **9** mK
- DT_{total} → 90.2 mK
- DT_{budget} → 100 mK (100 mbar, condenser side)

Condenser Vapor Space Volume

$$\frac{\Delta f}{\Delta P}\cdot\frac{\Delta P}{\Delta E}\cdot\frac{\Delta E}{\Delta t}=\frac{\Delta f}{\Delta t}$$

$$\frac{\Delta f}{\Delta P}=1\left(\frac{Hz}{mbar}\right)$$

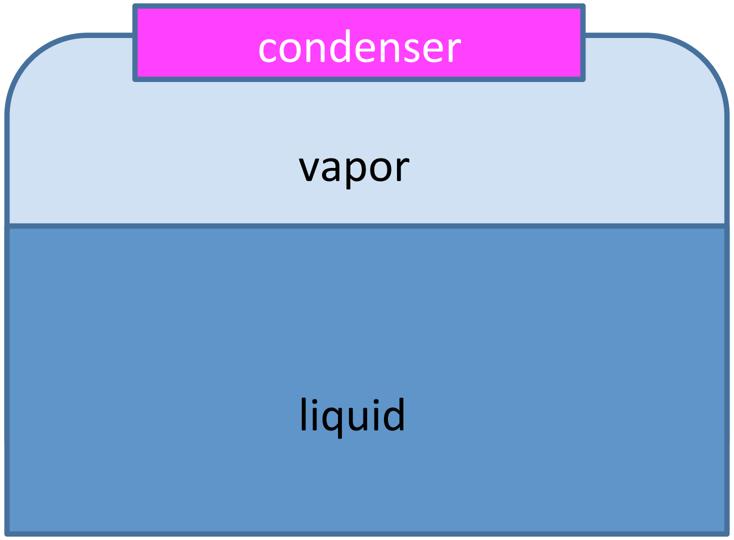
$$\frac{\Delta E}{\Delta t}=Q\ (W)=100W$$

$$\frac{\Delta P}{\Delta E}\propto\frac{1}{V_{vapor\ space}}$$

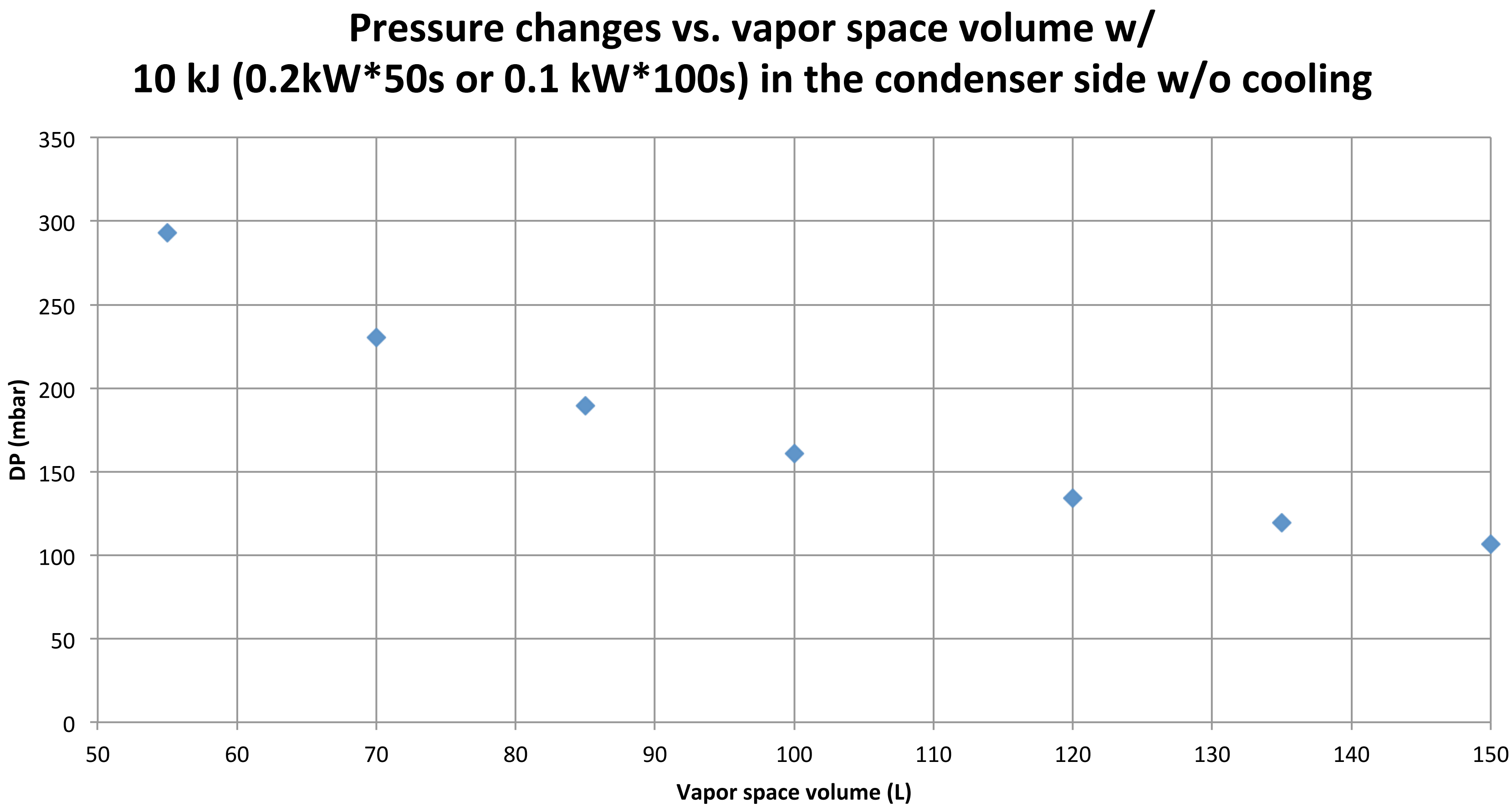
$$\frac{\Delta f}{\Delta t}\approx 2\left(\frac{mbar}{\sec}\right),100L$$

Heat transfer gradient across condenser/
boiler set pressure
change in cavity volume between 0 load to
full load, e.g. 100W

Condenser Vapor Volume sets the
pressure rise rate dP/dτ



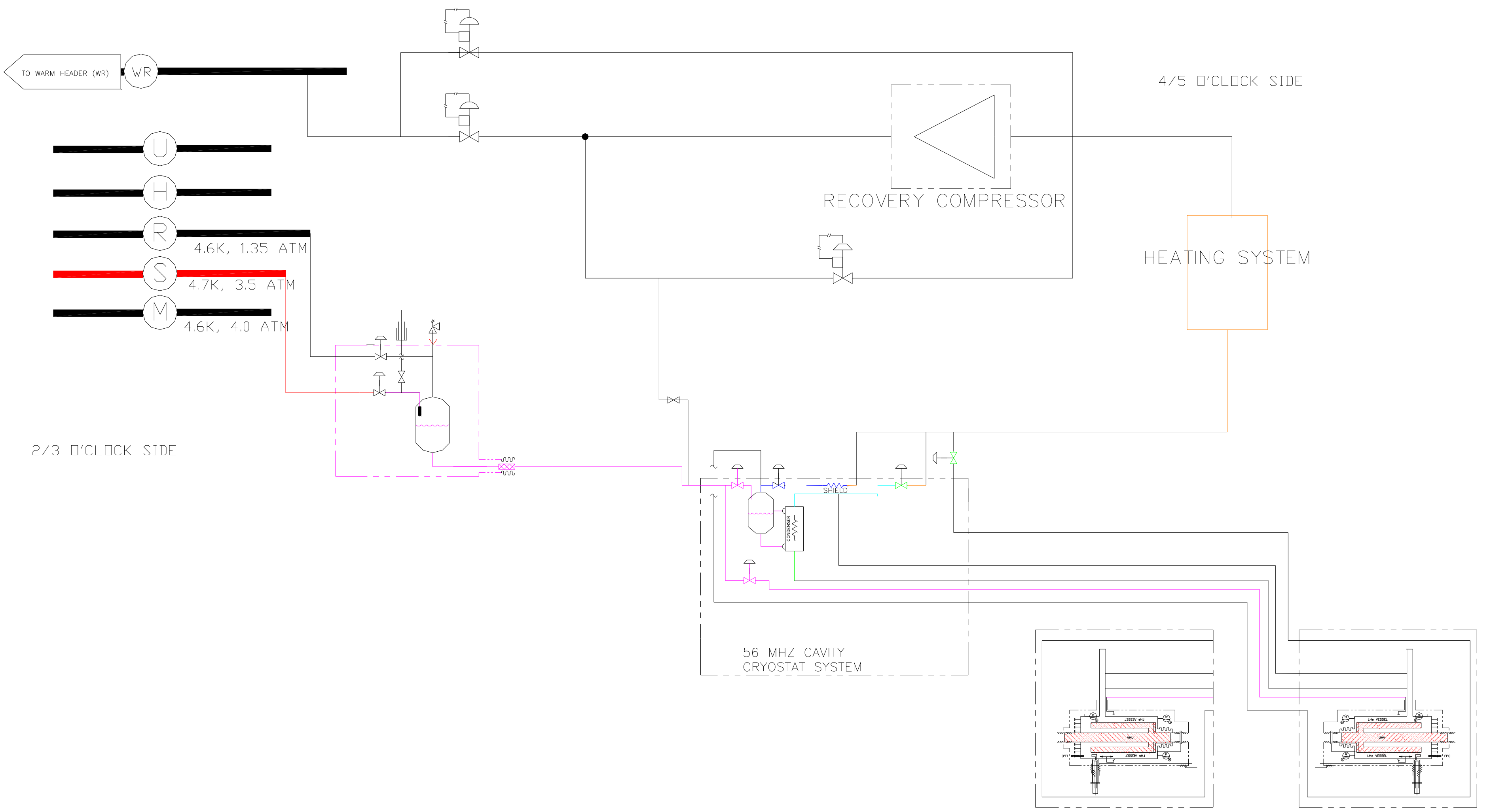
Condenser Buffer Volume



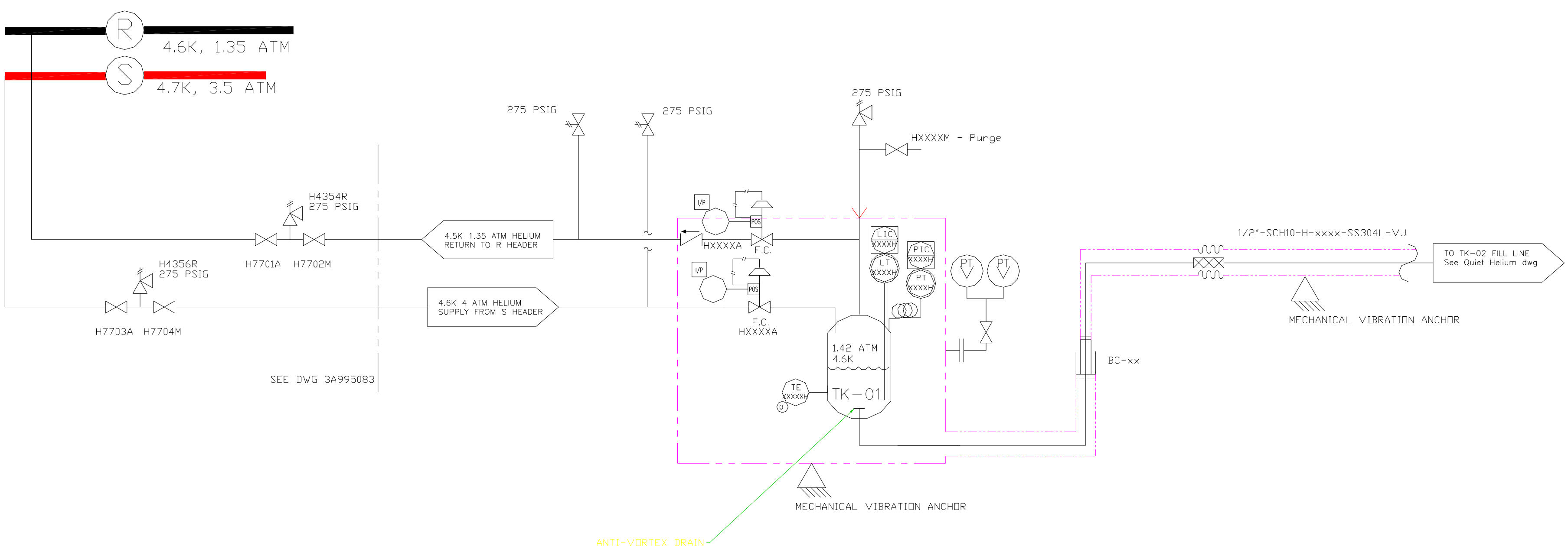
IP-4 Quiet Cryogenic Delivery Subsystem

- Transfer lines from S and R line taps plus 1st phase separator to supply condenser cryostat
- Condenser Cryostat with:
  - Boiler/Condenser Heat exchanger
  - Interfaces to 56 MHz Cavity cryostat
  - Cryogenic Valves
  - Reliefs
  - Shield supply to cavity cryostats
  - Liquid supply to cavity cryostats
  - Vapor return to Condenser cryostat
- Local Booster compressor
- Heating System for return vapor + warm piping
- Instrumentation & Controls

Process Flow Diagram



Process & Instrumentation Diagram Helium tap-ins and Phase Separator

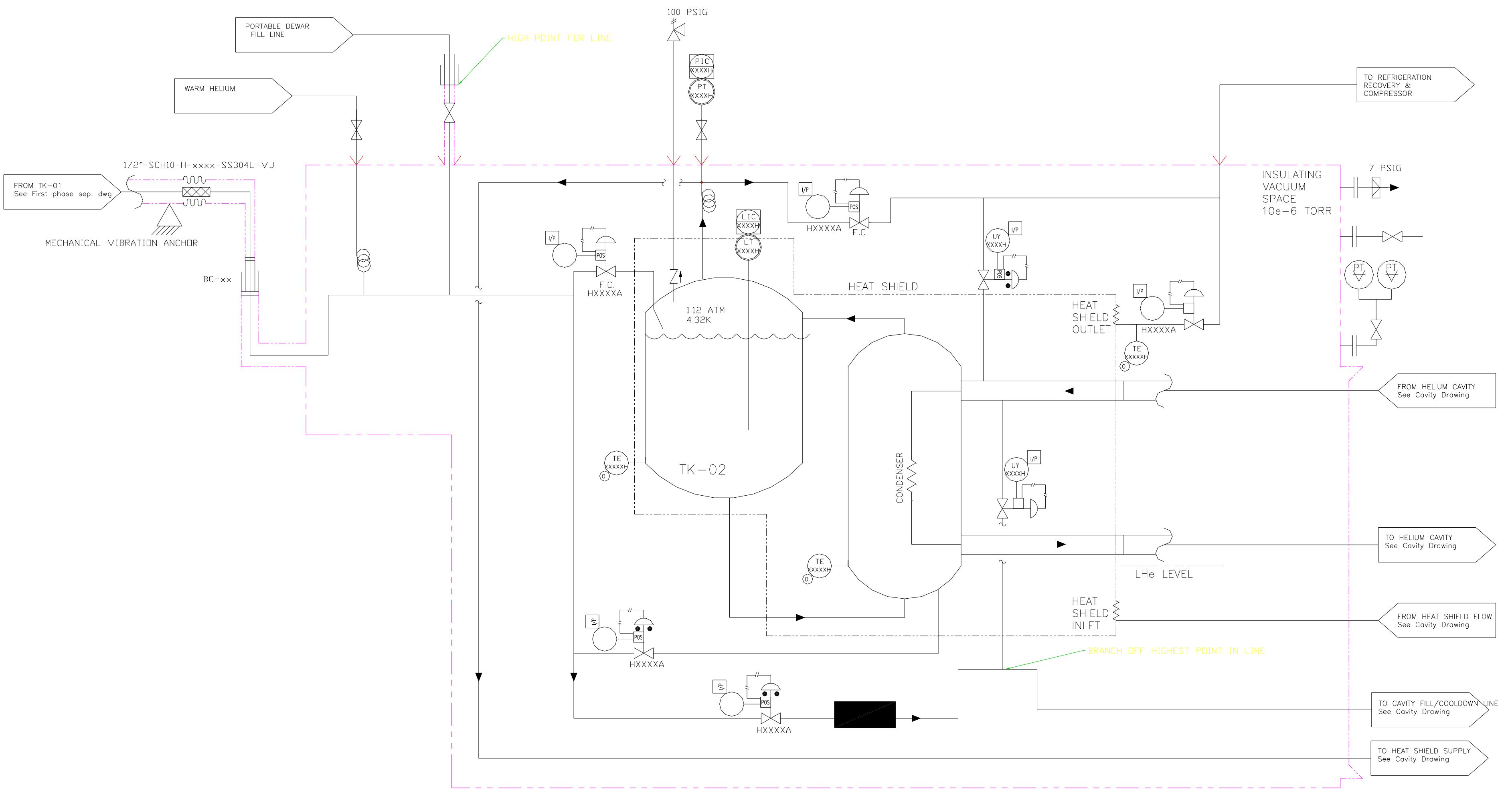


Transfer lines from S and R line taps plus 1st Separator

- Transfer lines
- Tap from S main header
  - Warmer Liquid helium than M main header
  - 3.5 atm, 5.3K
  - Pressure variation
  - 10Hz source
- Tap back into R header
  - Vapor return from 1st phase separator

- 1st Separator
  - Operates at 1.34 atm
  - Takes warmer S line helium and produce 4.55K liquid
  - Recycles vapor back to R main header
  - Vapor from warm S header liquid, + Heat leak from supply transfer line

Process & Instrumentation Diagram Boiler and Condenser Cryostat



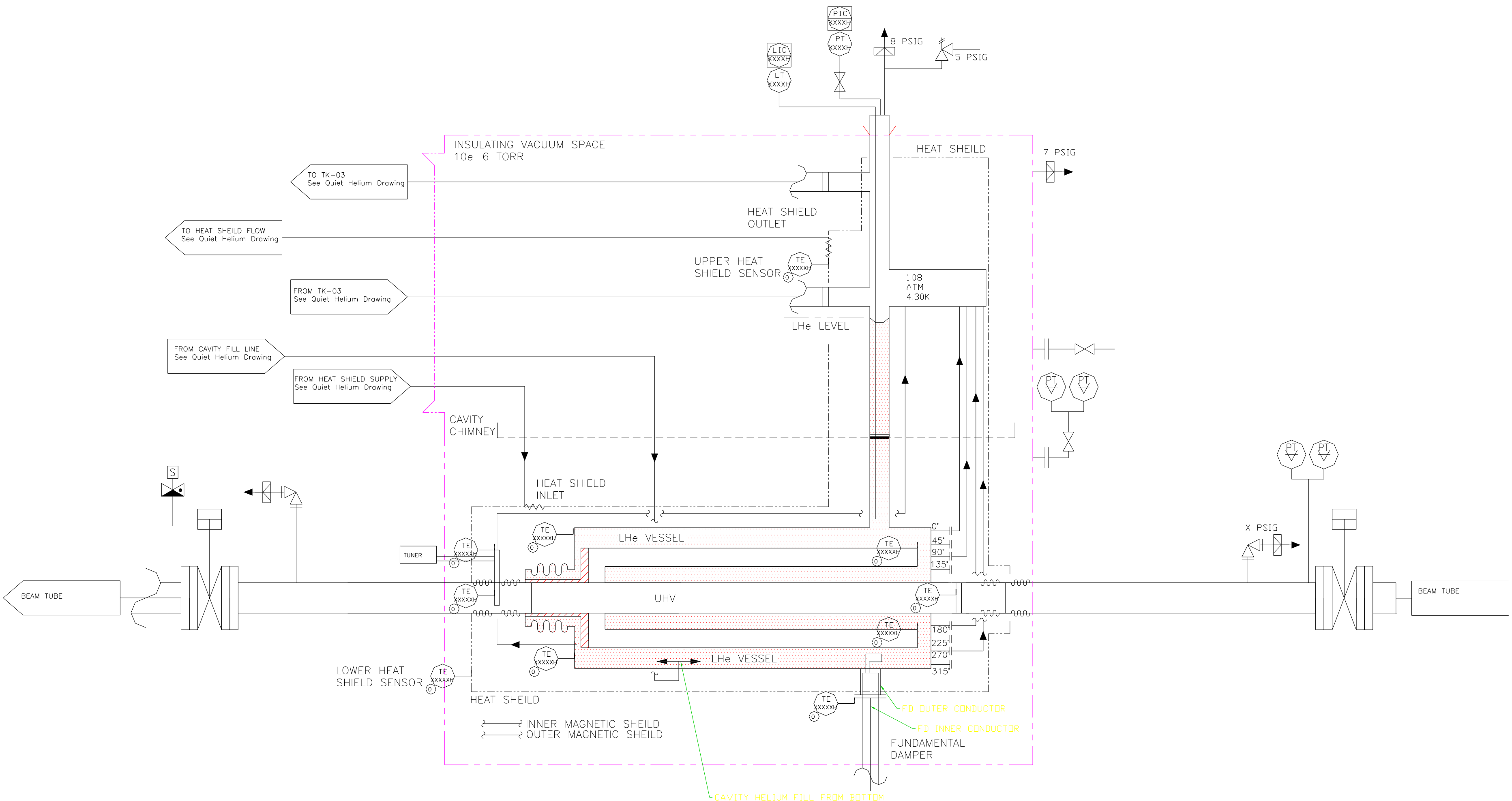
Boiler and Condenser Cryostat: Valves and lines

- Cooldown /Fill supply valve and line to cavity
- Vapor Vent valve and return line back to condenser
- Condenser liquid supply line to cavity
- Shield supply line to cavity shield from boiler
- Return shield line and control valve
- Boiler vapor vent back pressure control valve
- Equalization valve between cooldown fill and condenser vapor space
- Boiler Fill valve
- Cooldown valve condenser

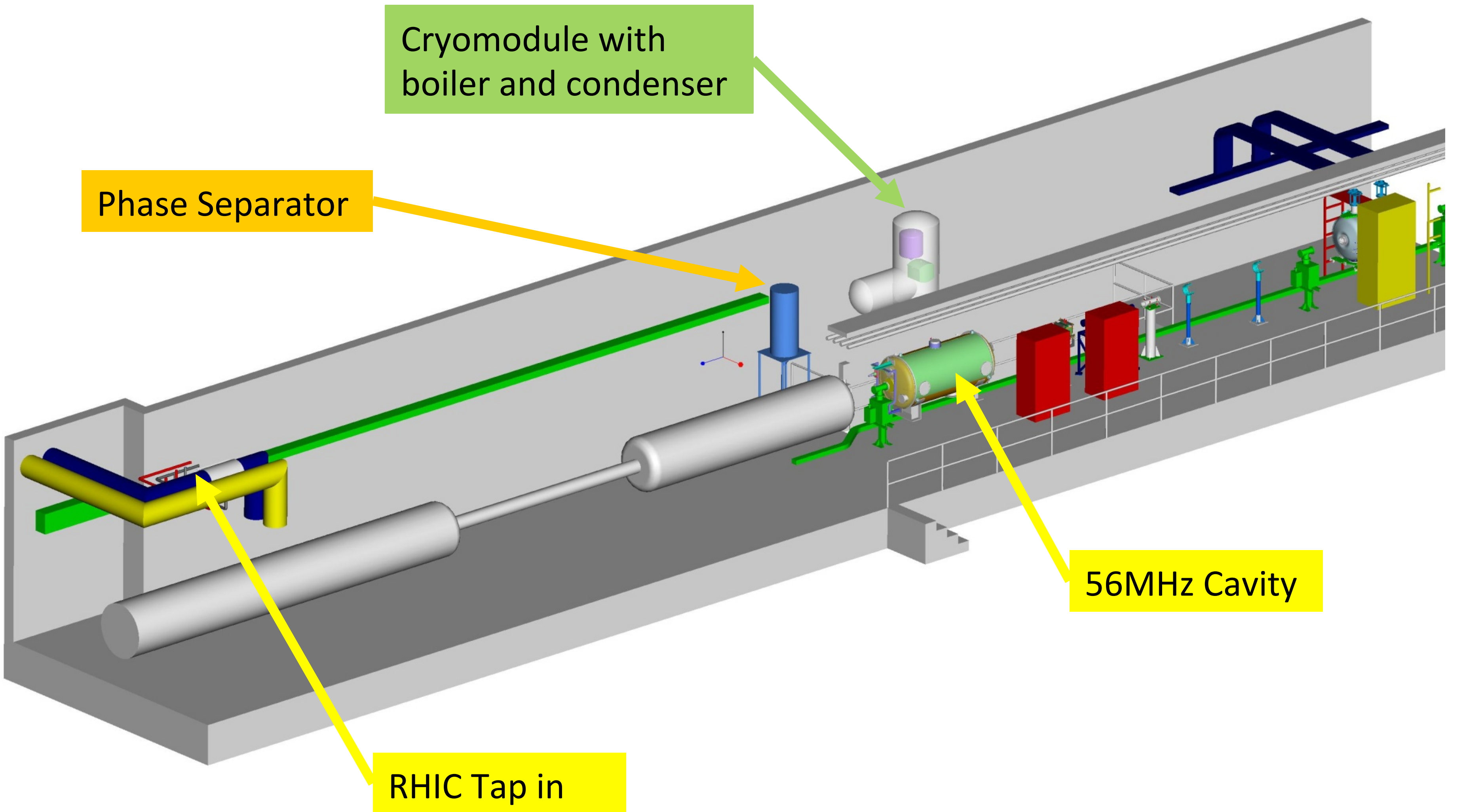
Process Control

- Boiler liquid Level control on supply valve
- Boiler Back pressure control on vapor valve
- Shield Temperature control on shield return valve
- Pressure relief control on condenser vapor vent control valve
- 1st separator
  - Level control on fill valve
  - Back pressure control on vapor return valve on bath

Process & Instrumentation Diagram
Cavity Cryostat Interface



Physical Layout at IP4



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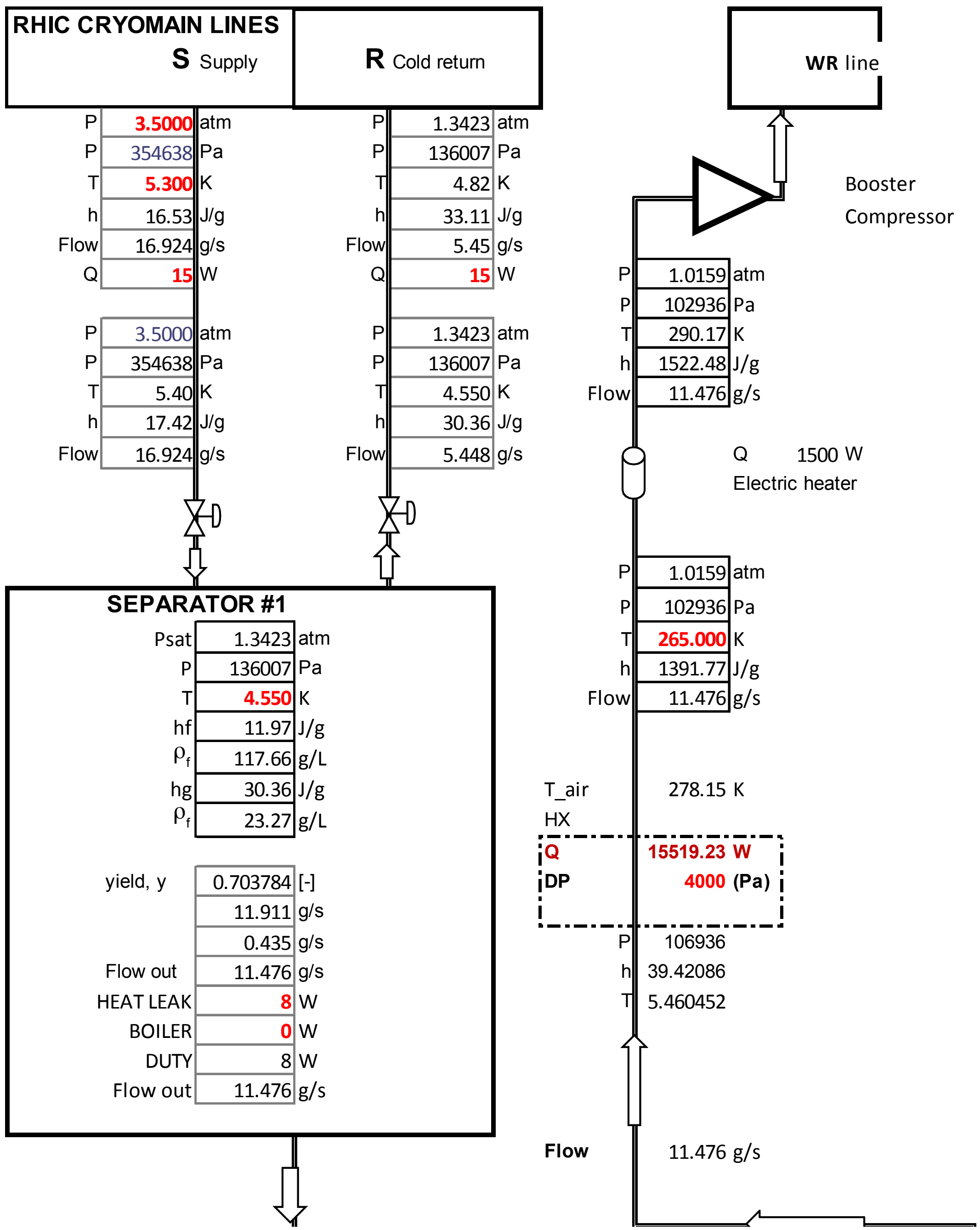

Reference Point

P	1013	[mbar]
T	0	[C]
P	101300	[Pa]
T	273.15	[K]
density	0.1784	[kg/m^3]

Suction T	20	20	20	[C]
Suction P	0.9	1	1.2	[bar]
Discharge	2	2	2	[bar]
Flow rate	240	270	340	[Nm3/hr]
m flow rat	42.83	48.18	60.67	[kg/hr]
m flow rat	11.90	13.38	16.85	[g/s]

Helium flow

Heat Shield

Helium vessel

DT_max	272.69	K
DT_min	13.150	K
LMTD	85.603	K
UA	181.29	W/K

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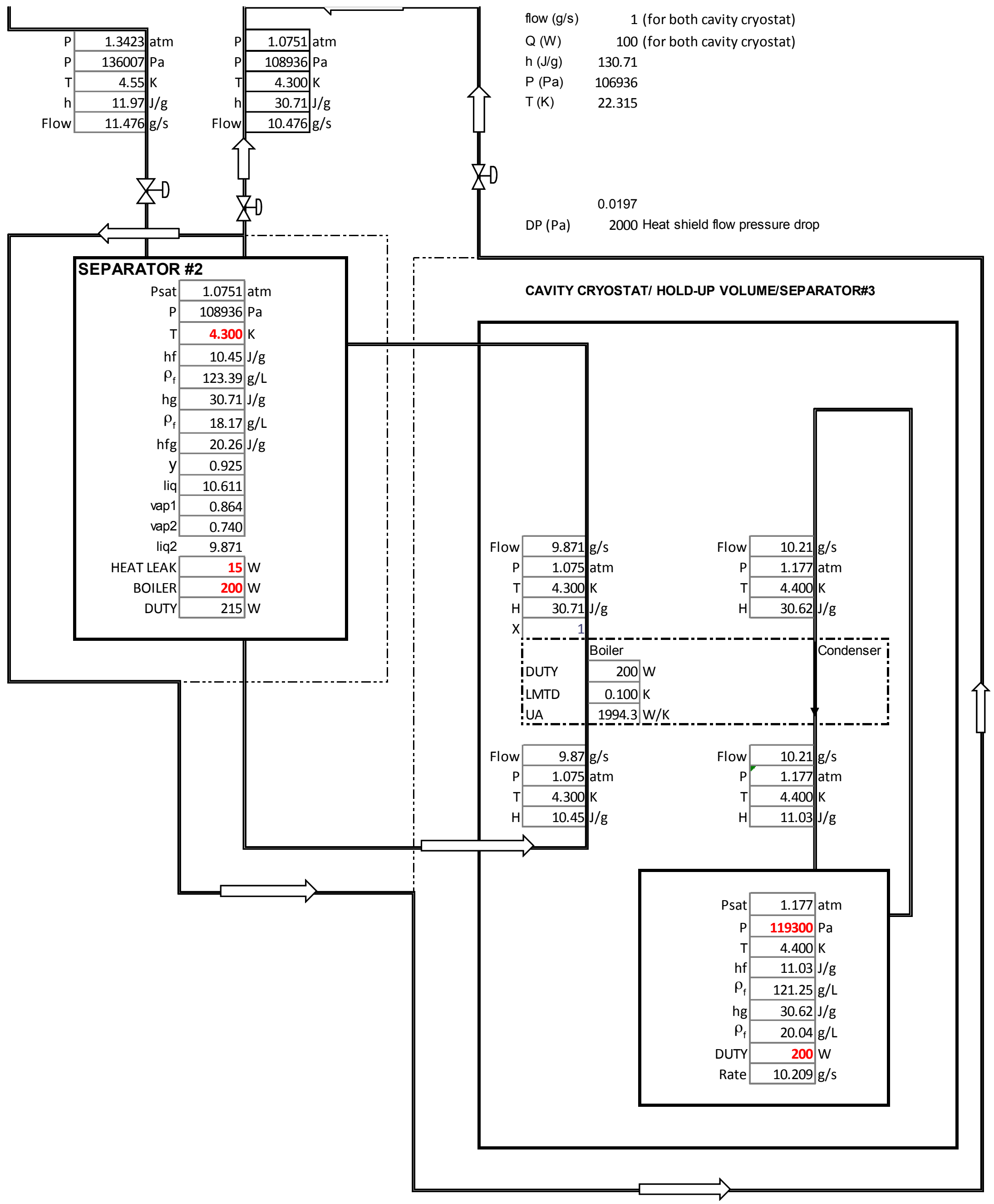

Booster Compressor

Takes low pressure helium from condenser cryostat's return vapor heating system and boost it to send into WR (Warm return) Header at IP4 and return to the main cryo plant's suction side header

- Oil free compressor
- 4 cylinder piston
- 11 - 12 g/s helium
- Leak tightness: $1E^{-3}$T-L/s
- P_suction: 0.9 bar
- P_discharge: < 2.0 bar
- Air cooling
- Power: < 20 HP
- < 15 psig: not ASME VIII
- European CE/PED Code

- Gas Management
  - Suction pressure control
  - Bypass valve High to Low
  - Return back to WR header at ~ 1.25 bar

Booster: Haug Compressor

- **Type QTOGX 180 LM-L**
- **Oil free compression of dry, filtered Helium**
- **4 cylinders, 1-stage, air-cooled, gastight with magnetic coupling**

Medium		**Helium, dry and filtered**		
Dew point		**- 80 ° C.**		
Operating conditions		**min**	**normal**	**max**
Suction temperature	°C	**20**	**20**	**20**
Suction pressure p1	bar(abs)	**0.9**	**1.0**	**1.2**
Discharge pressure p2	bar(abs)	**2.0**	**2.0**	**2.0**
Free gas delivery (referred to 1013 mbar, 0° C.)	Nm^3/h	**240**	**270**	**330**
Massflow	kg/h	**43.0**	**48.5**	**59.5**

11.9 g/s

Vapor Heating System + warm piping

- Ambient Air Exchanger
- Dual exchangers for defrost cycling, continuous duty
- ~ 15.5 kW @ 11.5 g/s

- Non Jacketed Piping:
  - Helium Boiler Cryostat to ambient heat exchanger to compressor suction, ~ 120 ft
  - Compressor discharge to WR header, ~ 120 ft

Condenser side Relief System

- 5 psig Relief Valves
  - Reliefs to boiler side
  - Handles cooldown, fill, warmup excursions
  - Reliefs to atm side
  - With Heater
- Vapor return valve
  - Set @ lower pressure to relief pressure to boiler return side
- Burst disk 7-8 psig
  - catastrophic failure
  - Discharge to IP volume
  - Vacuum switch to isolate supply valve
  - Sized for 50 kW (UHV side loss to air)
- Relief Header (not required) catastrophic failure release scenario
- Finite inventory

Cryogenic Instrumentation

- 56 Mhz Cavity Cryostat Instrumentation
  - Temperature: Diodes
    - on upper/lower longitudinal ribs: Cooldown monitors
    - HOM FLANGES
    - Fundamental damper
    - SHIELD
  - Redundant SC Level Probe
  - Pressure transmitters
  - Vacuum: insulating vacuum

- Condenser Cryostat Instrumentation
  - Temperature: Diodes
    - Condenser: Cooldown monitor
    - SHIELD
  - Redundant SC Level Probe
  - Pressure transmitters
  - Vacuum: insulating vacuum

*Supplied by vacuum group

RHIC 56 MHz Cryomodule

External Review 03/08/11

- <u>Major Cryogenic Components Milestones</u>

(Not part of this technical review - FYI only)

Vacuum Jacketed Supply/Return & 1st Separator Installed	11/23/11
He Compressor Ordered , Warm Piping Installed	10/31/12
Ambient Vaporizer Installed	10/31/12
Cryogenic Controls & Instrumentation installed	10/12/12
Cryostat / Condenser Installed	08/31/13