# BEAM TUBE BAKEOUT READINESS REVIEW

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# LIGO REQUIREMENTS

- LIGO Science Requirements Document
  - **sets the goal for residual gas pressure "....at a level or below an equivalent strain noise of $2\times10^{-25}$ $Hz^{-1/2}$"**

# DESIGN REQUIREMENTS

- COMPONENTS TO BE BAKED
  - **All vacuum surfaces of the bake volume (i.e., tube wall material, expansion joints, pump ports, pump port hardware, 114/122cm gate valves, etc.)**
- PARTIAL GAS PRESSURES DURING THE BAKEOUT
  - **Control by suitable choice of pumping speeds and control of temperature rate-of-rise**
  - **Maintain the RGA in its linear range**
  - **Water vapor pressure shall be $P(H_2O) < 2\times10^{-8}$ torr @ 150˚C at the end of the bake**
  - **Sum of partial pressures for AMUs 41, 43, 55 and 57 shall be $P(41,43,55,57) < 2\times10^{-9}$ torr @ 150˚C at the end of the bake**

# DESIGN REQUIREMENTS (CON'T)

- BAKE TEMPERATURE
  - **Minimum temperature at any surface shall be > 130˚C**
  - **Maximum temperature of the beam tube wall shall be < 170˚C**
  - **Maximum temperature of the beam tube bellows shall be < 400˚C**
  - **Maximum temperature at any point on the 114/122 cm gate or gate valve shall not exceed 170˚C**
- MAXIMUM DIFFERENCE IN TUBE WALL TEMPERATURES - mechanical overstress
  - **axial - the average temp of the beam tube wall of a section between fixed supports shall not differ from the average temp of any other section by more than 40˚C**
  - **transverse horizontal - the average temp of any right half of a section between guided supports shall not differ from the average temp of the left half by more than 5˚C**
  - **transverse vertical - the average temp of any top half of a section between guided supports shall not differ from the average temp of the bottom half by more than 30˚C**

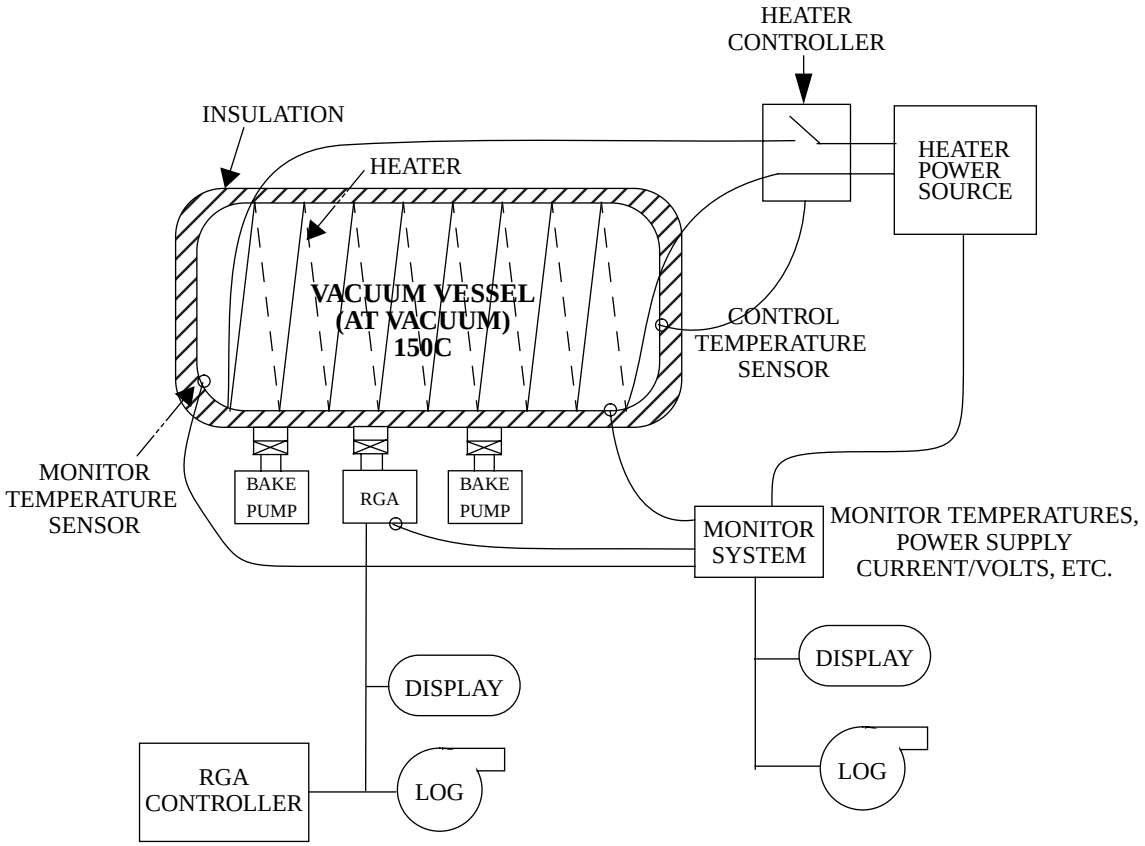
# DESIGN REQUIREMENTS (CON'T)

- BAKE DURATION
  - **The coldest spot of the module under bake shall be maintained T > 130˚C for the earlier of either:**
    - an elapsed time of 30 days, or
    - a water outgassing rate $J(H_2O) < 1 \times 10^{-11}$ torr l/s $cm^2$ at 150˚C
  - **If the temp of any tube wall monitoring sensor falls below the minimum bake temperature, the bake time shall be extended as needed to ensure minimum time requirement is met**

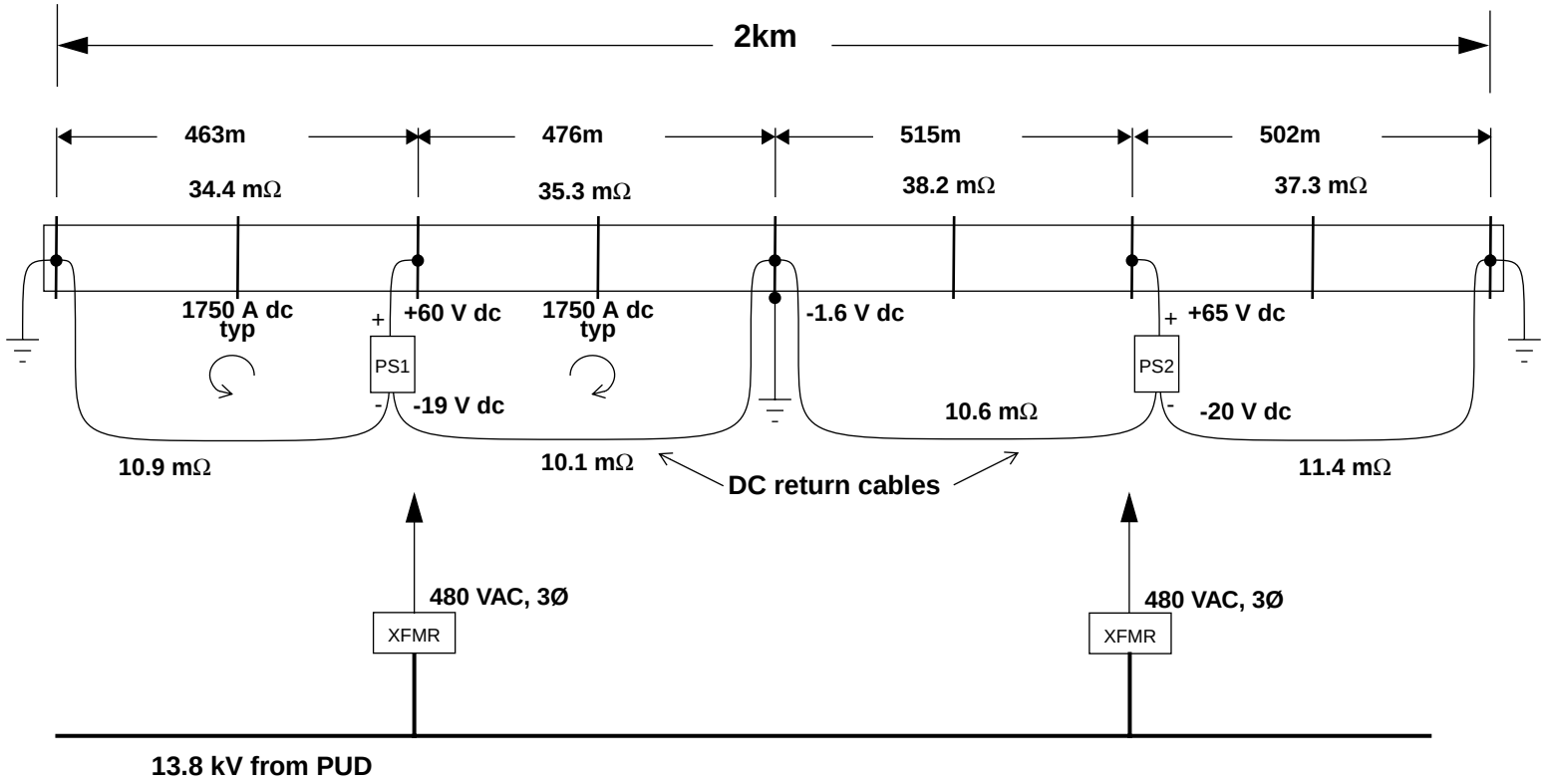
# DESIGN REQUIREMENTS (CON'T)

- DATA ACQUISTION, DISPLAY, MONITORING & RECORDING
  - **Wall temperatures at representative positions (including anticipated hot or cold spots)**
  - **Temperature interfaces at the end gate valves, supports and pump port hardware**
  - **Temperatures at the 114/122 cm gate valves and terminations**
  - **At least one RGA to measure partial pressures through AMU 100 (bakeout and post-bake)**
  - **DC power supply currents and voltages**
  - **Operating status of equipment (i.e., vacuum pumps)[state vector]**
  - **Other engineering data (e.g., ambient environment conditions)**

# EQUIPMENT CONFIGURATION DURING BAKEOUT



# BEAM TUBE BAKEOUT ELECTRICAL HEATING POWER

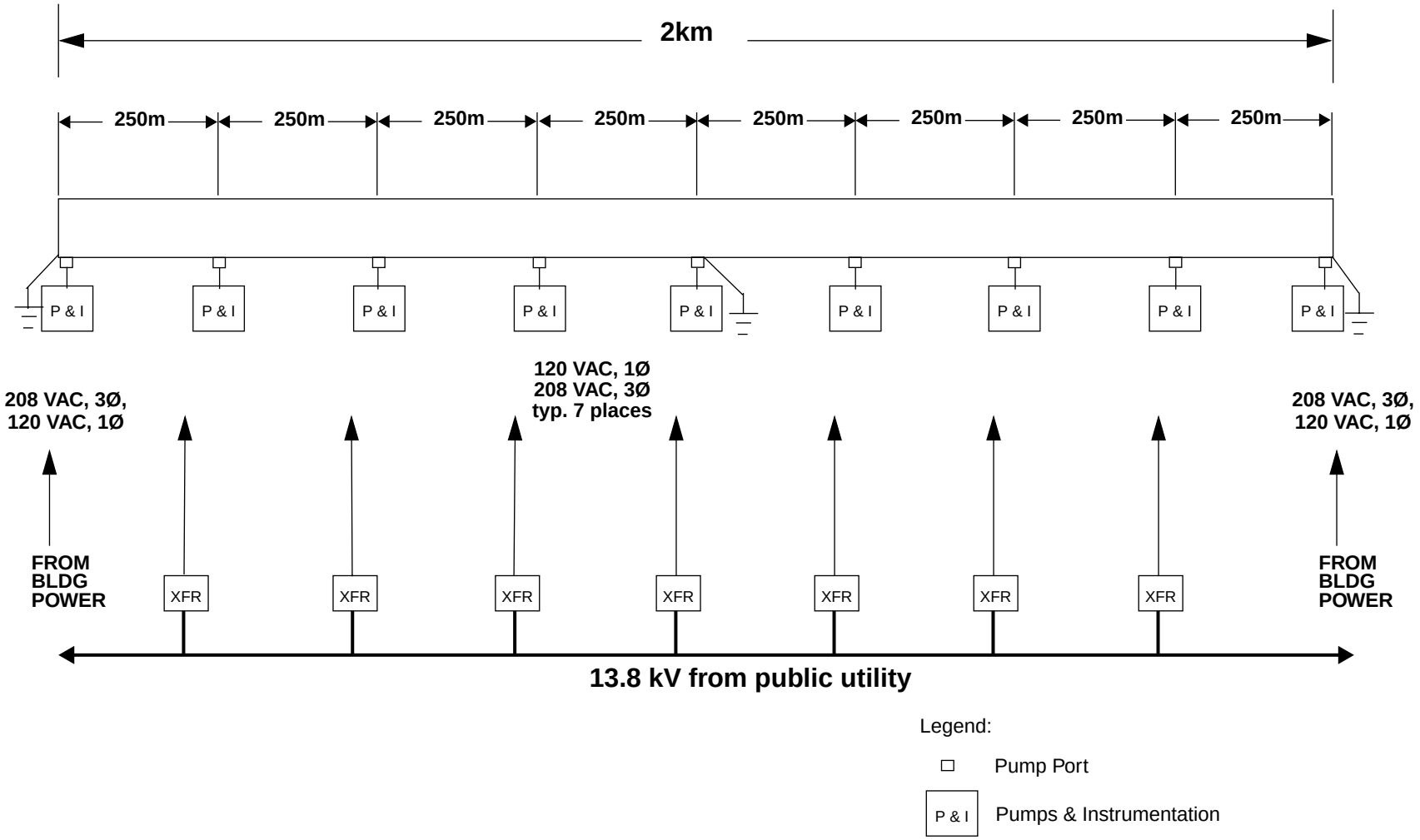



**Legend:**

PS — **Low voltage, high current DC power supply**

XFMR — **Power Transformer**

# ELECTRICAL POWER FOR HEATER JACKETS, PUMPS AND INSTRUMENTATION

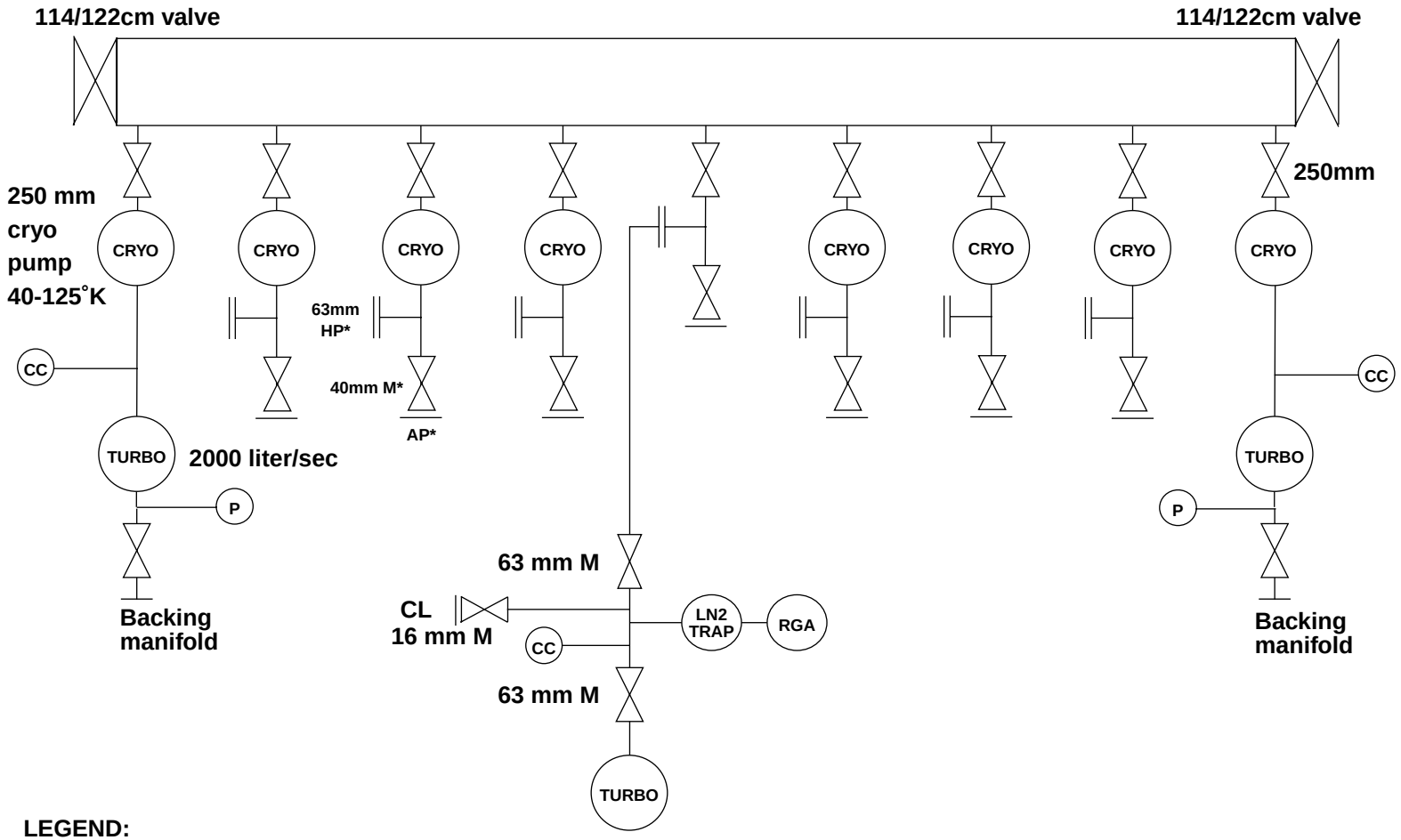



Legend:

□ Pump Port

P & I Pumps & Instrumentation

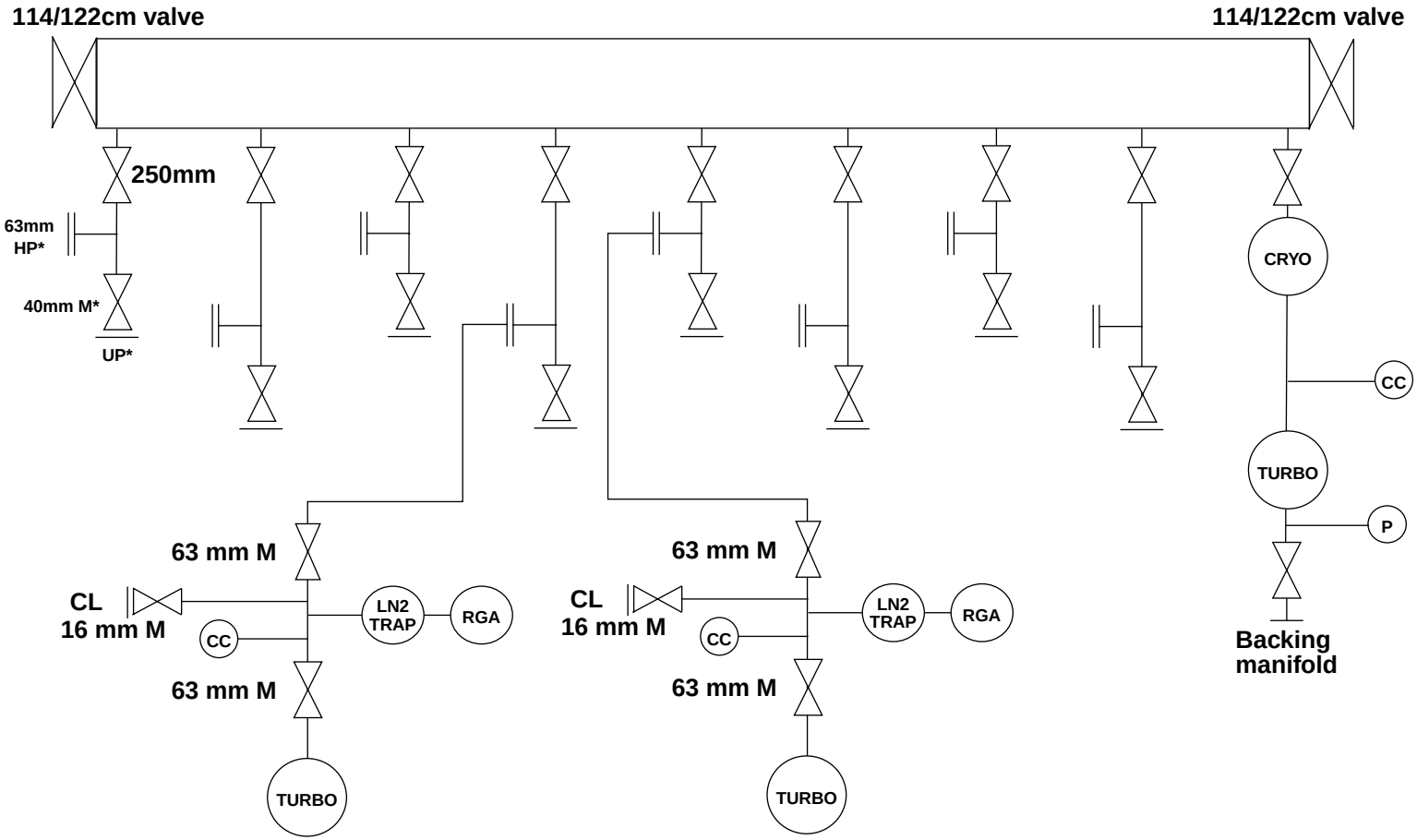
# SCHEMATIC OF PUMPS AND RGA DURING BAKEOUT




**LEGEND:**

**AP** Port for auxiliary turbo pump
**CC** Cold Cathode gauge
**CL** Port for calibration leaks
**HP** Port for RGA head installation
**M** Metal sealed valve
**P** Pirani gauge
***** Type H Pump Port Hardware furnished by CBI

# POST-BAKE TEST CONFIGURATION

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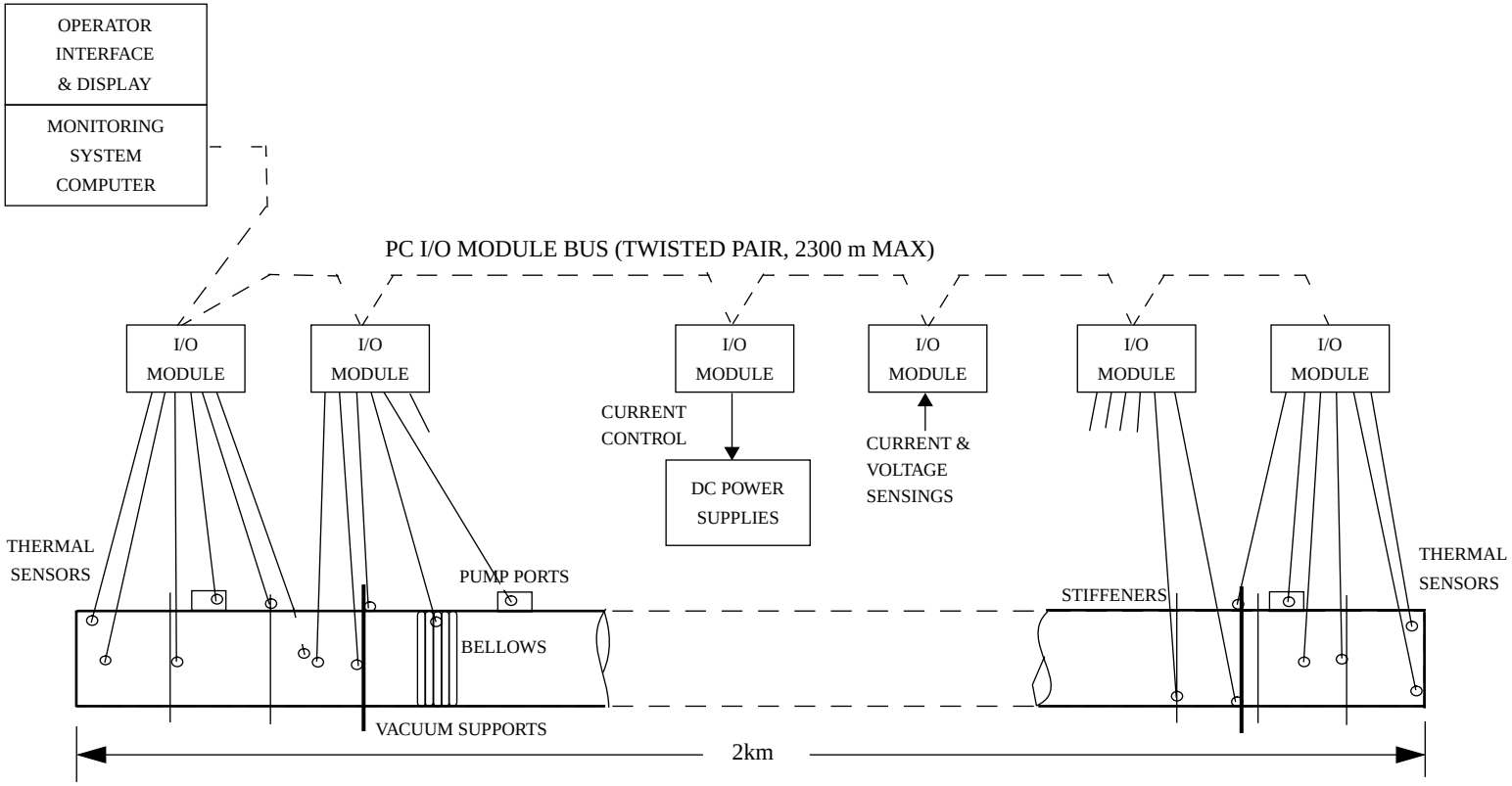
# CALIBRATION ASSEMBLY

# MONITORING SYSTEM



# MONITORING SYSTEM CHANNELS

- Temperature channels (353 total):
  - **28 channels “prime” tube wall temperatures - 7 locations, 4 clock angles**
  - **119 channels at each end (1st 60 m) of beam tube -- gate valve, pump port, anchor, fixed supports, bellows, guided supports, tube wall**
  - **10 channels at each pump port -- 4 around tube wall (3, 6, 9, 12 o’clock) and 6 at port hardware**
  - **26 temperature channels monitoring ambient air (inside BTE) and equipment**
- Power supply electrical (16 channels DC + 18 channels AC)
- Vacuum gauges (4 channels)
- Equipment status [state vector]
- Weather station (wind, RH, etc.)

- OUTPUTS (2 channels): PS1 and PS2 current settings

# PRELIMINARY DESIGN REVIEW RECOMMENDATIONS

| Recommendation/Comment | Response |
|---|---|
| 1. Bigger turbopumps at RGAs | 180 l/s turbos incorporated |
| 2. Magnetic shielding for RGAs | Need TBD |
| 3. Replace cal cart air inlet valve w/ capillary leak | Done. |
| 4. FEA for support thermal design | Not done. |
| 5. Freeze protection for PS cooling units | 50% ethylene glycol |
| 6. Valve between RGA head and LN2 trap | Not done |
| 7. Cabling and I/O module mounting carefully defined | Done |
| 8. Consider RGAs other than Balzers | Considered |
| 9. Check electrical isolation of supports | Done |
| 10. Put as-built bellows spring rates into model | Not done |
| 11. Control 44” gate valve temp rate of change | Incorporated into bakeout procedure |
| 12. Test corrosion due to insulation in LA | Mockup wrapped in insulation at LA site |

# BAKEOUT STATES

1. Pre-bake - DC power not connected to tube
2. Pre-bake - DC power connected to tube
3. Bake
   - **3a. Equipment end-to-end checkout**
   - **3b. Ramp up temperature**
   - **3c. Hold temperature**
   - **3d. Ramp down temperature**
4. Post-bake - DC power disconnected
   - **4a. Temperature stabilization - cryopumped**
   - **4b. Pumped at one end only, bake and post-bake RGAs installed**
   - **4c. Pumped at one end only, post-bake RGAs installed**
5. Post-bake - connected to and pumped by Vacuum Equipment

# EQUIPMENT CHECKOUT PROCEDURE

- One-time procedures
  - DC cable length matching
  - Power supply coolant leak test
  - Power supply functional check
  - Power supply return current shunt calibration
- Routine pre-bake end-to-end system checkout
  - Equipment configuration checklist
  - Data channel checklist
  - Manual valve status
  - Main turbopump run status
  - Cryopump turn-on and cold-head temperature check
  - RGA, Calibration Assembly operational status
  - DC supply functional check and transfer function calibration
  - Heater jacket controller temperature and ramp-rate limits; heater jacket responses
  - System safety, security check

# BAKEOUT PROCEDURE

- Requires that Equipment Checkout Procedure be completed
  - ›› Initiates data acquisition
  - ›› Initializes turbopump and cryopump operation
  - ›› Sets cryopump heating at ports Y22, Y23, Y24, Y26, Y27, Y28 to 150 °C
- Establish thermal equilibrium over the tube and ends
- Ramp temperature up to 150 °C at 2 °C per hr (e.g., 60 hr from 30 °C)
  - ›› Requires changing setpoint on each of 44 heater jacket controllers - initially 6 C steps each 3 hrs
- Hold temp at 150 °C for 30 days or < $2 \times 10^{-8}$ torr
- Ramp temperature down at 2 °C per hr
  - ›› At T=30 C shutdown DC power ($\tau$ = 9 hr)
- Move to post-bake state - procedure TBD

# BEAM TUBE ENCLOSURE ENTRY PROCEDURE

- Special bakeout-specific lock tumblers installed at doors
- Part A - for use near grounded ends of beam tube
  - ›› Operator issues BLUE key and logs entry and exit
  - ›› User returns key to operator after work is completed
- Part B - for use at all other doors
  - ›› Operator sets DC power supply voltage to zero
  - ›› Operator issues GREEN key and logs entry
  - ›› User locks out power supply nearest work point
  - ›› After work is performed, user unlocks and turns on power supply, then returns key to Operator
  - ›› Operator restores power supply operation and logs exit and key return
  - ›› 2-way radio contact maintained throughout operation
  - ›› 2 people required for work away from lighted door areas

# POWER SUPPLY EMERGENCY SHUTDOWN

- Bakeout Operator sets power supply control to zero
- If that is imprudent or doesn't work, push EMERGENCY STOP buttons on each DC power supply (mounted outside for ready access)

# OTHER BAKEOUT SAFETY MEASURES

- Lighting in work areas
- Flashing beacons at access doors during operation
- Flashing beacons at emergency exits inside beam tube enclosure
- Signs on all access doors and electrified equipment
  - NO ENTRY - EMERGENCY EXIT ONLY on all single doors except at ends
  - DANGER - HOT on all double doors and at ends
  - DANGER - ELECTRICAL HAZARD - AUTHORIZED PERSONNEL ONLY on double doors at ports 2, 3, 4, 6, 7, and 8
  - DANGER - HIGH VOLTAGE on cryopump stands at ports 2, 3, 4, 6, 7, and 8
- CO2 fire extinguishers at each pump port (including ends)
- Ethylene glycol (PS coolant) storage, handling and spill cleanup equipment

# BAKEOUT PLAN

- Conduct first 2 km module bakeout to:
  - **Validate insulation, heating and pumping designs**
  - **Evaluate beam tube mechanical behavior during bake**
  - **Shakedown the setup, bakeout and post-bake procedures (and maybe the post-bake leak localization and repair procedures)**
- Iterate procedures and designs as needed
- Bake 3 remaining modules at Hanford, ship equipment to Louisiana, and bake 4 modules
- On-site staffing:
  - **Site scientist/engineer to supervise setup, bakeout, data evaluation**
  - **2 site technicians for equipment installation, checkout and removal**
  - **4 temporary technicians for 1-person-24 hr. bake monitoring**