BEAM TUBE BAKEOUT
PRELIMINARY DESIGN REVIEW

AUGUST 18, 1997
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TOPICS FOR BAKEOUT PDR

- Design requirements for the bakeout equipment
  - **thermal insulation, heating power and controls, vacuum pumping, instrumentation, data acquisition and logging**
- Interfaces
- Preliminary Design
- Implementation Planning

DESIGN REQUIREMENTS REVIEW RECOMMENDATIONS

Recommendation/Comment	Response
1. Insulation life safety	Language incorporated (E960123-03-E, ¶ 3.2.1.2)
2. Hydrocarbon partial pressures	Language incorporated (E960123-03-E, ¶ 3.1.1.2)
3. Vertical transverse temperature gradient	Language incorporated (E960123-03-E, ¶ 3.1.1.3)
4. Power supplies from national laboratory	In process
5. Add 208VAC 3Φ	Language incorporated (E960123-03-E, ¶ 3.1.3.1.2)
6. High temperature insulation at bellows	Incorporated into prelim. design and insulation spec.
7. Ground midpoint	Language incorporated (E960123-03-E, ¶ 3.1.3.1.2)
8. Consider inductance effects on power supplies	Considered
Q4. Use VE main and auxiliary turbos	Now in plan
Q6. GNB specs on gate valves	Pending; adopted PSI's design
Q9. Electrical isolation of supports	Incorporated into bakeout plan
Q11. Equipment grounding and personnel safety	Still being worked
Q12. Pump backstreaming at PDR	Adopted Vacuum Equipment strategy
Q13. Metal gate valve at RGA	Not incorporated
Q14. Monitoring equipment same as CDS	No
Q15. Procurement schedule at PDR	In today's presentation
Q17. Control logic table at PDR	Example control logic provided in E970148-00

LIGO REQUIREMENTS

- LIGO Science Requirements Document
  - **sets the goal for residual gas pressure "....at a level or below an equivalent strain noise of 2×10^{-25} Hz$^{-1/2}$"**

ASSUMPTIONS AND DEPENDENCIES

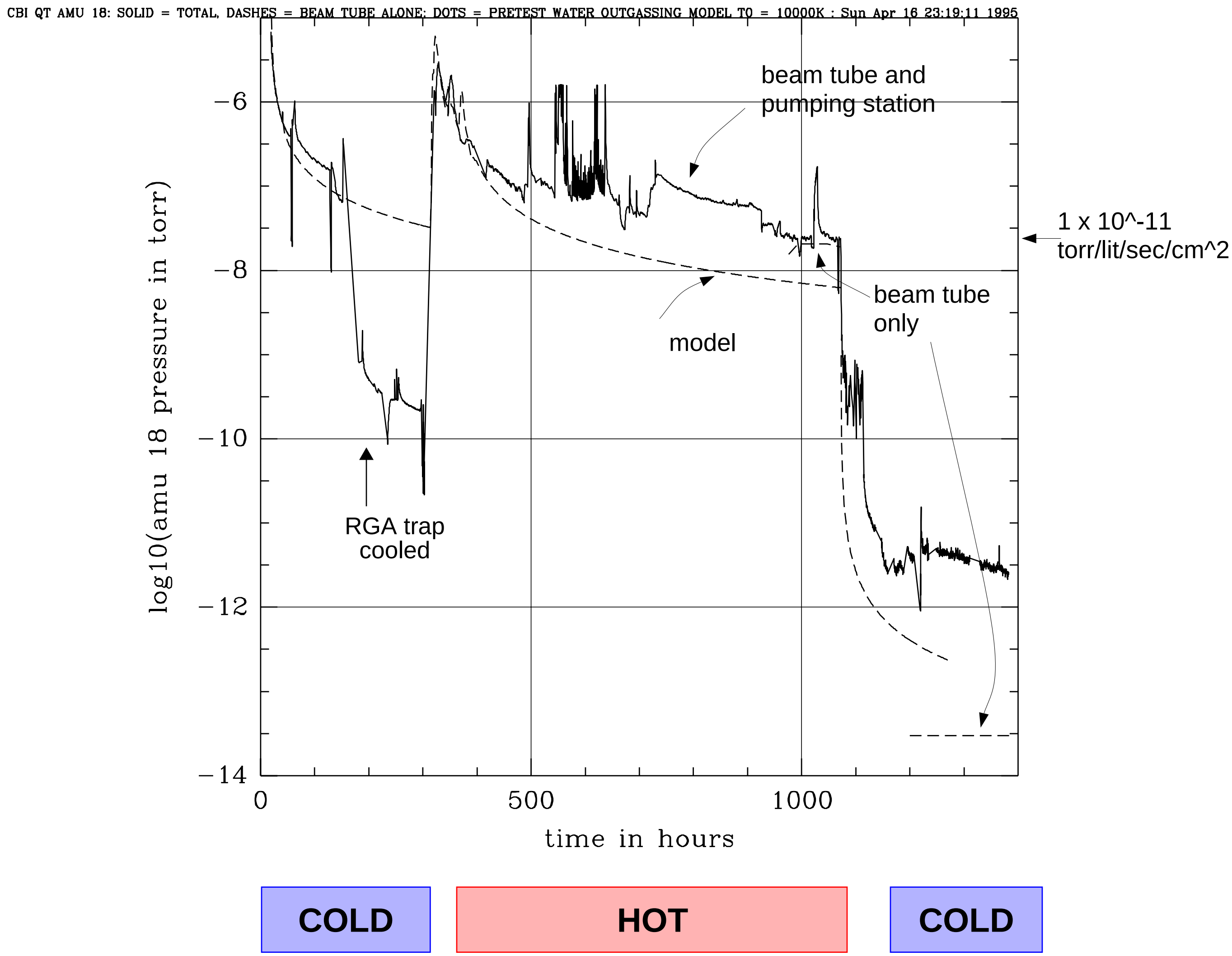
- The beam tube will be baked out in increments of 2 km modules
- Adequate AC power (13.8 kV, 1300 kVA) is available along the beam tubes
- Safe access to beam tube enclosures during installation and bake (if needed) will be allowed
- The beam tube will have been accepted from the beam tube fabrication and installation contractor and will meet its performance requirements (E950020)
- ~~The beam tube is left under rough vacuum up to the time of the bakeout~~*
- Leaks larger than the LIGO specification which are present after the bakeout will be identified and localized, but repair/recovery procedures are not within the scope of requirements document
- Insulation and thermal sensors ~~will~~ may be left in place after each beam tube module is baked†

*changed from the distributed update to the Design Requirements Document, E960123-03-E (8/8/97)
†changes since the Design Requirements Review (DRR): ~~deleted~~ added

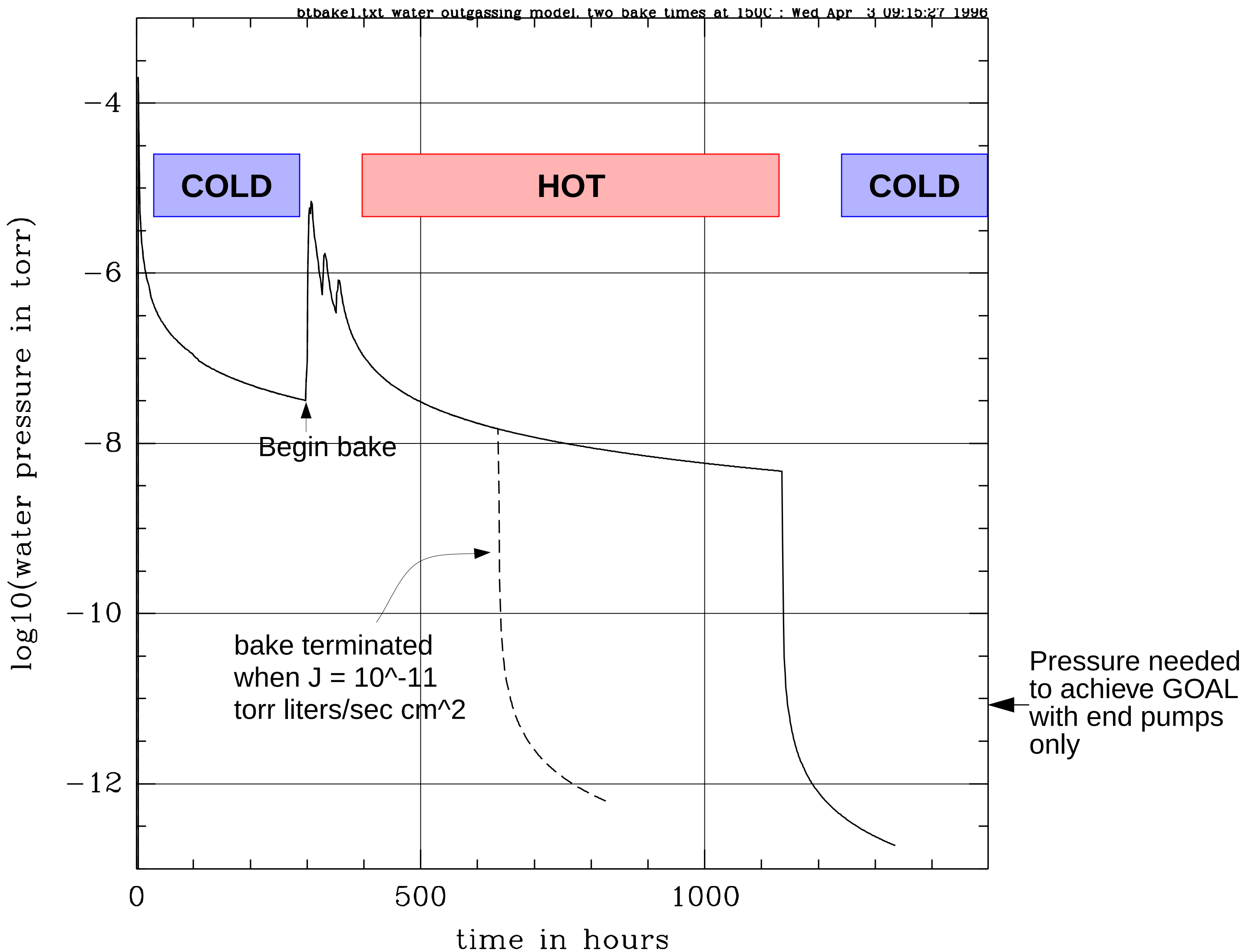
DESIGN REQUIREMENTS

- 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 $P(H_2O) < 2 \times 10^{-8}$ torr @ 150˚C at the end of the bake**
  - **Sum of partial pressures for AMUs 41, 43, 55 and 57 shall be $P(41,43,55,57) < 2 \times 10^{-9}$ torr @ 150˚C at the end of the bake**

H_2O PRESSURE - QT BAKEOUT



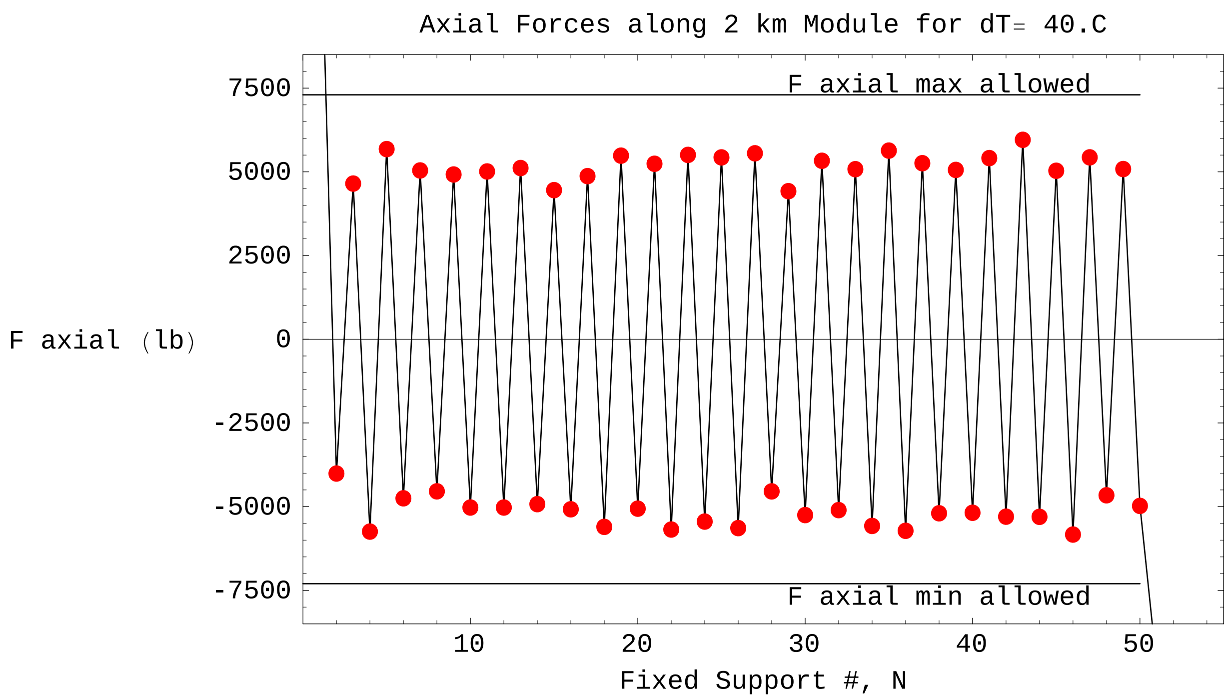
H_2O PRESSURE REDUCTION MODEL

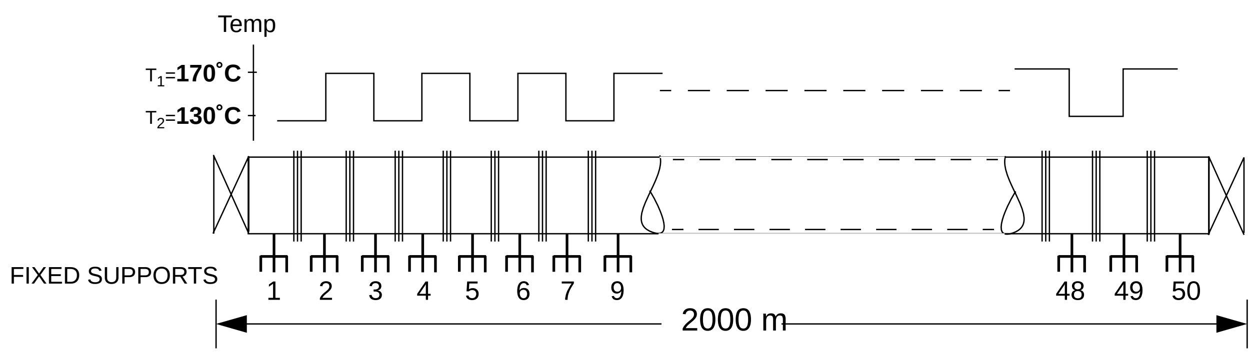


DESIGN REQUIREMENTS (CON'T)

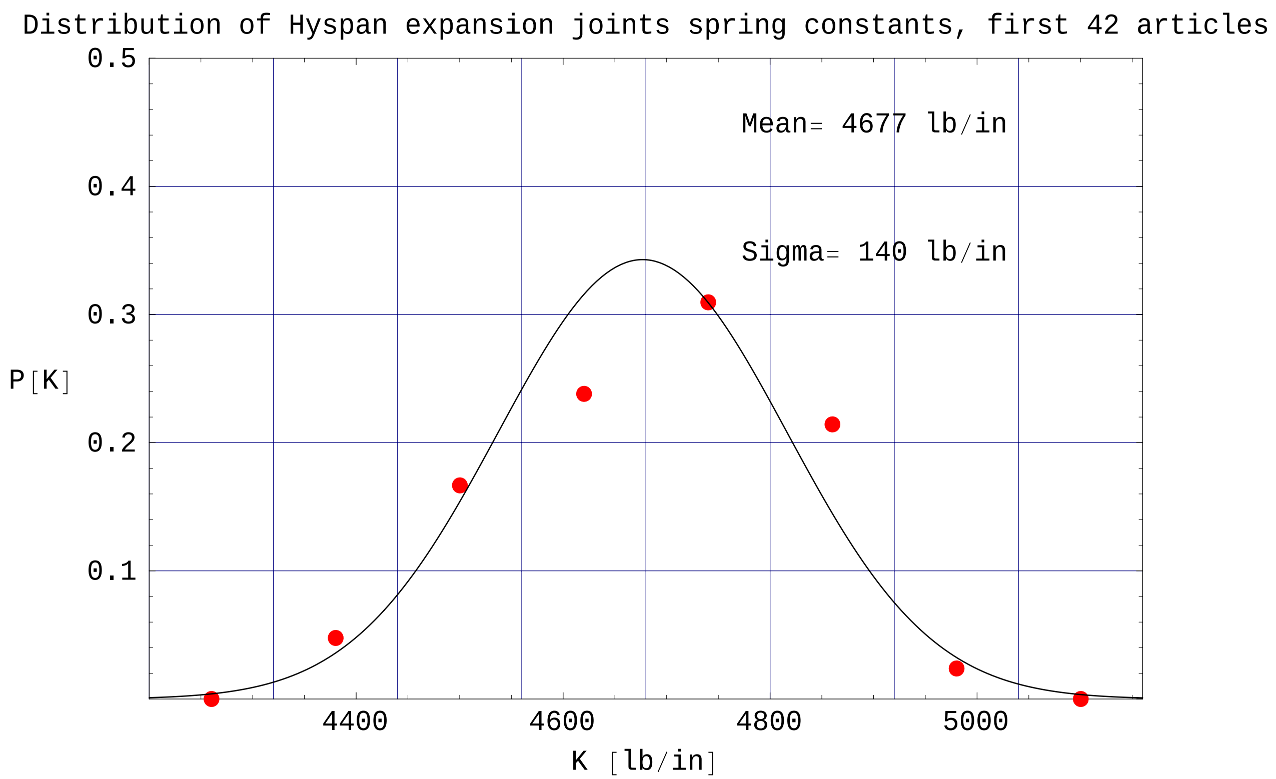
- BAKE TEMPERATURE
  - Minimum temperature at any surface shall be > 130°C
  - Maximum temperature of the beam tube wall shall be < ~~TBD~~ 170°C
  - Maximum temperature of the beam tube bellows shall be < ~~TBD~~ 400°C
  - Maximum temperature at any point on the 114/122 cm gate or gate valve shall not 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 ~~25~~ 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 ~~6~~ 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

Axial force at fix supports with tube sections between adjacent pairs of supports alternating temperatures (for dT= 40°C)

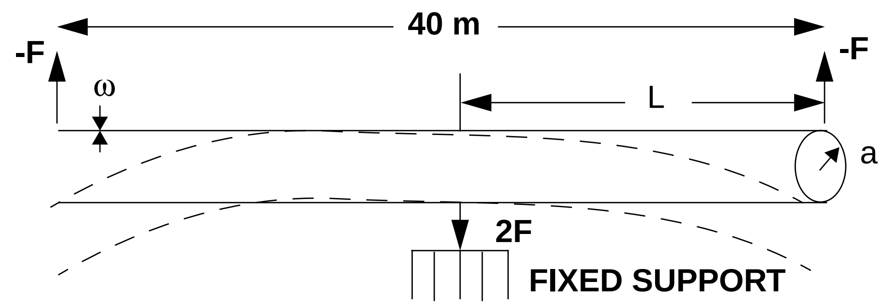




DISTRIBUTION OF HYSPAN EXPANSION JOINTS SPRING CONSTANTS, FIRST 42 ARTICLES



TRANSVERSE FORCES AT FIXED AND GUIDED SUPPORTS



PLAN VIEW (SCHEMATIC)

Single supported tube end

$$F(\Delta T)) = \frac{3\pi Y a^3 \omega\alpha}{2L} \cdot \frac{\Delta T}{\Delta z}$$

Y = Young's modulus of steel
a = tube radius
α = thermal expansion coefficient
ω = thickness of tube wall
L = tube length
ΔT/Δz = thermal gradient across tube
F = force (cantilevered end)

Force at guided support:
F (ΔT) = 52 kg/°C (114 lb/°C) × ΔT

Force at fixed support:
2F = 104 kg/°C (228 lb/°C) × ΔT

BEAM TUBE SUPPORT TRANSVERSE FORCES AND TEMPERATURE DIFFERENCES

	Allowable Load[1] (kg)	**ΔT °C**
Horizontal loads:		
Fixed support	584[2]	**5.6**
Guided support (total capacity, = 2F)	698[2]	6.7
Vertical loads[3]:		
Fixed support	4535[4]	43
Guided support (total capacity, = 2F)	3230[5]	**31**

[1]From Beam Tube - Civil Construction ICD

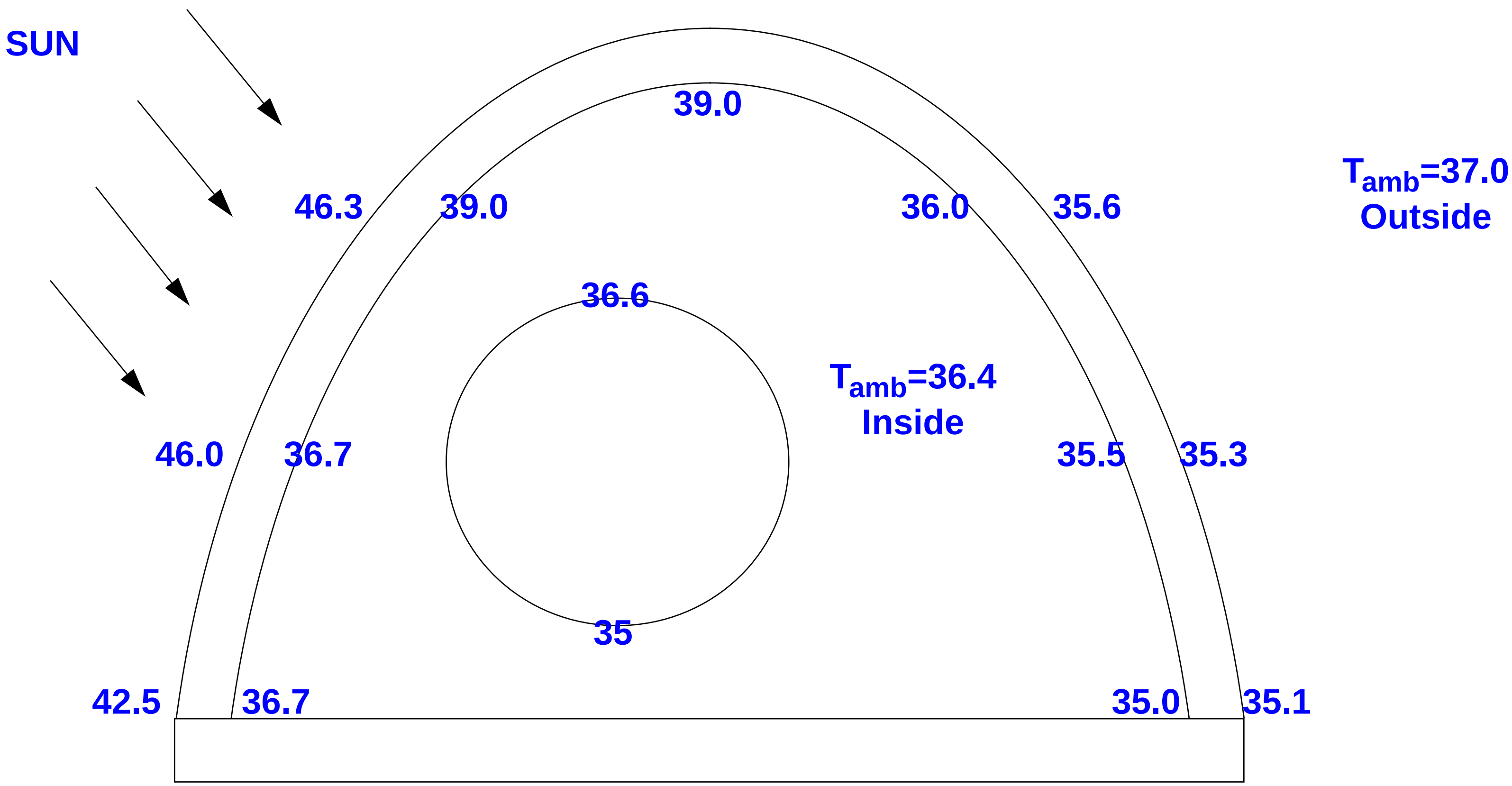
[2]Seismic plus thermal components

[3]For the case where the top side is warmer than bottom, lifting the dead weight from the fixed support (when the bottom side is warmer, the tube is nearly unconstrained)

[4]Dead load component (3410 kg) plus pullout strength of attachment bolts (est. 1125 kg)

[5]Dead load plus thermal components

TEMPERATURE DIFFERENCES INSIDE BEAM TUBE ENCLOSURE (°C)



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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 $J(H_2O) < 1\times10^{-11}$ torr l/s cm^2 at 150°C
  - **If the temp of any monitoring sensor falls below the minimum bake temperature, the bake time shall be extended as needed to ensure minimum time requirement is met**

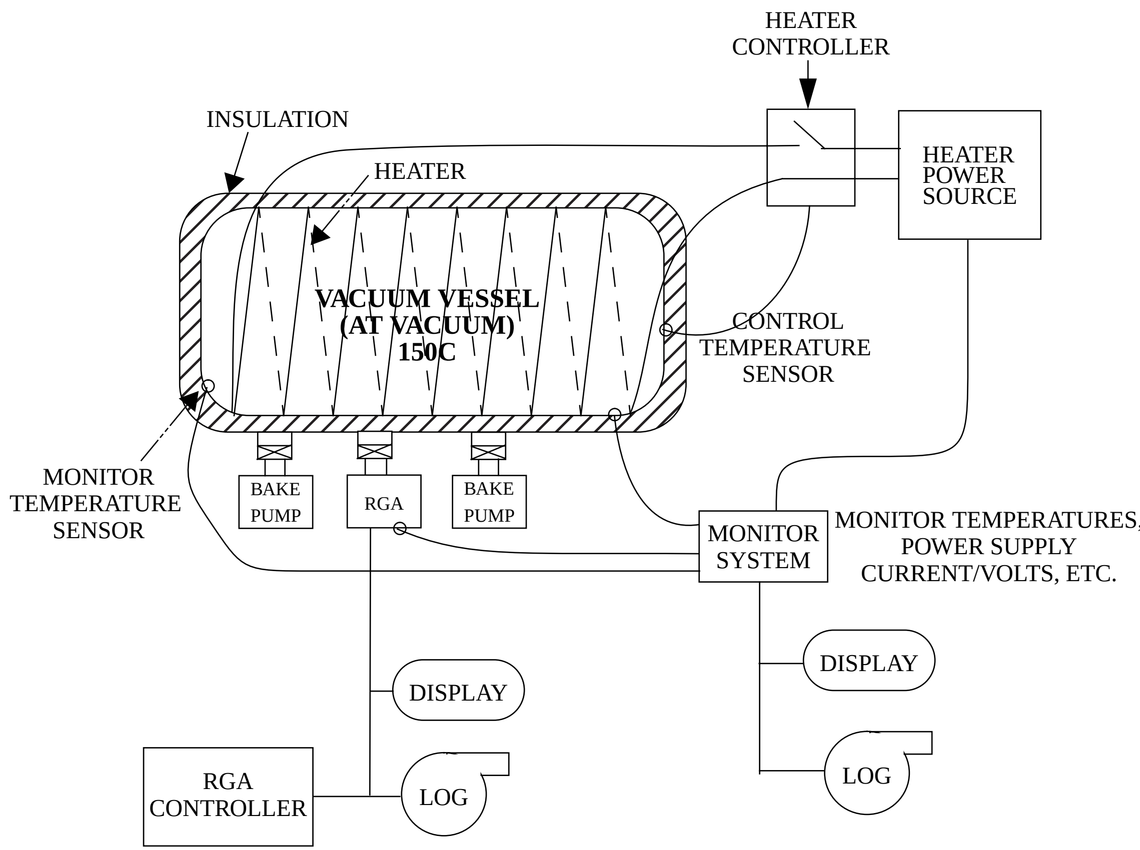
DESIGN REQUIREMENTS (CON'T)

- 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 ~~of H_2 and H_2O (during bakeout)~~ through AMU 100 (bakeout and post-bake)
  - Measure DC power supply currents and voltages
  - Operating status of equipment (i.e., vacuum pumps)[state vector]
  - Other engineering data (e.g., ambient environment conditions)
- BEAM TUBE INSULATION
  - Insulation as required to achieve bake temperature limits, non-corrosive and non-toxic
- VACUUM COMPONENTS
  - All vacuum components shall comply with the LIGO Vacuum Equipment Specification, section 5, for similar components

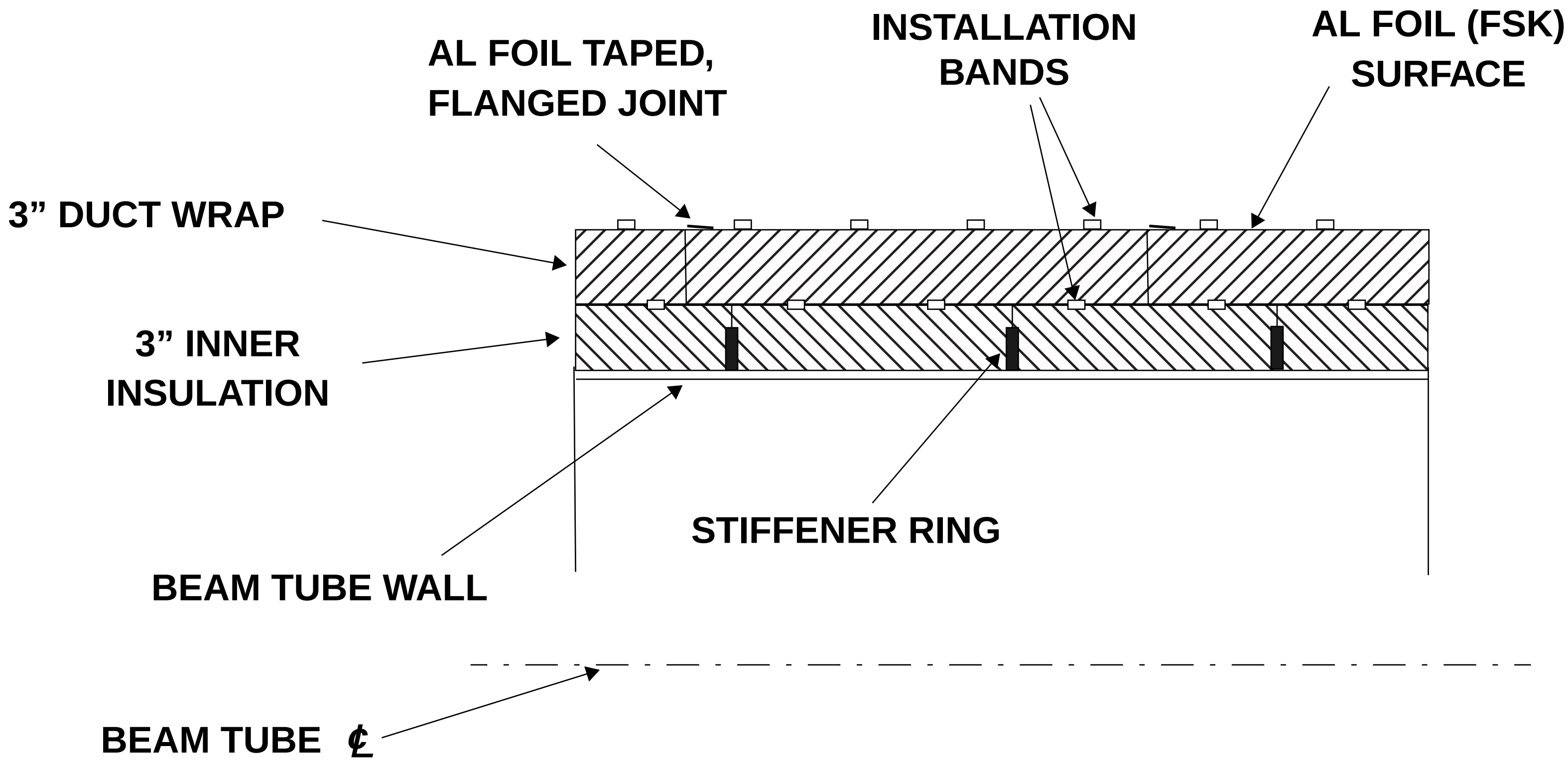
BAKEOUT INTERFACES

- MECHANICAL
  - **Vacuum hardware shall be compatible with the BT module pump port hardware, Type H, as called out in drawing D950027**
  - **Electrical connection for delivering DC heating power to the BT module shall use ~~bolted~~ clamp-on attachments ~~via holes drilled through BT support rings~~ near pump ports**
  - **Temperature sensors shall be attached to the BT wall using ~~TBD~~ techniques which do not pose a corrosion threat**
- ELECTRICAL
  - **Step-down transformers shall be used to provide needed AC power (480VAC 3Ø, 208VAC 3Ø, 120VAC 1Ø) from the site power**
  - **The beam tube shall be grounded at the ends and midpoint only during the bake (R to grounded points ≤ ~~0.035~~ 0.0175 ohm everywhere)**
  - **The beam tube shall have electrical connection to DC power supplies for heating**
  - **Monitoring and recording devices shall use separate AC power (120VAC, 1Ø), also derived from site utilities power**
  - **The bakeout equipment shall have adequate protection from lightning**

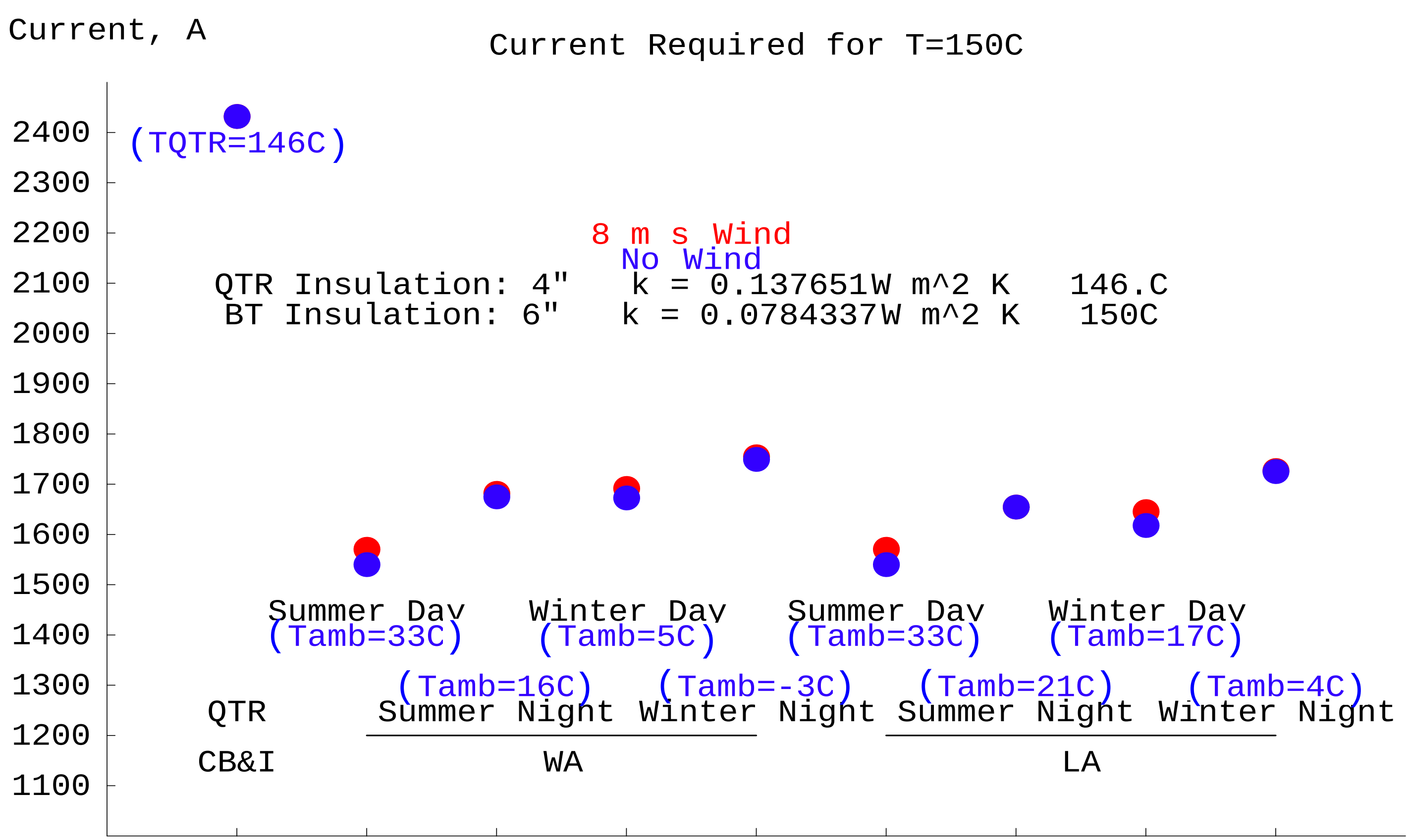
DIAGRAM OF EQUIPMENT DURING BAKEOUT AND COOLDOWN



TUBE WALL INSULATION



CURRENT REQUIRED TO MAINTAIN T_{wall}=150 °C VS. AMBIENT TEMPERATURE



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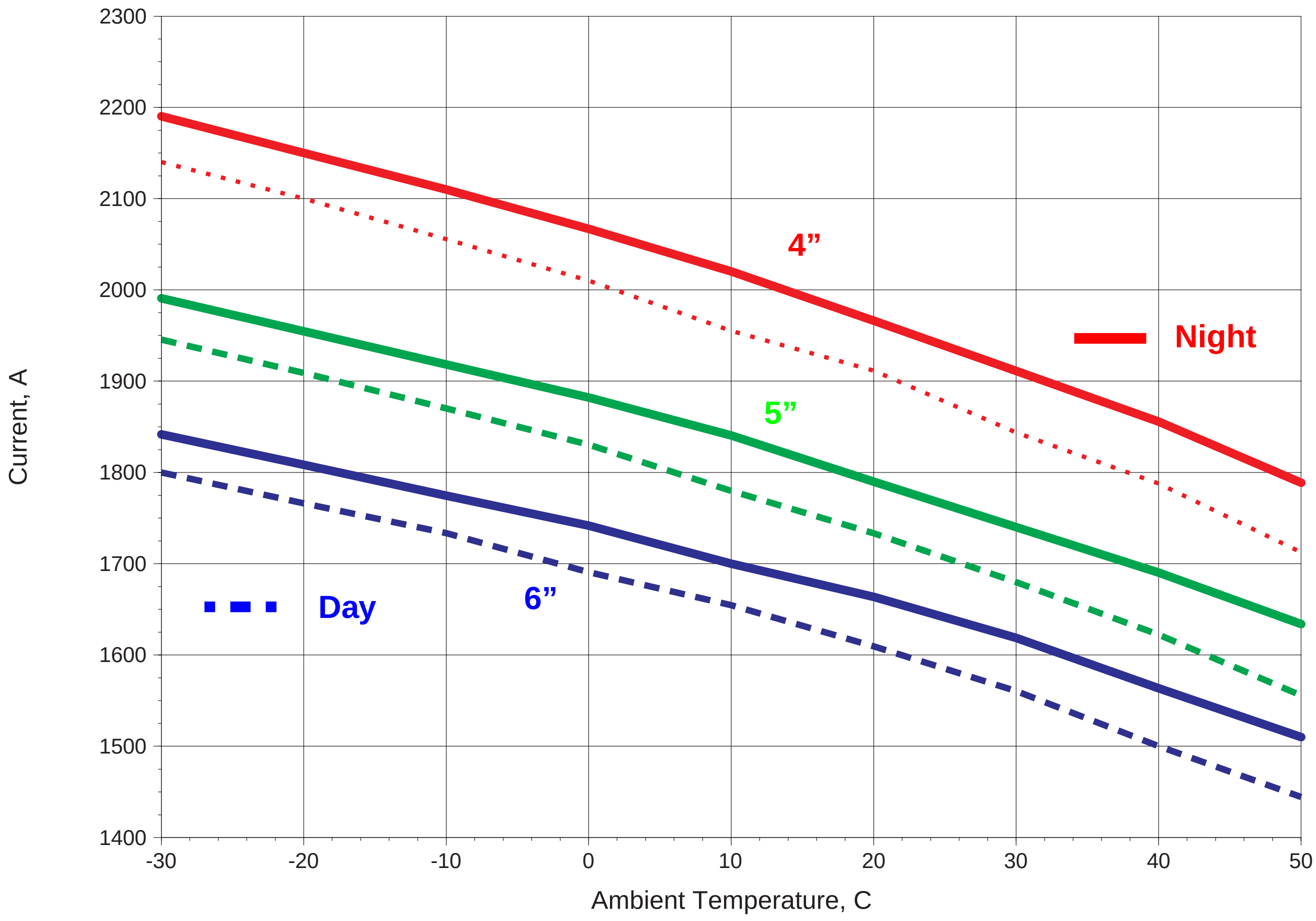
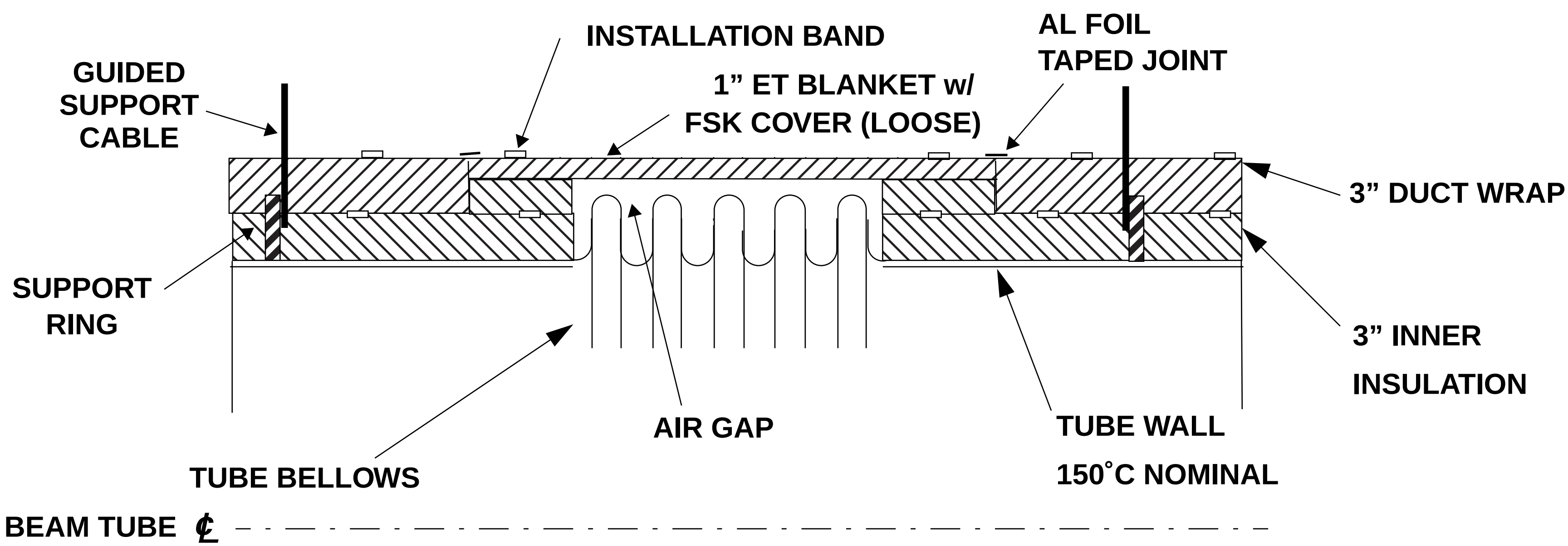
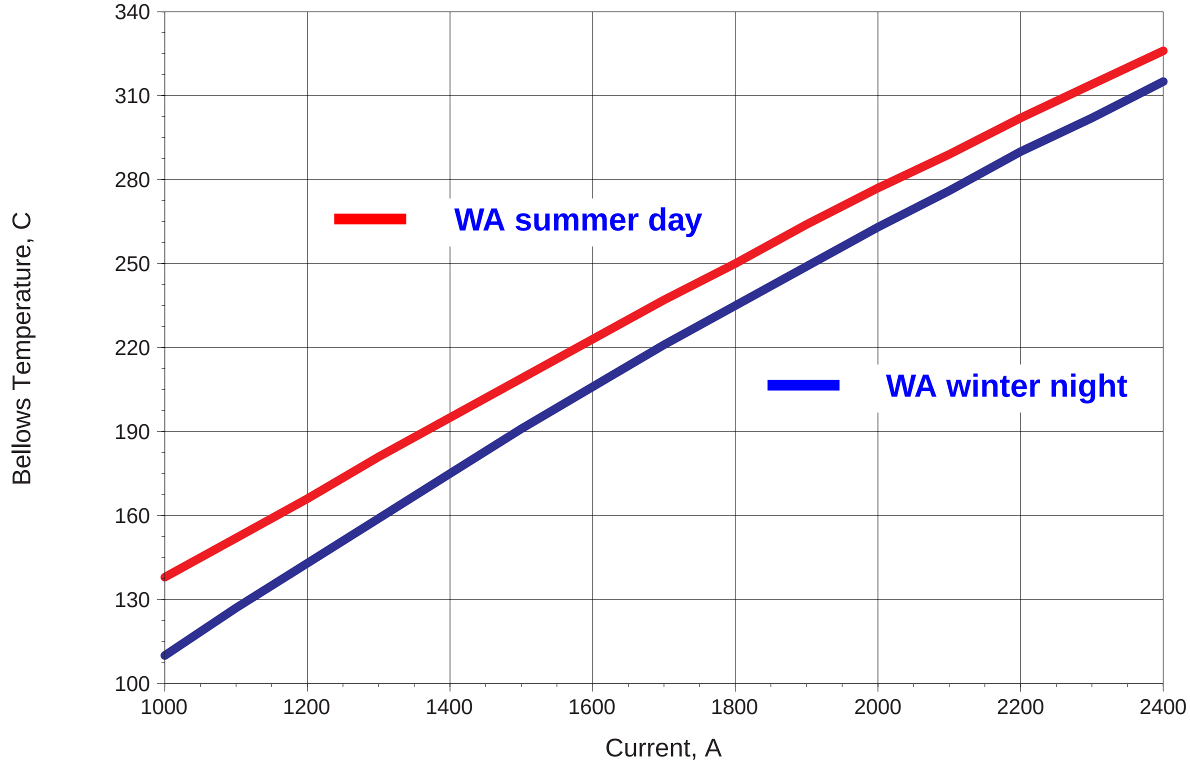


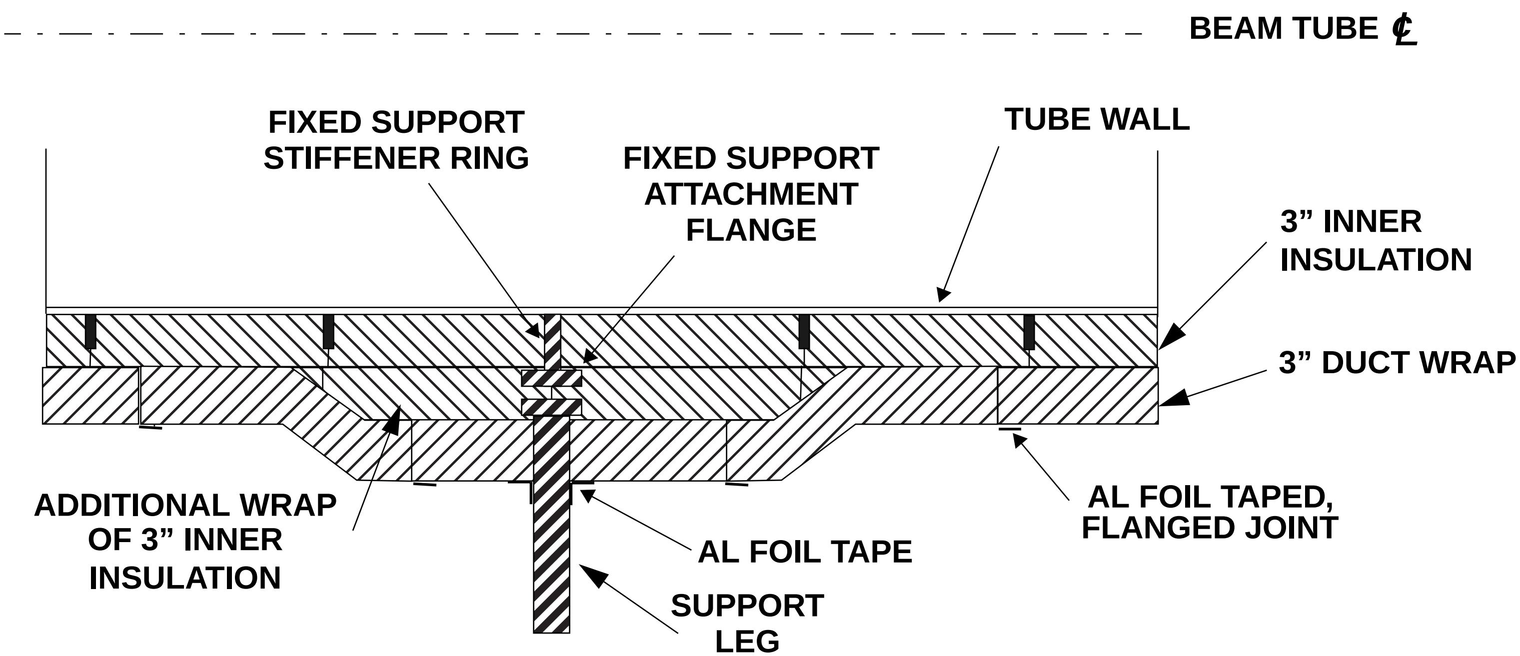
BELLOWS AND GUIDED SUPPORT INSULATION



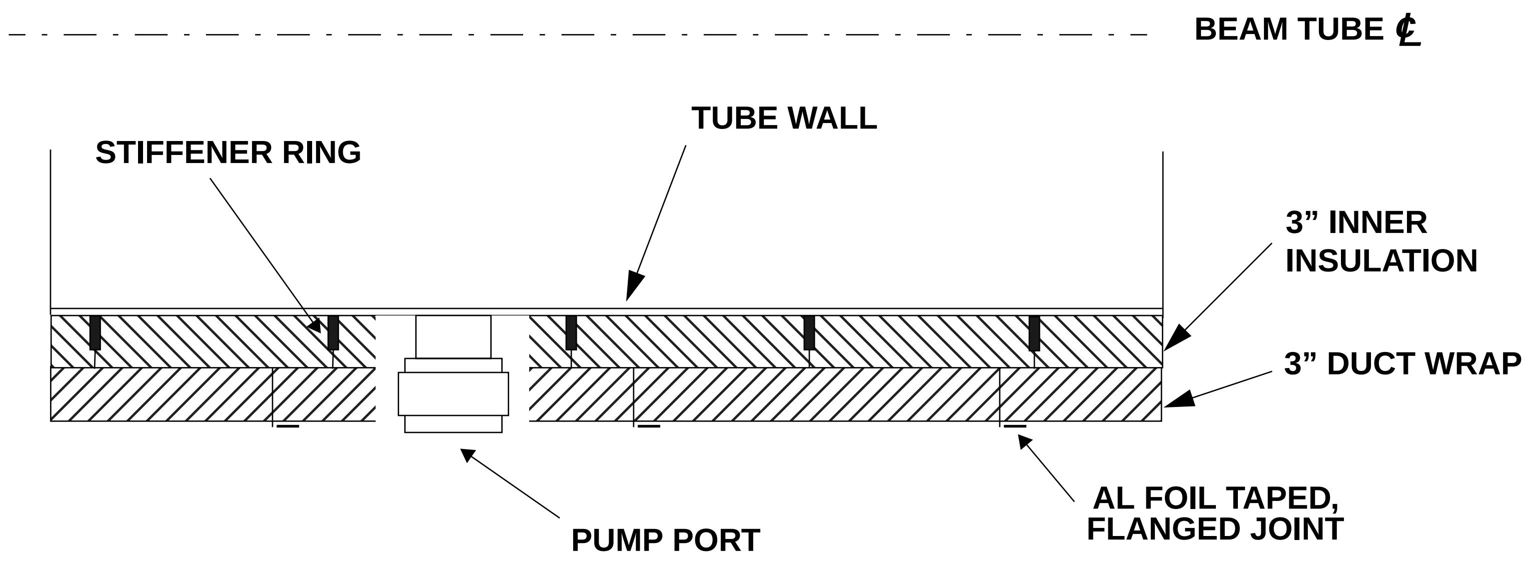
BELLOWS TEMPERATURE VS. CURRENT



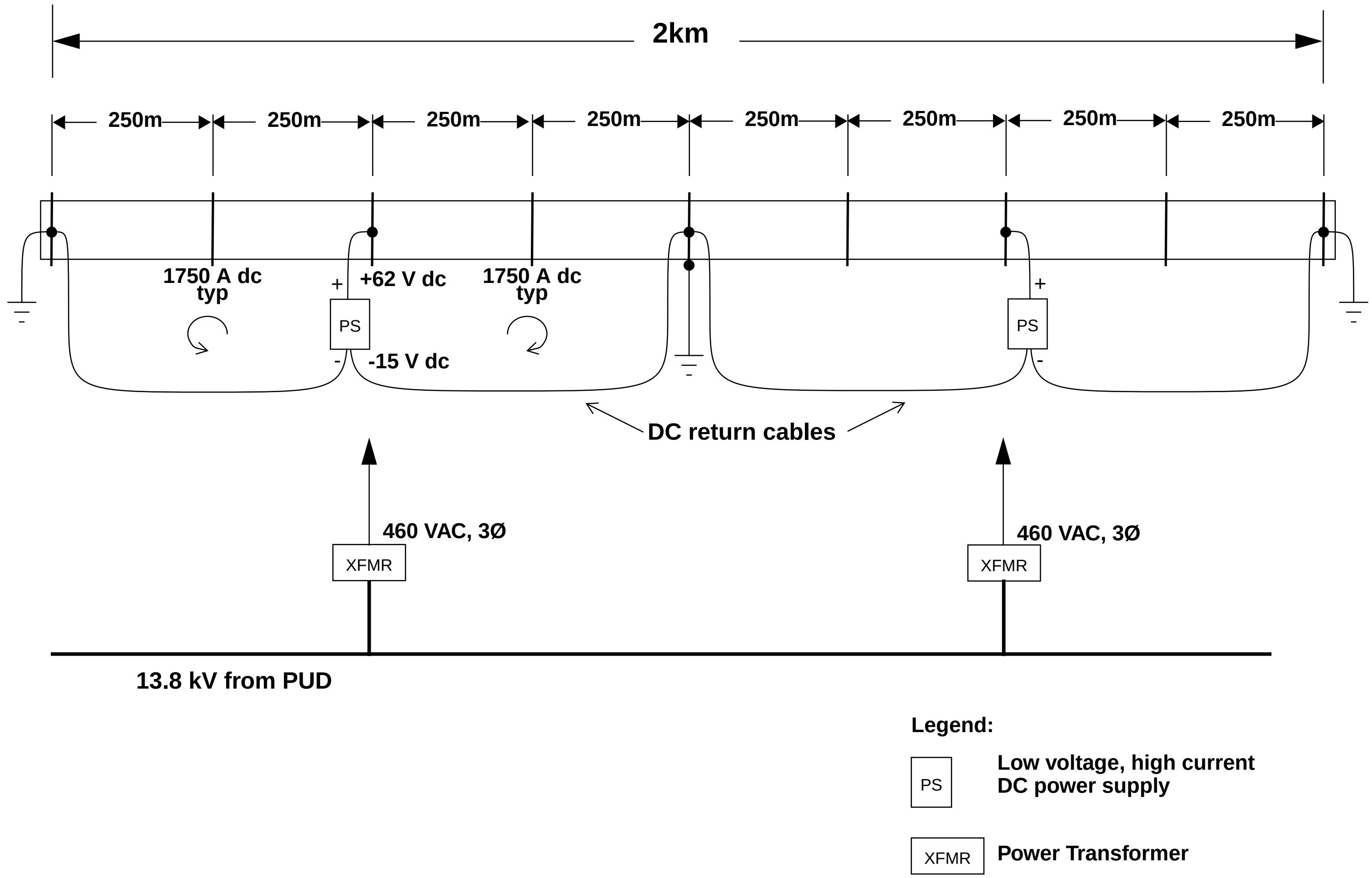
FIXED SUPPORT INSULATION



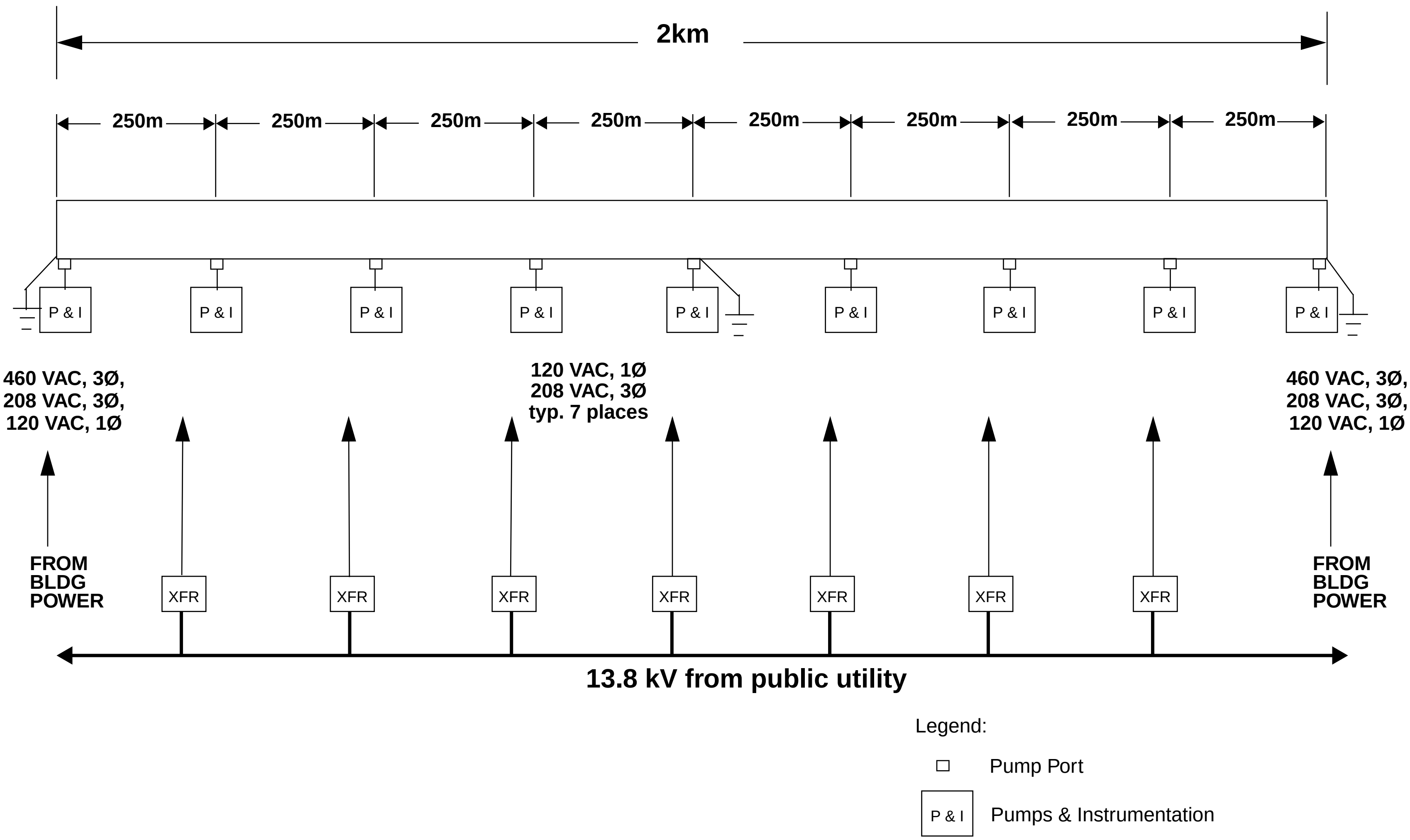
PUMP PORT INSULATION



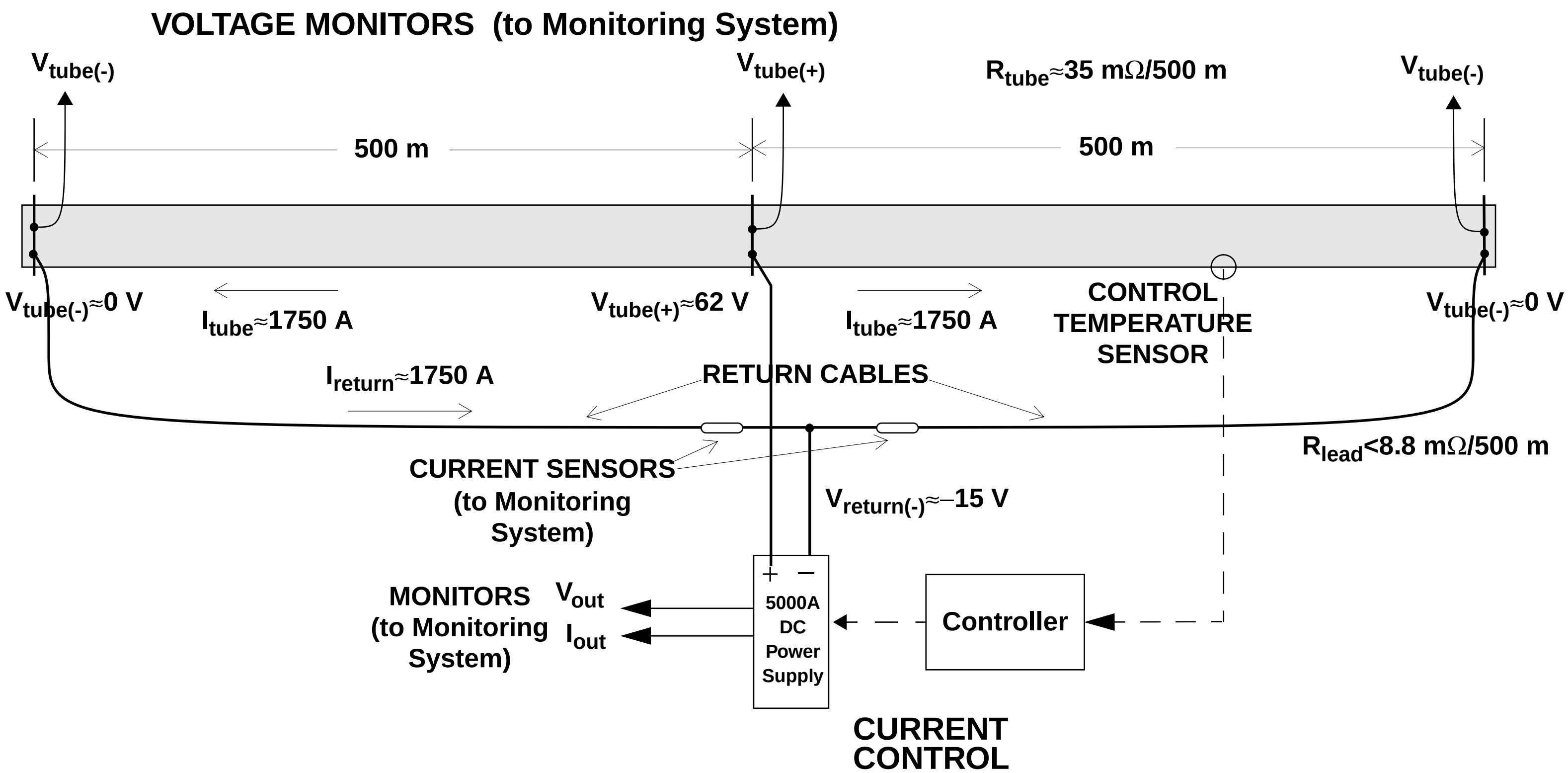
BEAM TUBE BAKEOUT ELECTRICAL HEATING POWER



ELECTRICAL POWER FOR HEATER JACKETS, PUMPS AND INSTRUMENTATION



DC POWER SUPPY CONNECTIONS, CONFIGURATION



EXAMPLE CONTROLLER ALGORITHM

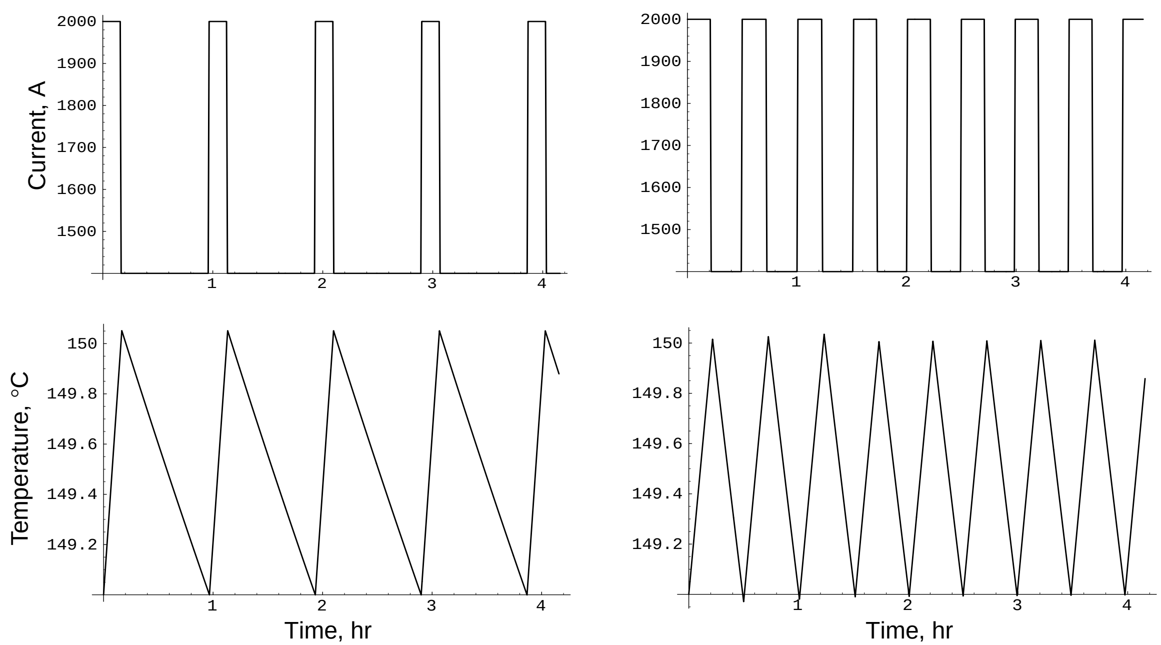
I_{high}=2000 A

$I(t)$

I_{low}=1400 A

$T_{tube}(t)$

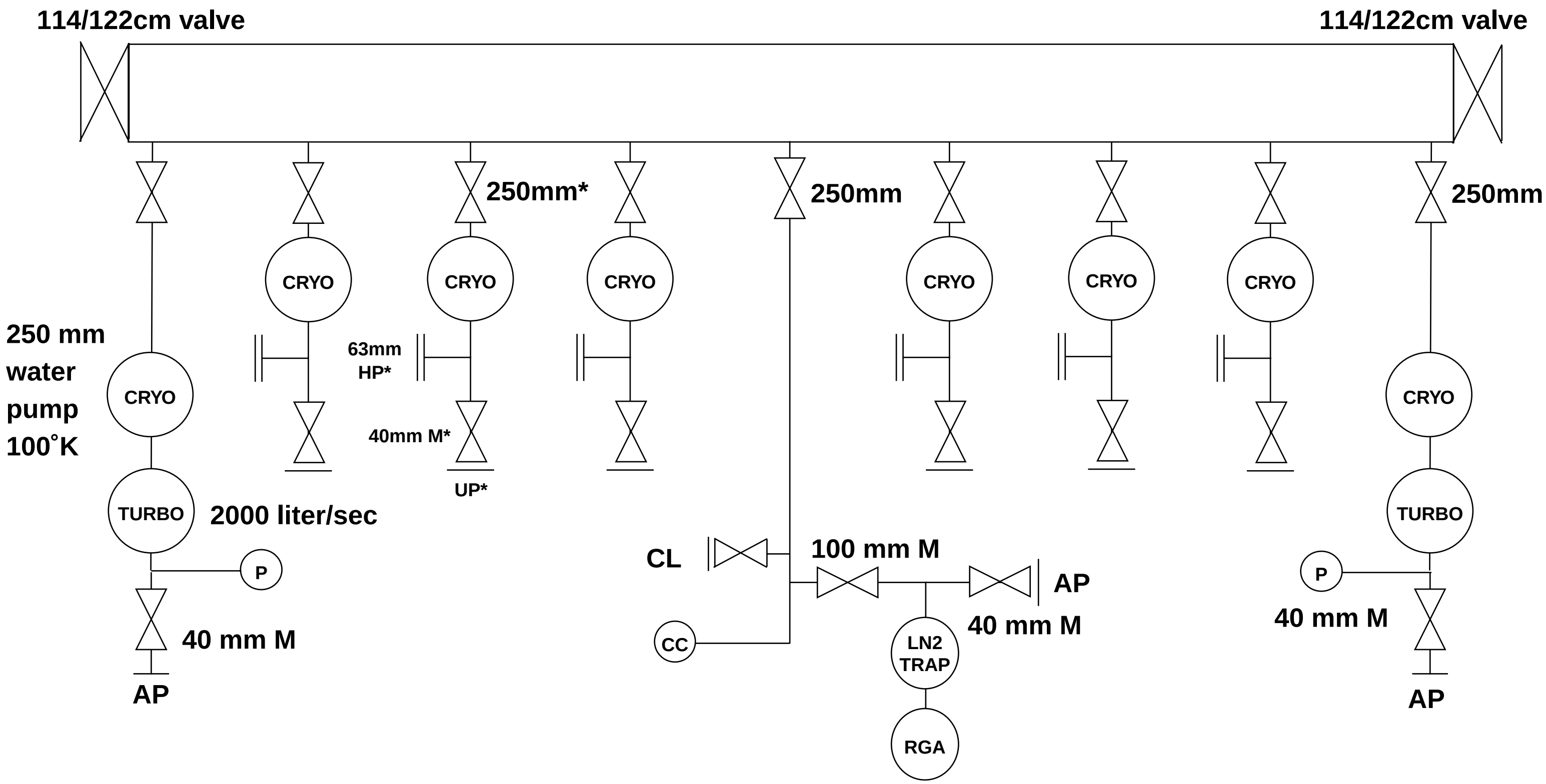
for
T_{set}=149.5 °C
$T_{deadband}$=1°C



a. Hanford site, summer days (no wind) ***b***. Hanford site, summer nights (no wind)

Condition		Controller response
Temperatures	Current	
$T_{tube}<T_{set}-{}^{1}/_{2}T_{deadband}$	don’t care	Set $I=I_{high}$
$T_{tube}<T_{set}+{}^{1}/_{2}T_{deadband}$	$I=I_{high}$	Set $I=I_{high}$ (no change)
$T_{tube}>T_{set}+{}^{1}/_{2}T_{deadband}$	don’t care	Set $I=I_{low}$
$T_{tube}>T_{set}-{}^{1}/_{2}T_{deadband}$	$I=I_{low}$	Set $I=I_{low}$ (no change)

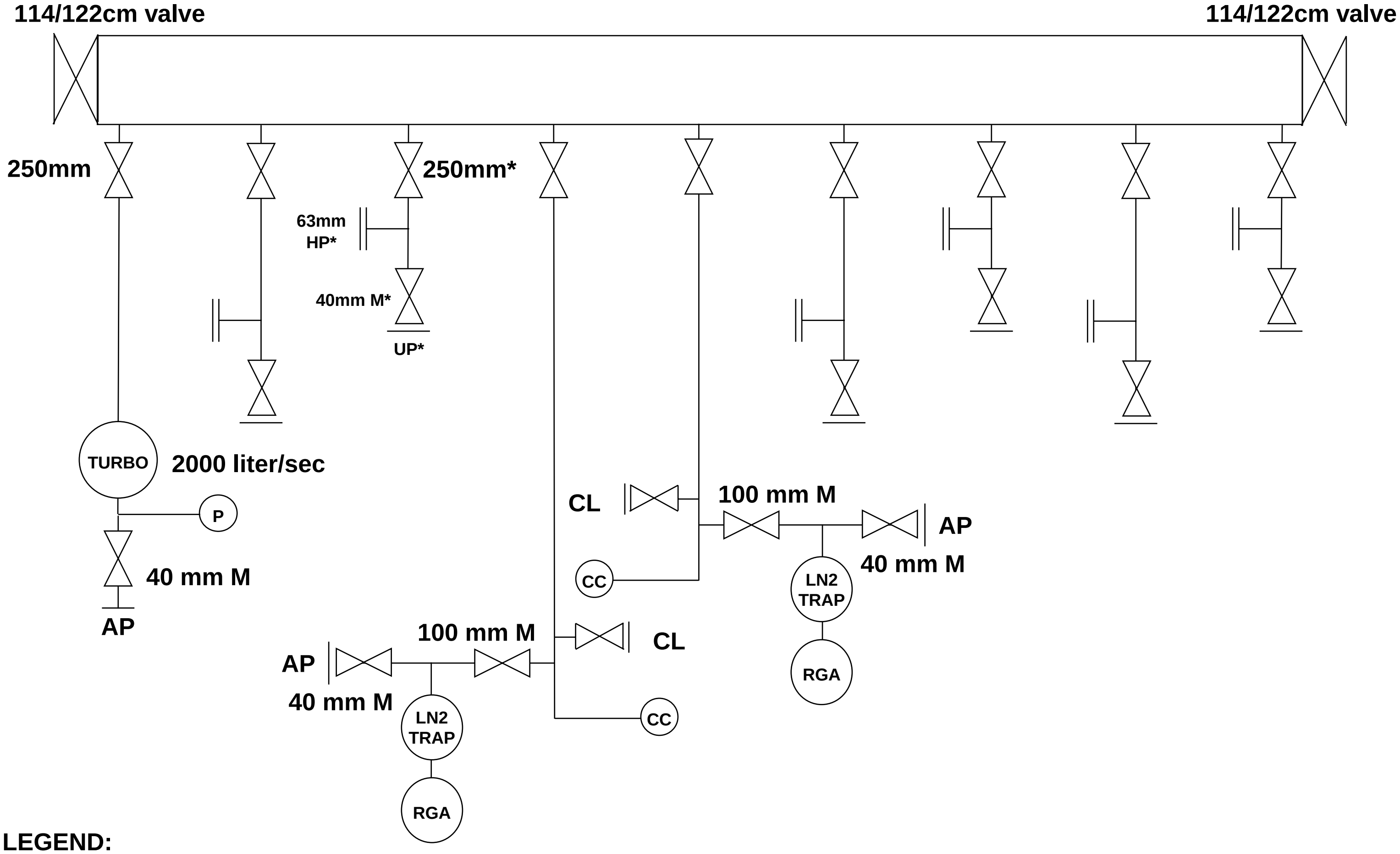
SCHEMATIC OF VACUUM PUMPS AND RGA DURING BAKEOUT



LEGEND:

AP	**Port for auxiliary turbo pump**	**M**	**Metal sealed valve**
BP	**250mm blank off plate**	**P**	**Pirani gauge**
CC	**Cold Cathode gauge**	**RP**	**Port for roughing**
CL	**Port for calibration leaks**	**UP**	**Port for utility purposes**
HP	**Port for RGA head installation**	*****	**Type H Pump Port Hardware furnished by CBI**

FINAL (POST-BAKE) TEST CONFIGURATION



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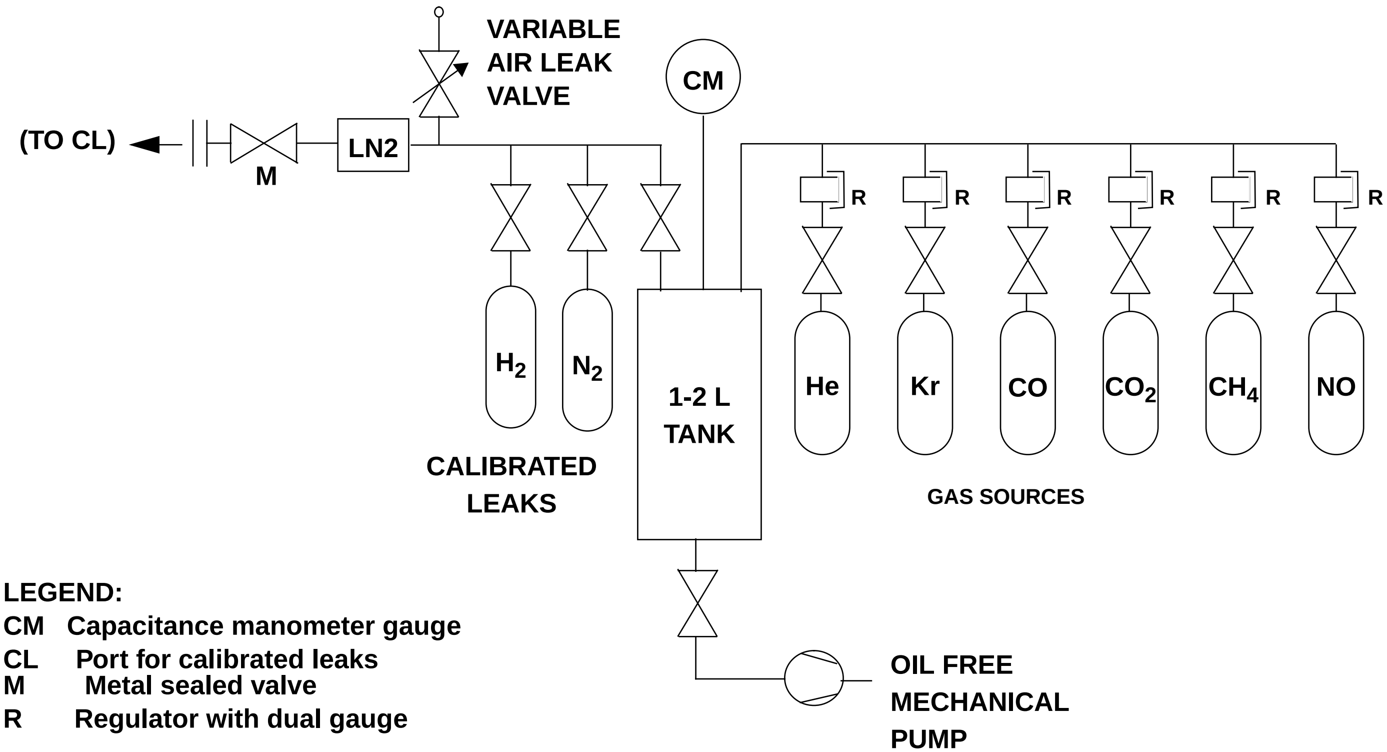
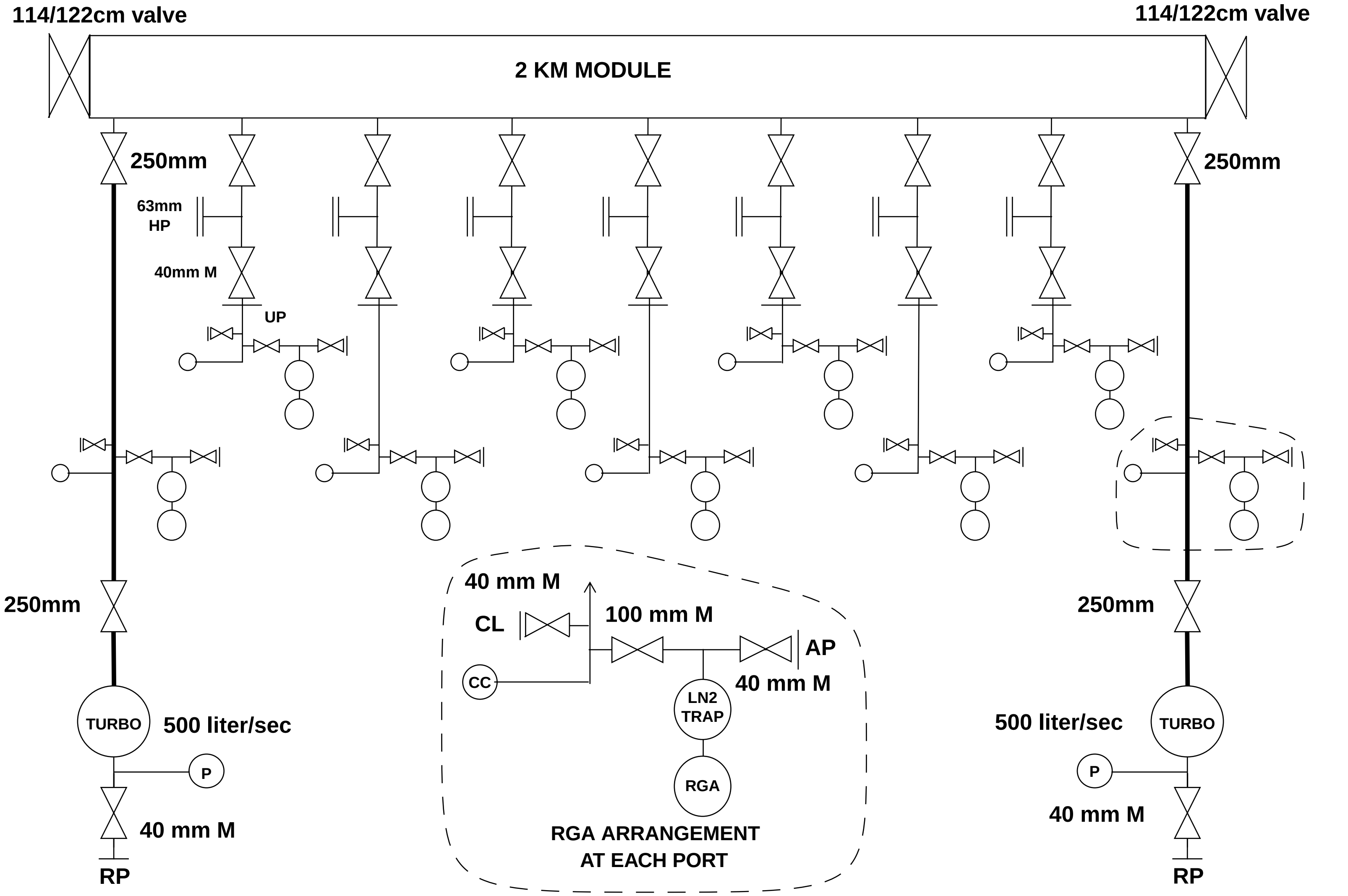
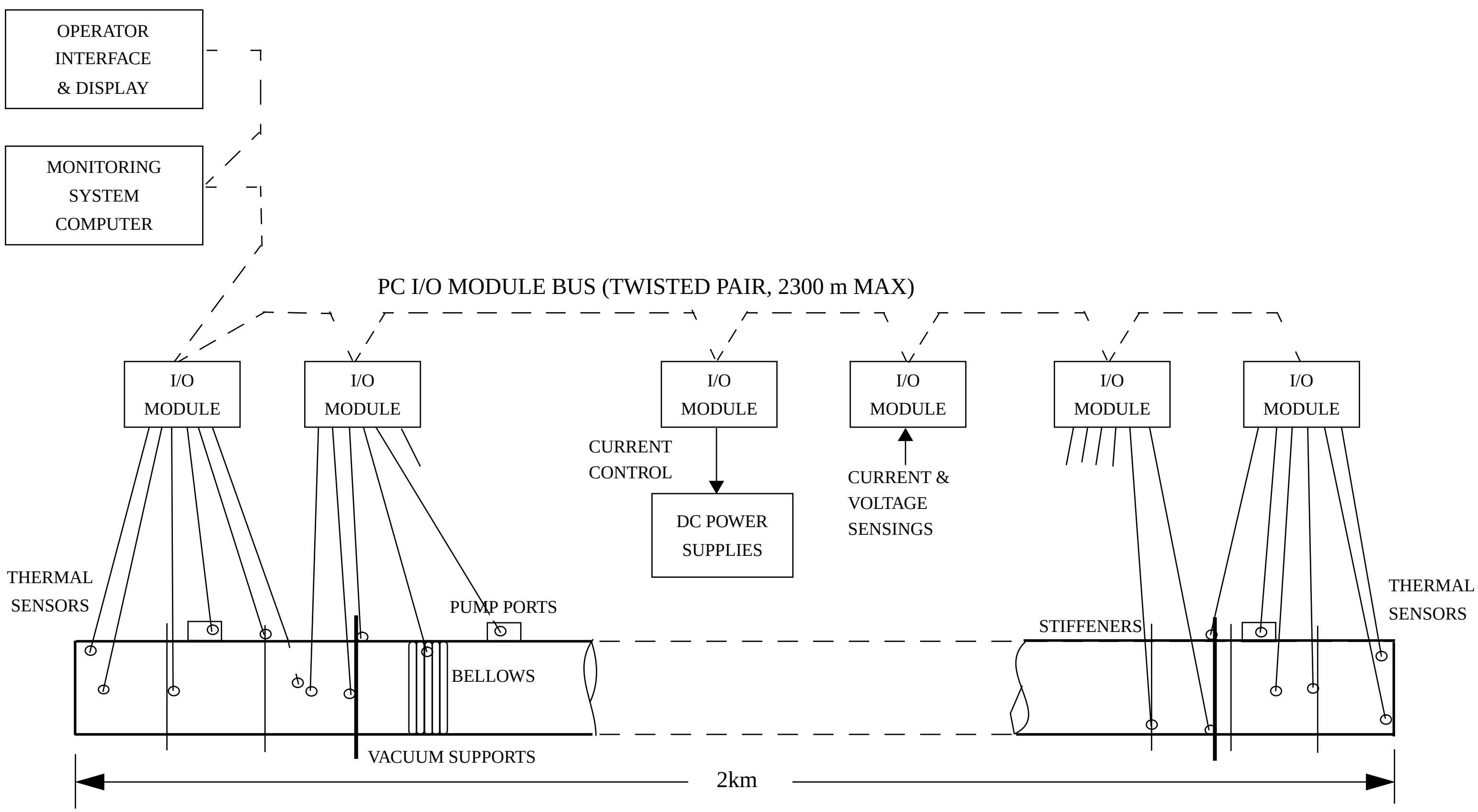
PORTABLE CALIBRATION MODULE



LEAK LOCALIZATION SETUP



MONITORING SYSTEM



MONITORING SYSTEM CHANNELS

- Temperature channels (132 total):
  - **60 channels near one end (1st 60 m) of beam tube -- gate valve, pump port, anchor, fixed supports, bellows, guided supports, tube wall**
  - **6 channels at each pump port -- 4 around tube wall (3, 6, 9, 12 o'clock) and 2 at port hardware**
  - **18 channels at other end**
  - **6-12 temperature channels monitoring ambient air (inside & outside)**
- Power supply electrical (18 channels total)
- Vacuum gauges (TBD channels total)
- Strain gauges - 4 measurements on each of two fixed supports
- Equipment status [state vector]
- Weather station (wind, RH, etc.)

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

BAKEOUT PLAN

- Conduct bakeout without interference with CBI and PSI installation activities
- Schedule bakeouts so that on-site LIGO staff can handle setup and execution
- 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 requirements:
  - **Site scientist/engineer to supervise setup, bakeout, data evaluation**
  - **2 site technicians (2 m-yr. per site) for equipment installation, checkout and removal**
  - **4 site or temp. technicians, 1.5 m-yr. per site for 1-person-24 hr. bake monitoring**

PROCUREMENT ACTIVITIES

- Subcontracts
  - Insulation contractor: purchase, prepare and install beam tube insulation
  - Power company: furnish, install and connect temporary transformers for primary AC power
  - Electrical contractor: install and connect DC power source and auxiliary AC power for pumps, instrumentation and controls
- Lead times for subcontracts and major equipment

Power transformers	PUD has ordered; 1st set 10/97; 2nd set 12/97
Insulation subcontract	IFB by 8/25, bid opening 10/2, complete 1st module by 3/15/98
Heater jackets	17 weeks ARO
DC supplies from FNAL	9/97
Cooling equipment for supplies	<13 weeks ARO
Cryopumps	6-8 weeks ARO
RGAs	6-8 weeks ARO
D/A equipment, s/w, computers	stock
Electrical installation subcontract	TBD
Port vacuum hdwr, cal module hdwr	TBD