SNS 87 MeV Drift Tube Linac and 185 MeV Coupled Cavity Linac Vacuum Systems

Final Design Review

January 19, 2001

SNS 104000000-DE0001 - R00

Accelerator Technologies Engineer Group

Lawrence Livermore National Laboratory

and

Spallation Neutron Source Division

Los Alamos National Laboratory

Participants

<u>Design Review Committee:</u>

- Michael Hechler, Chair, ORNL
- Bill Boedeker, LANL
- Dick Hseuh, BNL
- Bill Schneider, JLAB
- Walter Tuzel, LANL

- **Design Team:**
- John Bernardin, Lead Engineer
- Stewart Shen, LLNL
- Gerald Bustos, LANL
- Robert Gillis, LANL
- Keith Kishiyama, LLNL
- Pilar Marroquin, LANL
- William Morrison, LLNL
- Walter Nederbragt, LLNL
- Louann Tung, LLNL

Agenda

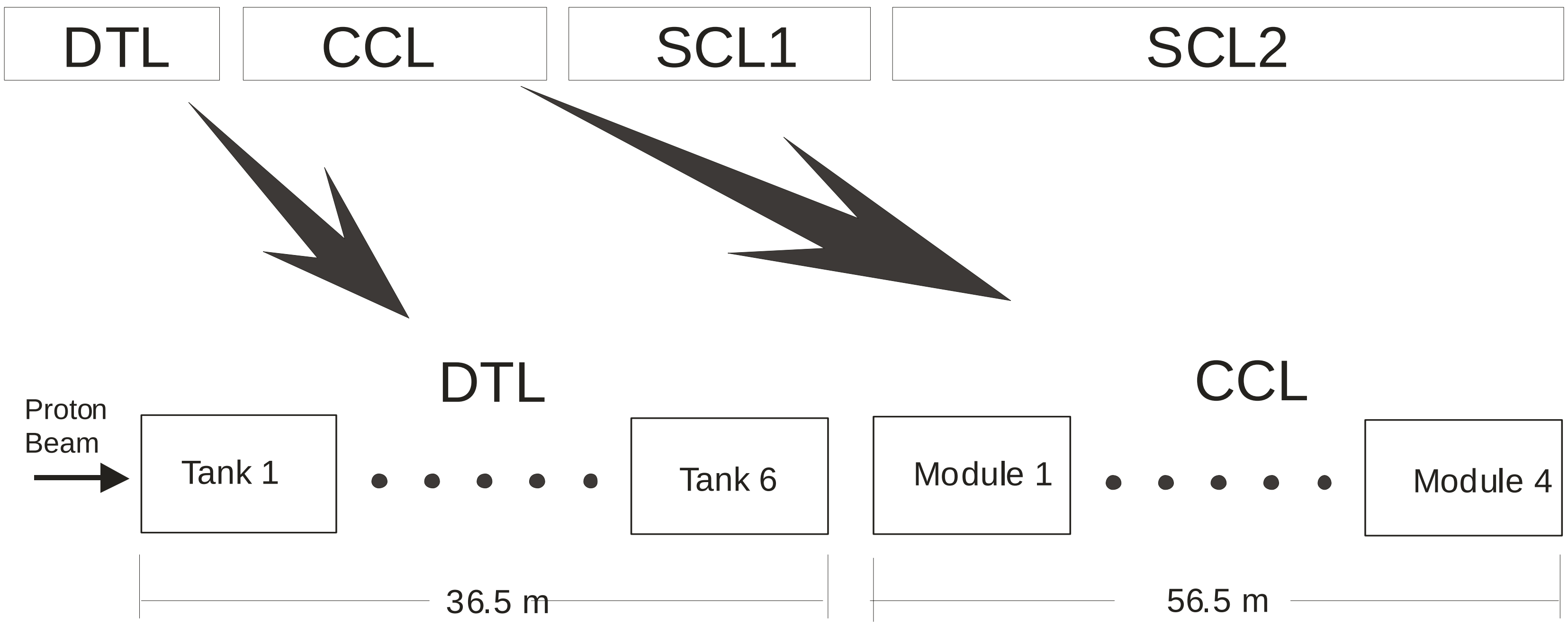
Introduction & System Requirements	Bernardin	8:00
Vacuum System Design Summaries	Bernardin	8:30
Vacuum Analyses	Shen	9:15
Break		10:15
Vacuum Analyses continued	Gillis	10:30
Mechanical Design	Bustos, Shen	11:00
Lunch		12:00
Facility Interface	Bernardin	1:00
Instrumentation and Controls	Kishiyama, Marroquin	1:15
Procurement Plans, Costs, QA	Bernardin	2:15
Assembly & Installation,	Bernardin	2:35
Safety & Reliability	Bernardin	3:00
Project Status & Schedule	Bernardin	3:15
Break		3:30
Committee Review and Wrap-up		3:40-4:30

Charge to Review Committee

- **Are the design tasks and requirements (scope) clearly defined?**
- **Is the engineering design approach sound?**
  - Are numerical modeling and experimentation tools sufficient?
  - Are engineering drawings adequate?
  - Are all design topics addressed?
- **Are control and safety features adequate?**
- **Are all interfaces with facility & subsystems identified**
- **Are procurement, assembly, & installation tasks clearly identified and reasonable?**
- **Are cost and schedule predictions accurate/reasonable/adequate?**
- **Should we proceed with the hardware procurements?**

Introduction

SNS Drift Tube & Coupled Cavity Linacs

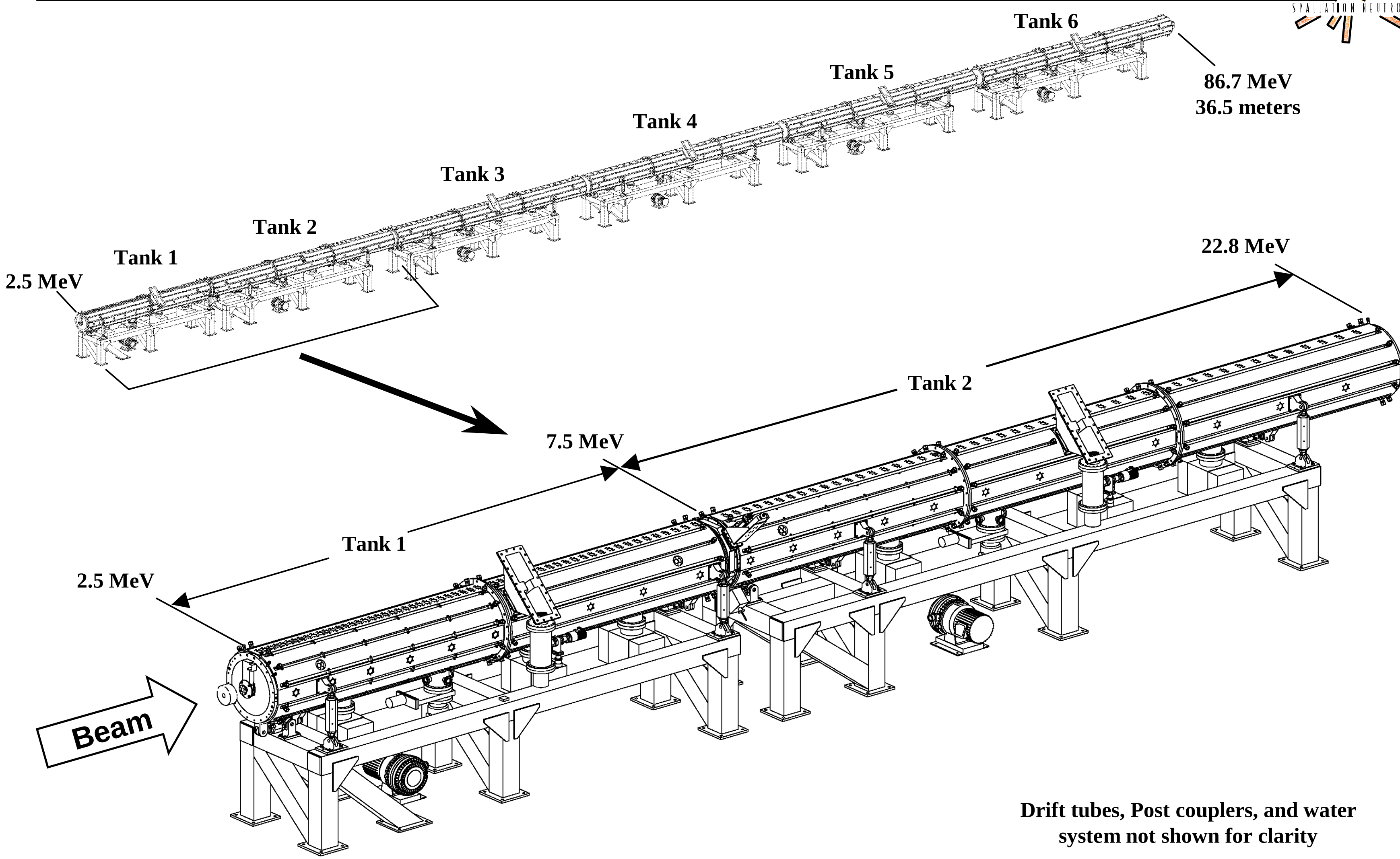


1 independent vacuum system per
DTL tank consisting of
3-300 L/s ion pumps
1-300 L/s turbo/roughing pump
1-70 L/s turbo pump
1-1300 L/s NEG pump
1 set of gauges & RGA
1 control system (PLC, rack, computer)

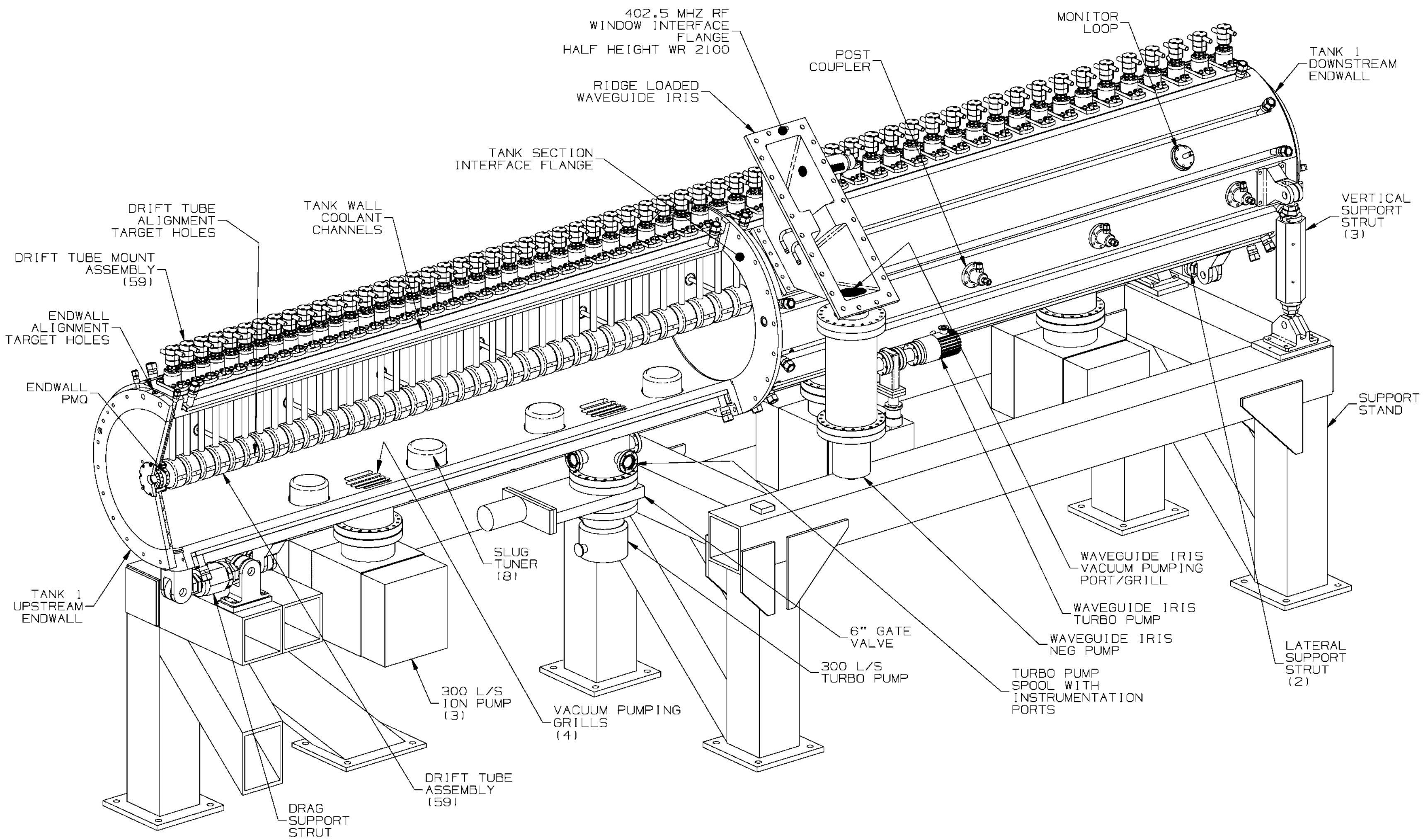
1 independent vacuum system per
CCL module consisting of
10-300 L/s ion pumps
2-300 L/s turbo/roughing pumps
2-70 L/s turbo pumps
2-1300 L/s NEG pumps
1 set of gauges & RGA
1 control system (PLC, rack, computer)

Figure 1.1. General layout of the SNS Linac and basic summaries of the DTL and CCL vacuum systems.

Drift Tube Linac (DTL) Structure

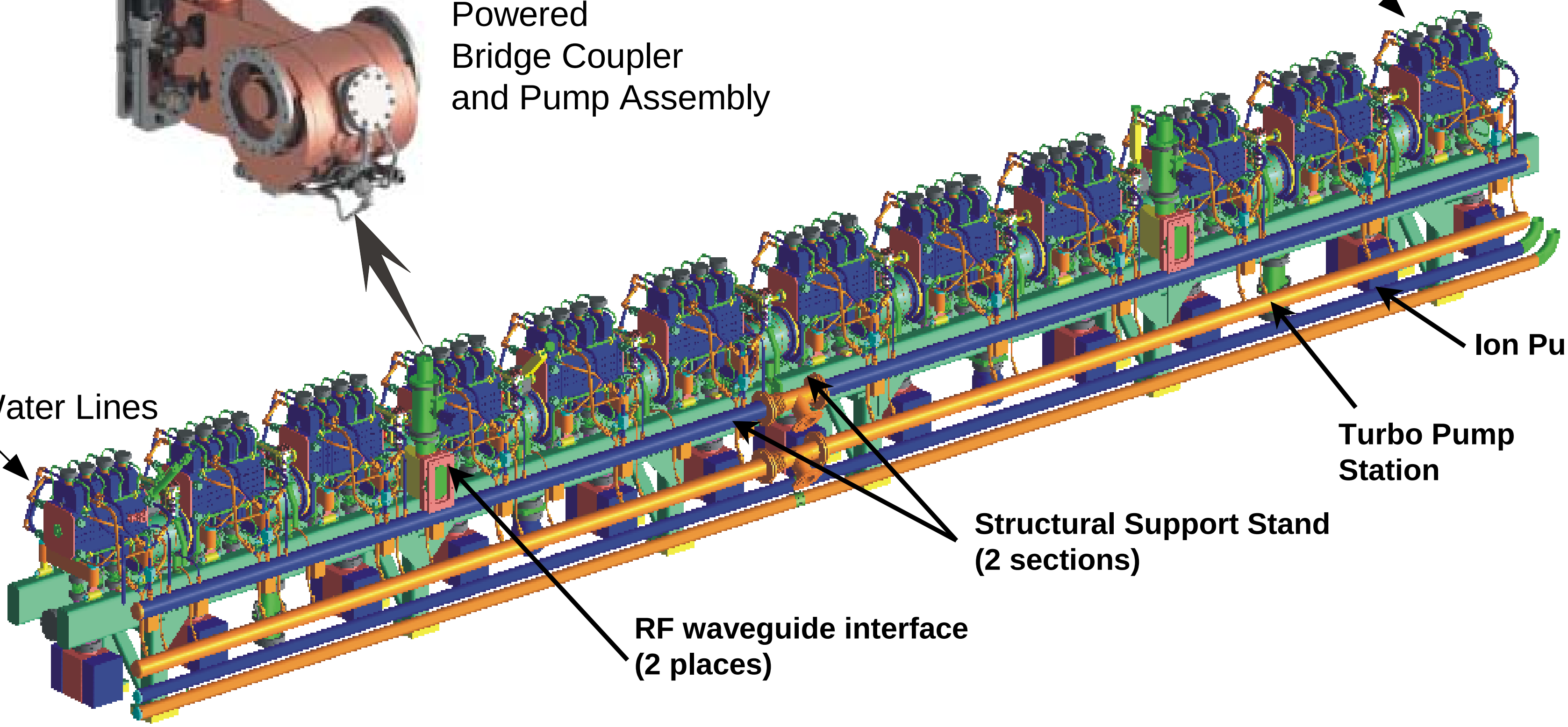


DTL Tank #1 Assembly



Coupled Cavity Linac (CCL) Structure

Typical CCL Module (4 total)
- **Two halves form 1 module**
- **12 Segments**
- **96 Accelerator Cavities**
- **Length: 12 to 15 meters**



DTL/CCL Vacuum Systems
Scope and Design Requirements

Scope

Design, analyze, fabricate, assemble, install and test a robust vacuum system (pumps, hardware, instrumentation, controls, etc) that provides a sufficient vacuum for the RF environment and minimizes beam stripping and associated activation.

Technical Specifications

$$\mathbf{P_{allowable} = W_{He}\,P_{He} + W_{H2}\,P_{H2} + W_{H2O}\,P_{H2O} + W_{N2}\,P_{N2} + W_{CO}\,P_{CO} + W_{O2}\,P_{O2} + W_{CO2}P_{CO2}}$$

– where the weighting factors for the primary gas constituents of interest are as follows:

$W_{He} = 0.125$, $W_{H2} = 0.15$, $W_{H2O} = 0.66$, $W_{N2} = 1.0$, $W_{CO} = 1.0$, $W_{O2} = 1.0$, $W_{CO2} = 1.5$

Linac Section	DTL Tank or CCL Module	Exit Beam Energy	Max Allowable Pressure
	No.	MeV	Torr
DTL	1-6	2.5 to 86.8	1.84×10^{-7}
CCL	1	107.2	1.84×10^{-7}
CCL	2	131.1	1.53×10^{-7}
CCL	3	157.2	1.21×10^{-7}
CCL	4	185.6	0.89×10^{-7}

Final Design Deliverables

1) Definition of operational requirements and all mechanical/electrical interfaces with Linac and facility

2) Design and layout of vacuum system components.

3) Vacuum and stress analyses.

4) Specification sheets for manifolds, plumbing, valves, seals, pumps, controls and instrumentation.

5) Design of control system architecture and operational/safety features

6) P&Ids, assembly, & detail drawings.

7) Specifications and procedures for material preparation and cleaning following manufacturing.

8) Procurement plans, hardware costs, quality assurance plan.

9) Specification of detailed assembly and installation plans.

10) Specification of system operation, reliability, and safety features.

11) Formal presentation (peer reviewed) of design including written report addressing all above mentioned aspects.

Comments & Action Items from PDR

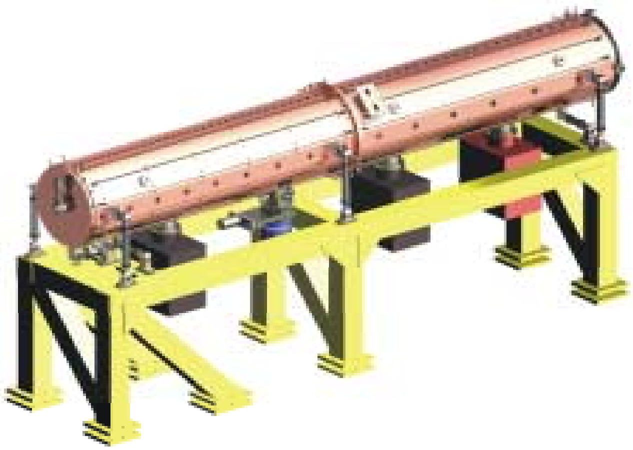
Com-ment #	Review Committee Comment	Design Team Response or Action
1	The “design goals" require further clarification in regard to their application of “design margins”.	A vacuum pressure design margin of 2 has been defined in the vacuum design criteria (and agreed upon by ORNL-ASD). Consequently, the vacuum system will be designed to achieve, under normal operation, an operational base pressure that is half of the required operating pressure value. This design margin will allow the vacuum system to still achieve operational pressures in the event of higher gas loads (from dirt, virtual leaks, unaccounted gas loads) and/or pump failure.
2	The interface with the RF, beam Interrupt, and mechanical structures require clarification.	A control system interface diagram was developed that identifies all signal/communication interfaces with the DTL/CCL vacuum systems and other control systems (global, low-level RF, RF power, etc.). Assembly drawings of the DTL and CCL were generated to look at mechanical interfaces of the vacuum system with the RF and support structures, as well as other subsystem hardware.
3	The RF window vacuum system needs further optimization. Additional window outgassing data needs definition.	Further optimization and design of the RF window vacuum system occurred. Additional outgassing data will become available from the CCL hot model testing in the upcoming months.
4	Evaluation of turbo-pump carts compared with permanently installed turbo-pump stations must be performed.	Mechanical positioning and clearance of a portable turbo cart with the DTL and CCL RF structures was studied and a turbo cart specification sheet was generated. In addition, the oughing pump-down time of a DTL tank and a CCL module as a function of turbo pump speed was calculated to determine number/size of carts.
9	The use of seal type, especially in the DTL Tank, should be investigated by the responsible design personnel to avoid future performance degradation by elastomer seals.	All vacuum seals and penetrations on the DTL and CCL RF structures were identified and reviewed by the vacuum system design team for vacuum compatibility and engineering design. Leak rates associated with all seals were included in vacuum models and found to be acceptable. Use of elastomer seals was based on acceptable leak rate levels, radiation compatibility, design functionality, cost, etc.
10	Personnel responsible for the vacuum must be directly involved in the design activities of all accelerator components that have a vacuum interface, from conceptual through final design phases, of all accelerator system. There is a sense of disconnection at this time.	LANL/SNS Division is implementing appropriate procedures. Plans have been developed to review the relevant hardware designs of the DTL and CCL RF structures (valves, seals, cleaning procedures, materials), beam diagnostic equipment, drift tube permanent magnets, etc. Vacuum engineer approval signature box has been added to the SNS drawing template title block.
12	The number, type, and configuration of in-vacuum diagnostics need to be defined and the outgassing effects evaluated during the design stage of that equipment.	A tabulation of the types, quantities, and locations, as well as descriptions of the designs/materials of the beam diagnostics hardware are being generated. Engineering vacuum calculations have been performed to define allowable loads requirements for all diagnostics.
13	DTL component gas loads and dimensions to be revised to reflect latest design	The numerical models were updated with the current DTL and CCL design parameters such as component geometries, outgassing rates, and seal types/quantities/gas loads.

Comments & Action Items from PDR

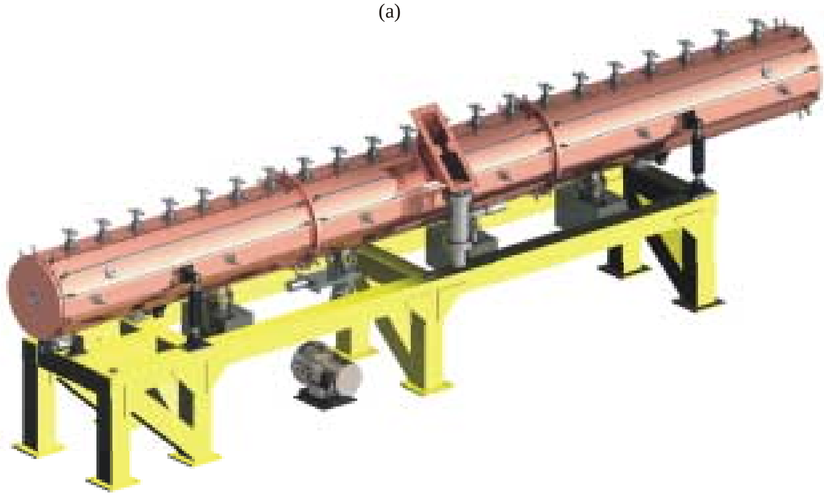
16	Utilize superposition to study other gas species such as water	Superposition of multiple gas species and weighted partial pressure design criterion (Shafer, 1999, "Beam Loss from H-minus Stripping in the Residual Gas," TN:LANSCE-1:99-085) was employed in DTL & CCL vacuum models.
17	Analytical Enhancement: the seismic levels used for the structural evaluations need to reflect the official project definitions.	The official seismic design requirements for the SNS project were incorporated in the mechanical strength analyses.
19	Standardization: the standardization of components with other machine areas shall be addressed as a priority, this shall include equipment specifications and associated procurement activities.	We have worked with BNL, JLAB, LBNL, LLNL, and ORNL engineers and held vacuum standardization meetings to identify common components and strive to standardize the specifications and procurement of these items during the final design phase. ORNL-ASD is constructing a vacuum standards handbook (with input from all SNS participating labs) to identify common design practices, hardware selection, and manufacturing/cleaning procedures. Vacuum hardware specification sheets have been developed to identify needed/desired design features of the DTL/CCL vacuum equipment and will be submitted to ORNL for incorporation in the project procurement plan. It was decided that basic ordering agreements will be set up by ORNL for the partner labs to procure vacuum hardware from selected vendors.
25	Correlate gauge locations with beam pressure predictions	This data was obtained from the DTL and CCL vacuum models. This pressure correlation information has been provided in the vacuum system FDR report and the beam tube pressure predictions (from gauge measurements) will be displayed on control system operating screens.
31	The clearance and mounting of the CCL modules needs to be addressed with the assembly drawings of the module structure support.	The assembly drawings of the CCL vacuum manifold and mounting fixtures were incorporated in the top level CCL module assembly drawing to ensure that the vacuum components (manifold, bellows, pumps, etc.) would interface properly with the RF and support structures.
33	The impact of the vacuum force on the CCL RF structures & alignment need to be evaluated.	This analysis has been performed.
35	A verification of the back-up and uninterruptable power requirements should be verified.	The back-up electrical requirements for the DLT/CCL vacuum systems have been completed and documented in the SNS DTL/CCL Vacuum System Description Document. The UPS requirements have also been submitted directly to the SNS conventional facilities team. Enough UPS will be supplied to keep the vacuum system PLCs and pressure gauge controllers active should a power failure occur.
38	Consider reducing the number of vacuum system PLCs	Two different control system architecture schemes were considered during the final design phase. Option A (PDR) required a PLC and independent vacuum system for each DTL tank and CCL module. Option B (to be configured), utilized one PLC for the entire DTL vacuum system and one PLC for the entire CCL vacuum system. Baseded on the weighted design criteria outlined in the SDD (functionality, cost, safety, etc.), and the Linac installation, commissioning, and operation plans,.option A was selected.
41	The issue regarding cable deterioration needs to be clarified, i.e. the provision of extra cables or use of extra cable lengths needs to be evaluated.	The issue of "HV cable deterioration" was evaluated with operational experience from LANSCE and other accelerators. A large database of radiation damage data for various types of cable insulation is well documented in a CERN issued report. This data was used as guidance in selecting vacuum pump and instrumentation cabling that is radiation resistant.
42	A check should be made with the vacuum pump manufacturers regarding the support of large pumps off the flange.	We have already contacted one manufacturer (Varian). Their pumps can be supported via the flanges. If necessary, other manufactures will be contacted to insure that mounting via the flange is acceptable. The support of ion pumps via the attachment flange (without additional support) will be specified in the procurement specifications. The stress induced on the DTL tank and CCL manifold by hanging the ion pumps without any additional support was found to be acceptable.

DTL/CCL Vacuum Systems: Design Summaries

DTL Vacuum System Design Features



(a)



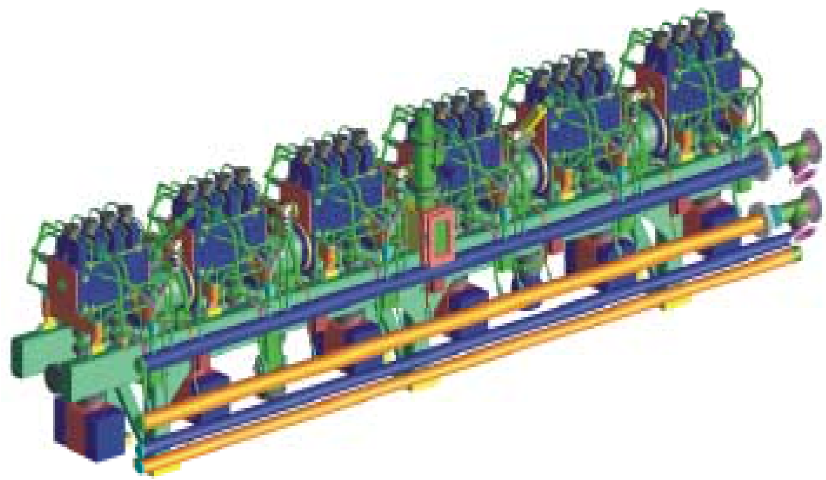
(b)

Figure 1.2. The Drift Tube Linac R F structure, support structure, and main vacuum pumps for (a) tank #1 and (b) tank #2..

Basic Design Features

- Distributed vacuum pumping system to provide necessary base pressure to satisfy RF operating and radiation activation requirements
- 6 DTL tanks with independent vacuum systems
- PLC control system per tank
- Pumps per Tank Body: Three-300 L/s ion pumps and One-300L/s turbo/roughing pump
- Pumps per RF Window: One-1300 L/s NEG pump, One-70 L/s turbo pump backed by scroll pump
- Distributed vacuum gauges, RGAs, purge lines, and valves

CCL Vacuum System Design Features



Basic Design Features

- Distributed vacuum pumping system to provide necessary base pressure to satisfy RF operating and radiation activation requirements
- 4 CCL modules with independent vacuum systems
- PLC control system per module
- Pumps per module: five-300 L/s ion pumps and two-300L/s turbo/roughing pumps
- Pumps per RF Window: One-1300 L/s NEG pump, One 70 L/s turbo pump and backing scroll pump
- Distributed vacuum gauges, RGAs, purge lines, and valves

Vacuum Interfaces

<u>SNS Vacuum Requirements from:</u>

ACCELERATOR SYSTEMS DIVISION VACUUM STANDARDS HANDBOOK

SNS 102020000-ST0001-R00

- » Front End $1x10^{-4}$ to $4x10^{-7}$ Torr
- » Drift Tube Linac $1.8x10^{-7}$ Torr
- » Coupled Cavity Linac $8.9x10^{-8}$ Torr
- » Superconducting Linac $<1x10^{-9}$ Torr
- » HEBT $5x10^{-8}$ Torr
- » Ring $1x10^{-8}$ Torr
- » RTBT 10^{-7} Torr

Note: We are designing the DTL & CCL operating pressures to be half of the above values

DTL Mechanical Interfaces

Interface Description	Vacuum Design Impact
Main tank pump ports	RF shielding is required for pump port
Instrumentation ports	Spool piece must be provided with an RF shield port
RF window pump ports	RF shielding is required for pump port
Vacuum isolation valves	• Isolation valves will be pneumatic with position indicators. • Beamline valves provided between tanks where clearance is available. • Turbo cart valves provided between pump port and pump cart.
DTL RF structural components (drift tubes, post couplers, etc.)	• Seals determined by vacuum design team. • Cleaning procedures given by vacuum design team.
DTL beam diagnostic equipment	• Seals determined by vacuum design team. • Cleaning procedures given by vacuum design team • Total outgassing rate for beam diagnostic equipment in a single location will be kept below levels specified by vacuum team

Electrical Interfaces

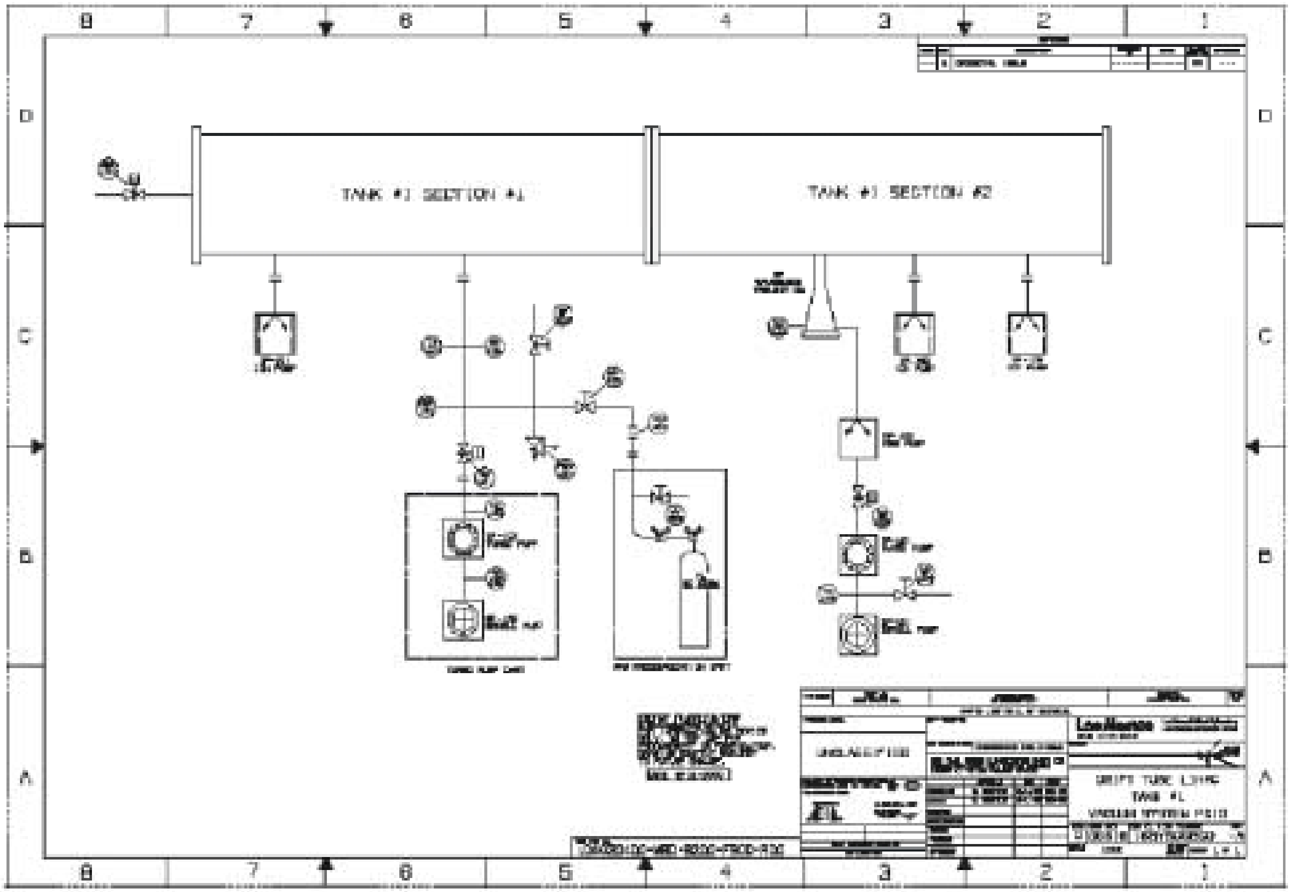
Summary of SNS building utilities required for the DTL & CCL vacuum systems.

Linac Structure	Air line pressure in tunnel for vacuum valve actuation	N_2 gas purge available in tunnel	Electrical in linac tunnel (Qty/KVA/ V/Phase)	Electrical in klystron gallery (Qty/KVA/V/Phase)
DTL	125 psia	Yes	6/2.0/120/1 (turbo cart)	6/3.0/120/1 (elec. rack)
CCL	125 psia	Yes	8/2.0/120/1 (turbo cart)	8/3.0/120/1 (elec. rack)

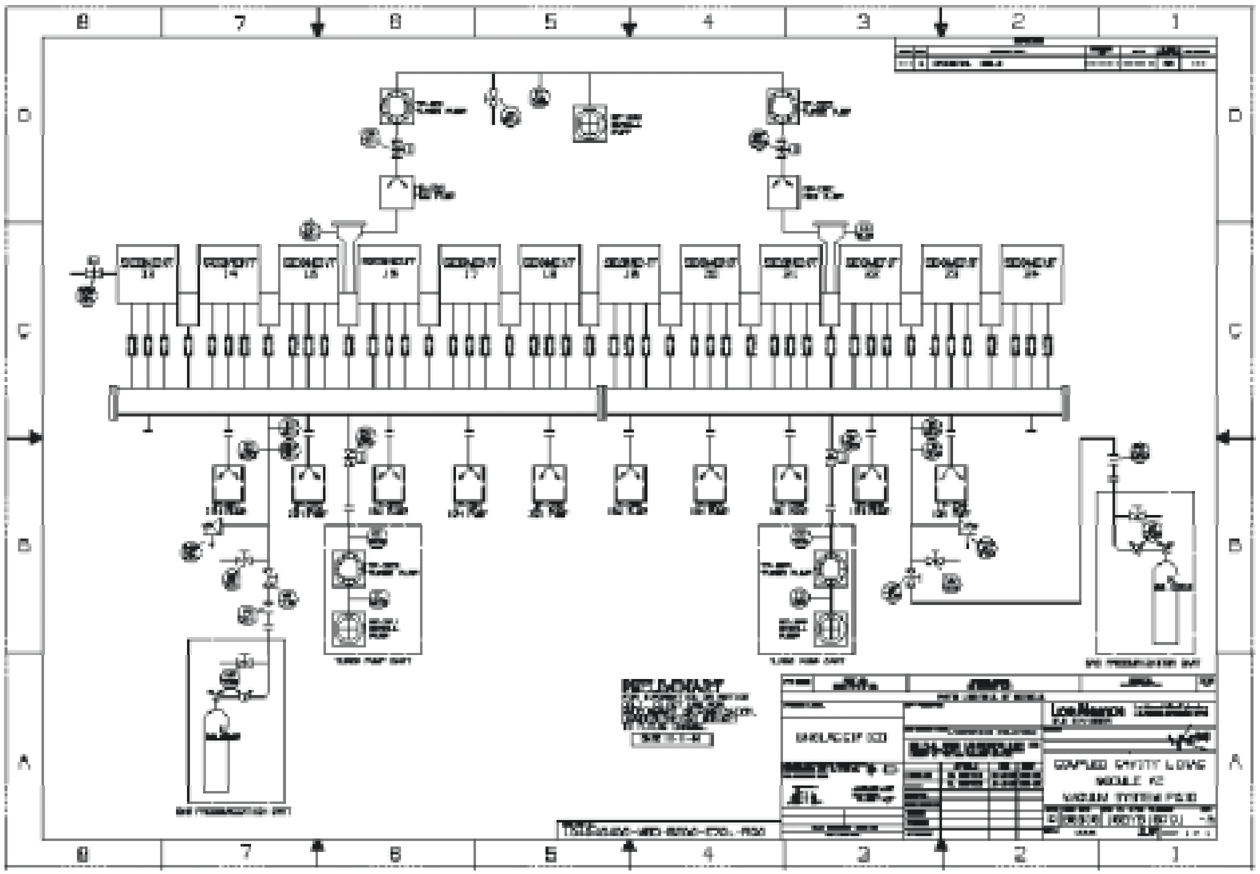
Summary of UPS requirements for the DTL & CCL vacuum systems.

Equipment	Voltage (volts)	Phase	Start-up current (Amps)	Steady-state current (Amps)
RGA	120	1	4	4
PLC & IOC	120	1	4	4
Gauge Controller	120	1	0.5	0.5

DTL Tank #1 Vacuum System



CCL Module #2 Vacuum System

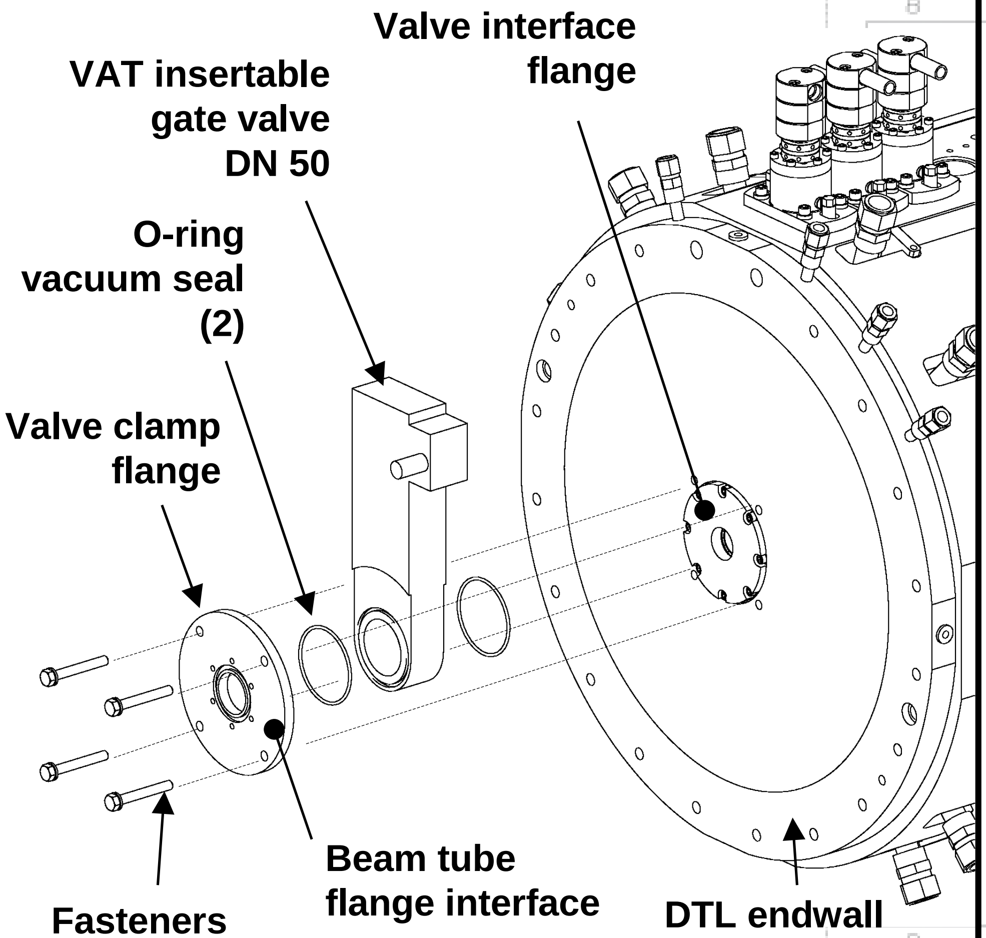


Valves

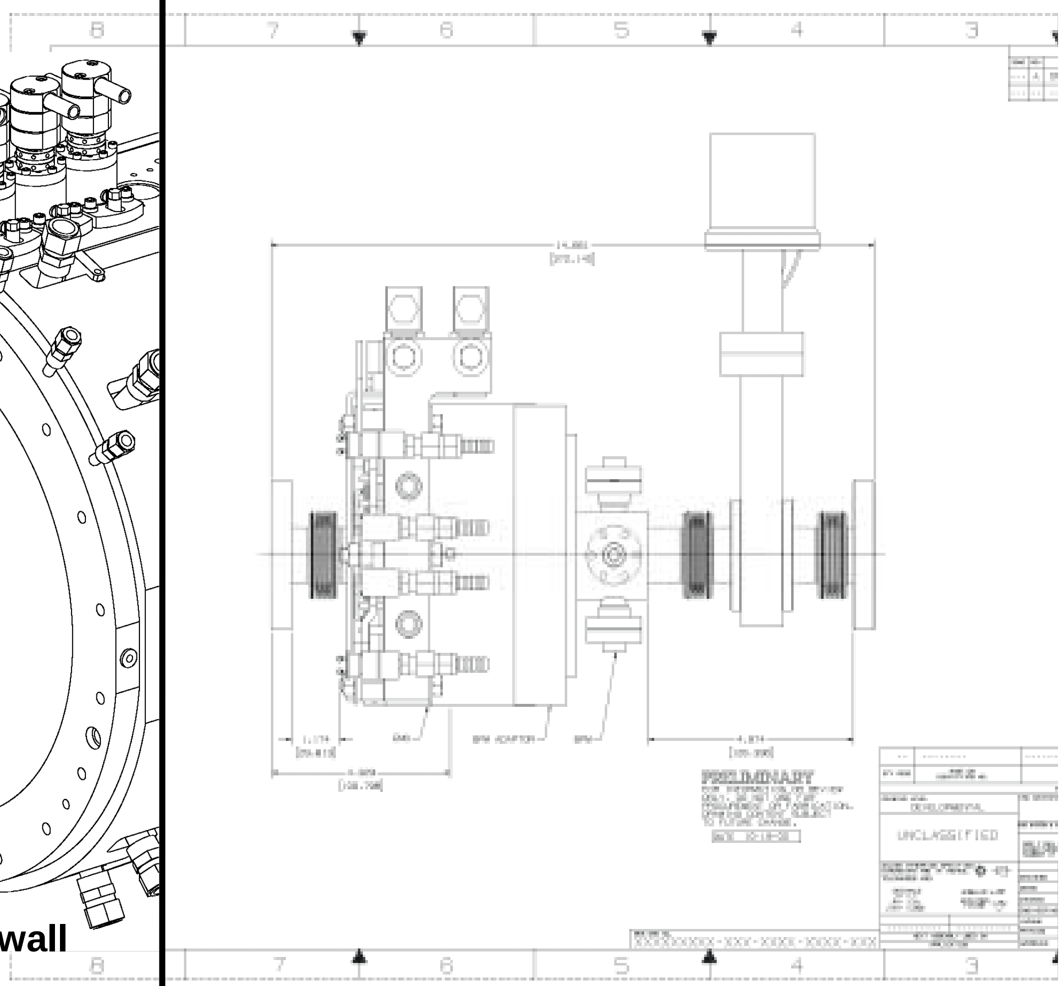
- **Beam Isolation Valves**
  - Electropneumatic (24VDC, 125 psia)
  - Valve position output signal tied into beam permit
  - Located at the ends and between each DTL tank and CCL module (exception of DTL inter-tank regions 1-2 and 2-3)
  - Fail in the closed position
- **Turbo Pump Isolation Valves**
  - Electropneumatic (24VDC, 125 psia)
  - Valve position output signal
  - Located at cart ports and between RF window NEG and turbo
  - Fail in the closed position
- **Gas Handling System**
  - Manual
  - Visual position indicator
  - Used for isolation of N_2 bottle and venting to atmoshpere

Valves - continued

DTL Beam Isolation Valve



CCL Beam Isolation Valve

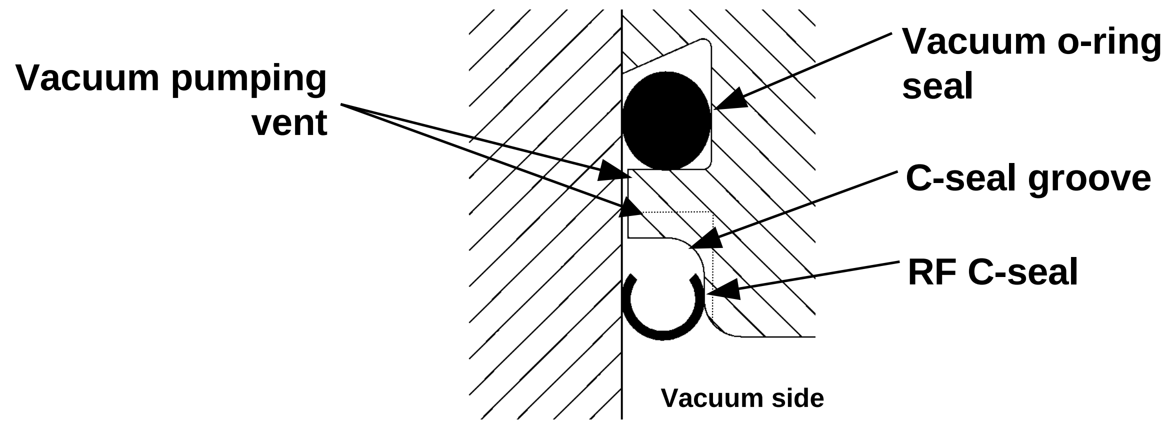


Vacuum Seals

- **Seals used for various penetrations and connections on the DTL and CCL**
- **Seal types, quantities, and gas loads defined for each DTL tank and CCL module (see FDR reports)**
- **Seal gas loads included in vacuum models**
- **Acceptable seals include**
  - Knife-edge (I.e., conflat)
  - C-seals (normal, spring, diamond)
  - O-rings (Viton, neoprene, and Buna)
- **Metal C-seals will require specific surface finishes (vendor supplied) on sealing surfaces and torque requirements**

DTL Vacuum & RF Seal Design

- **Silver plated Inconel C-seals are used at the Endwalls, Drift tube mount base, tank mating sections, slug tuners, iris waveguide, and vacuum pump spools.**
- **Multi-contact bands are used in the drift tube mounts and Post couplers.**
- **RF seal grooves are vented to vacuum seal grooves to prevent virtual leaks.**
- **RF C-seal compression load ranges from 200 lb/in to 300 lb/in.**



Typical RF and vacuum seal groove design

RF Grills

- **RF grills used to shield vacuum pumps and instrumentation from RF energy (< 50 milliWatts)**

- **Grill locations include**
  - DTL main tank pump ports
  - DTL and CCL RF window NEG pump port

- **No grills needed on CCL manifold as bellow port diameters were sufficiently small and the SCCs are not energized for the Pi/2 mode of CCL.**

- **RF attenuation formula by Morino used to design grills:**

$$\alpha_g := \left[8.69 \cdot \sqrt{\left(2 \cdot \frac{\pi}{\lambda_c}\right)^2 - \varepsilon_1 \cdot \left(2 \cdot \frac{\pi}{\lambda}\right)^2} \right] \cdot z$$

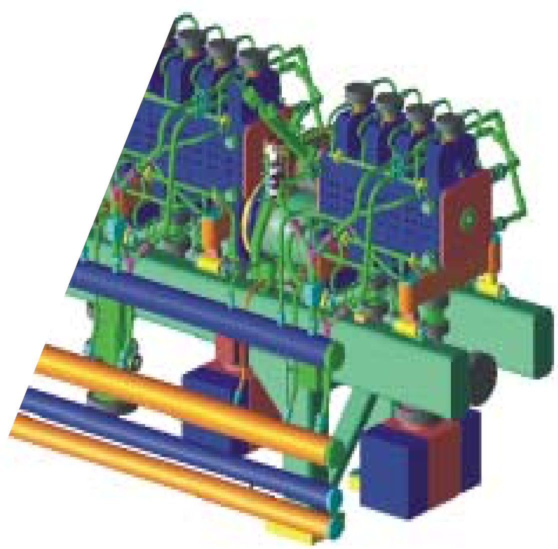
T. Morino, "Micorwave Transmission Design Data", equation 8-21, page 140

Vacuum Pumps

- **<u>Turbo-Scroll Pump Carts</u> (300 L/s)**
  - **Conditions each DTL tank and CCL module prior to ion pumps**
  - **Portable cart design to be used on all SNS vacuum systems.**
- **<u>Ion Pumps</u>** (300 L/s)
  - **Steady-state pumping of DTL tanks (3 each) and CCL modules (10 each)**
- **<u>NEG Pumps</u>** (1300 L/s)
  - **Conditioning and steady-state pumping of RF windows**
  - **Lightweight and small package**
  - **High pumping speed for hydrogen, can't pump inert gases**
  - **Must be initially activated and periodically conditioned with a small turbo pump**
  - **Successful operation on LEDA**
- **Turbo-Scroll Pump Station** (70 L/s)
  - **For backing and conditioning NEG pump**

Vacuum Pumps - continued

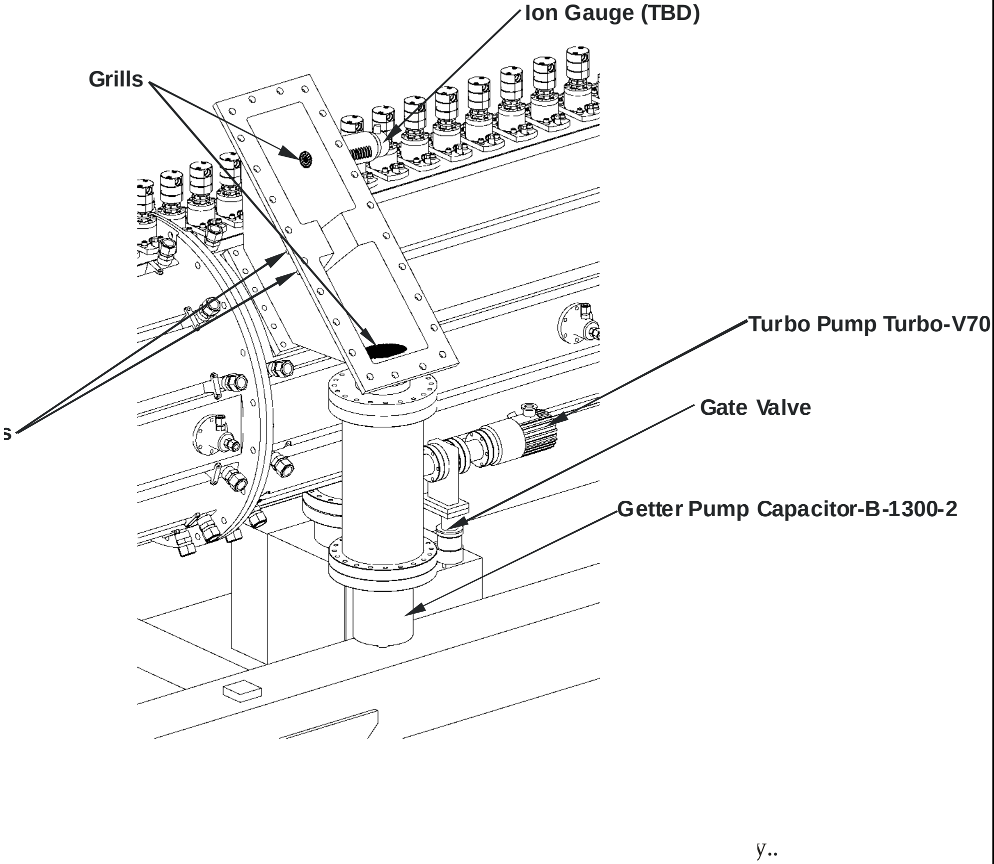
Ion Pumps



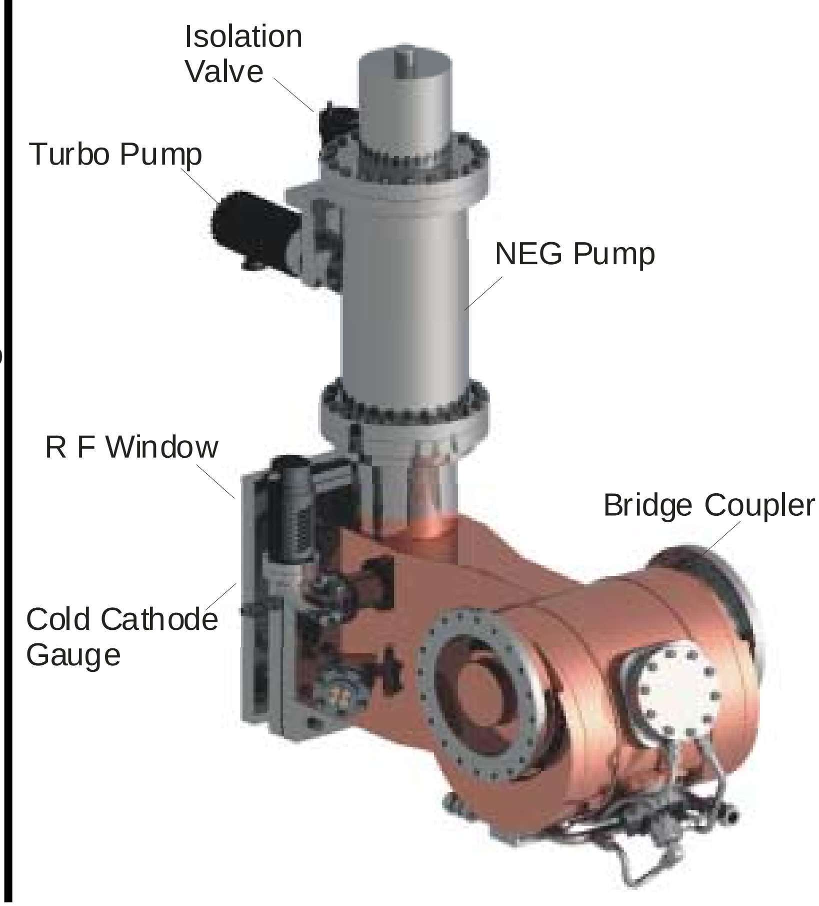
Turbo Cart

Vacuum Pumps - continued

DTL RF Window Pumping Assembly



CCL RF Window Pumping Assembly



Instrumentation

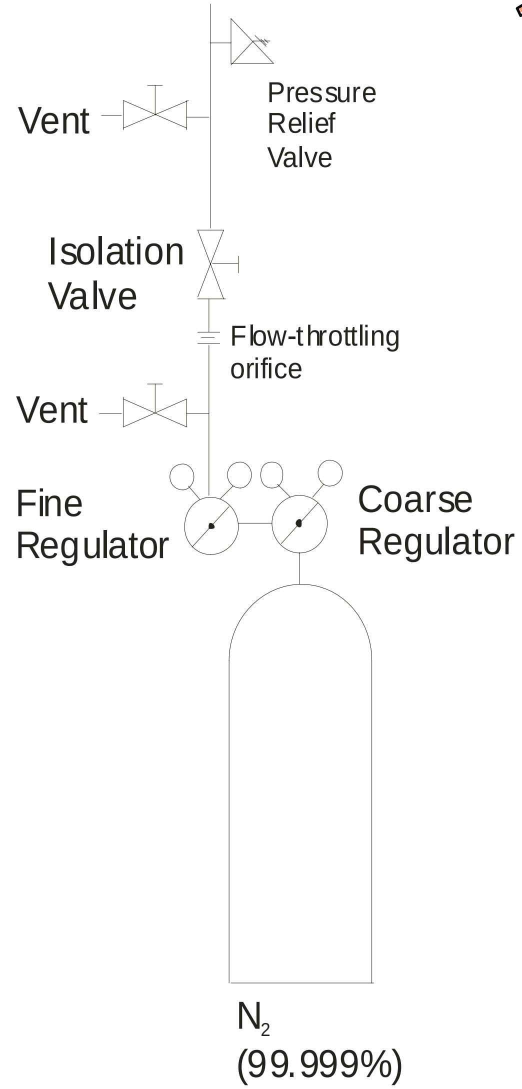
- **Convectron Gauge**
  - Measure low vacuum from atmospheric pressure to approx. 0.001 Torr
  - One gauge on each DTL tank, one on each CCL manifold half, one between each turbo and scroll pump
- **Cold Cathode Gauge**
  - Measure high vacuum from 10^{-3} to 10^{-9} Torr
  - No particulate generation - good for SCL
  - 50% accuracy is much worse than an ion gauge (10% or better)
  - Safety interlock for RF power and beam permit
  - One gauge on each DTL tank, one on each CCL manifold half, one on each RF window
- **Residual Gas Analyzer**
  - Measures partial pressures of gas species (1-100 AMU)
  - Diagnostic tool for leak checking and system performance
  - Controls remotely mounted in electronics rack
  - One per DTL tank and one per CCL module

Controls

- **One independent control system per DTL tank and CCL module**
- **Operational Modes**
  - Local Control Mode (touchscreen interface) for assembly and installation check-out, trouble shooting, maintenance, etc.
  - Global Control Mode (EPICS terminal) for steady-state operation
- **Control System Architecture**
  - Allen Bradley ControlLogix PLC - SNS Standard
  - Allen Bradley touchscreen interface
  - Vacuum pump and instrumentation controllers
  - Portable laptop computer
  - APW Electronics Rack - SNS Standard
- **All signals sent to local PLC and on to global controls IOC with the exception of rapid time response signals needed for RF & beam permit**

Gas Pressurization & Relief

- Portable clean gas (99.999% N_2) system for bringing Linac up to atm. pressure for maintenance.
- Dual gas regulators on N2 bottle to step down pressure.
- Pressure relief valves (1-2 psig) to prevent overpressurization of DTL and CCL. Safety factor of 25.
- Flow-throttling orifice to keep gas flow less than dissipation rate of relief valve.
- Fill time of DTL tank < 5 minutes.
- Manual atmospheric vent valves for safety.



Vacuum System Analyses

Final Design Review

LANL

January 19, 2001

Presented By

Stewart Shen &

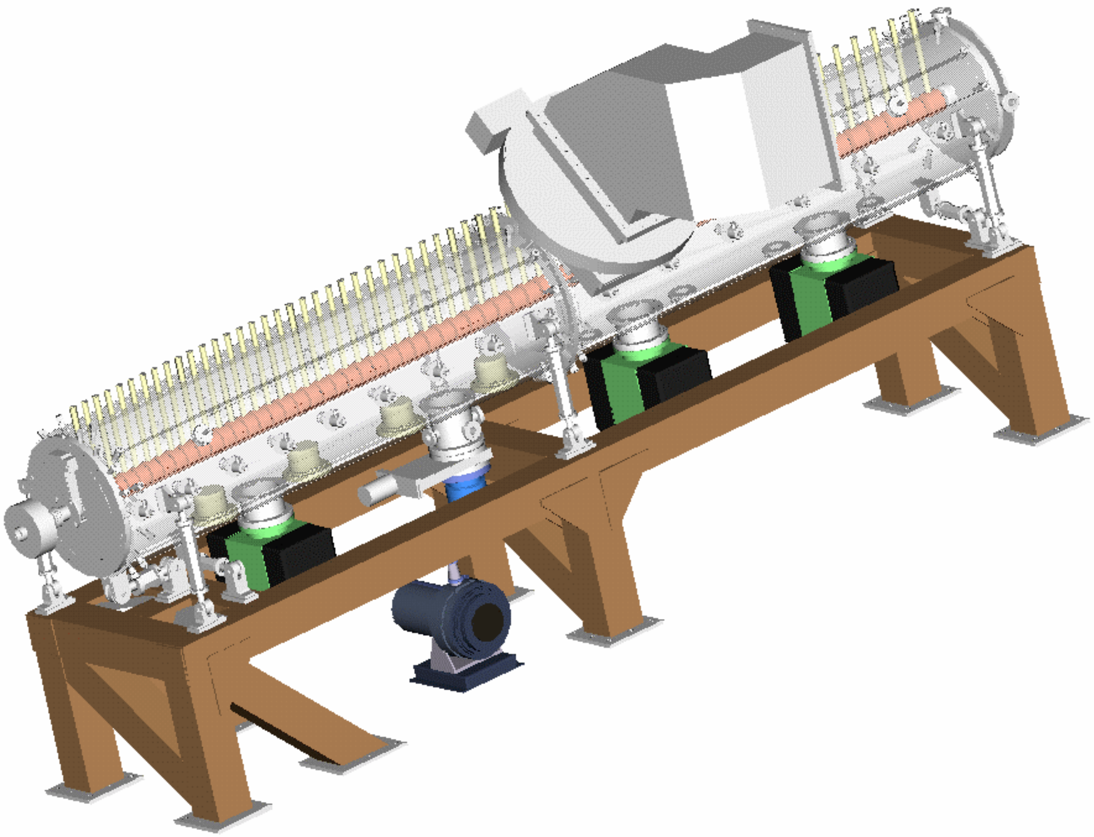
LLNL/ATEG Design Team

Vacuum Design Requirements for SNS DTL

Parameter		Requirements / Value
Surface Outgassing Rates		• x 10^{-10} Torr-L/sec/cm^2 (at 100 hrs: post-cond.) 2.5 x 10^{-9} Torr-L/sec/cm^2 (at 100 hrs: pre-cond.)
Drift tube bore pressure • Post - rf conditioned • Normal mode of operation: all ion pumps functioning	Design Required	9.2 x 10^{-8} Torr (avg.) for mixed gases < 1.84 x 10^{-7} Torr for mixed gases
Drift tube bore pressure • Post - rf conditioned • Failure mode of operation: all but 1 ion pump functioning	Design Required	1.84 x 10^{-7} Torr (avg.) for mixed gases < 1.84 x 10^{-7} Torr for mixed gases

System requirements specified by SNS and Design Values for all 6 DTL Tanks

SNS/DTL Pumping System



SNS/DTL Vacuum System Design Features

- **Design Considerations**

  All outgassing are taken into account:

  Metal Surfaces
  Seals
  All components & penetrations

- **High-Vacuum Pumping Scheme**

  Directly-mounted IPs

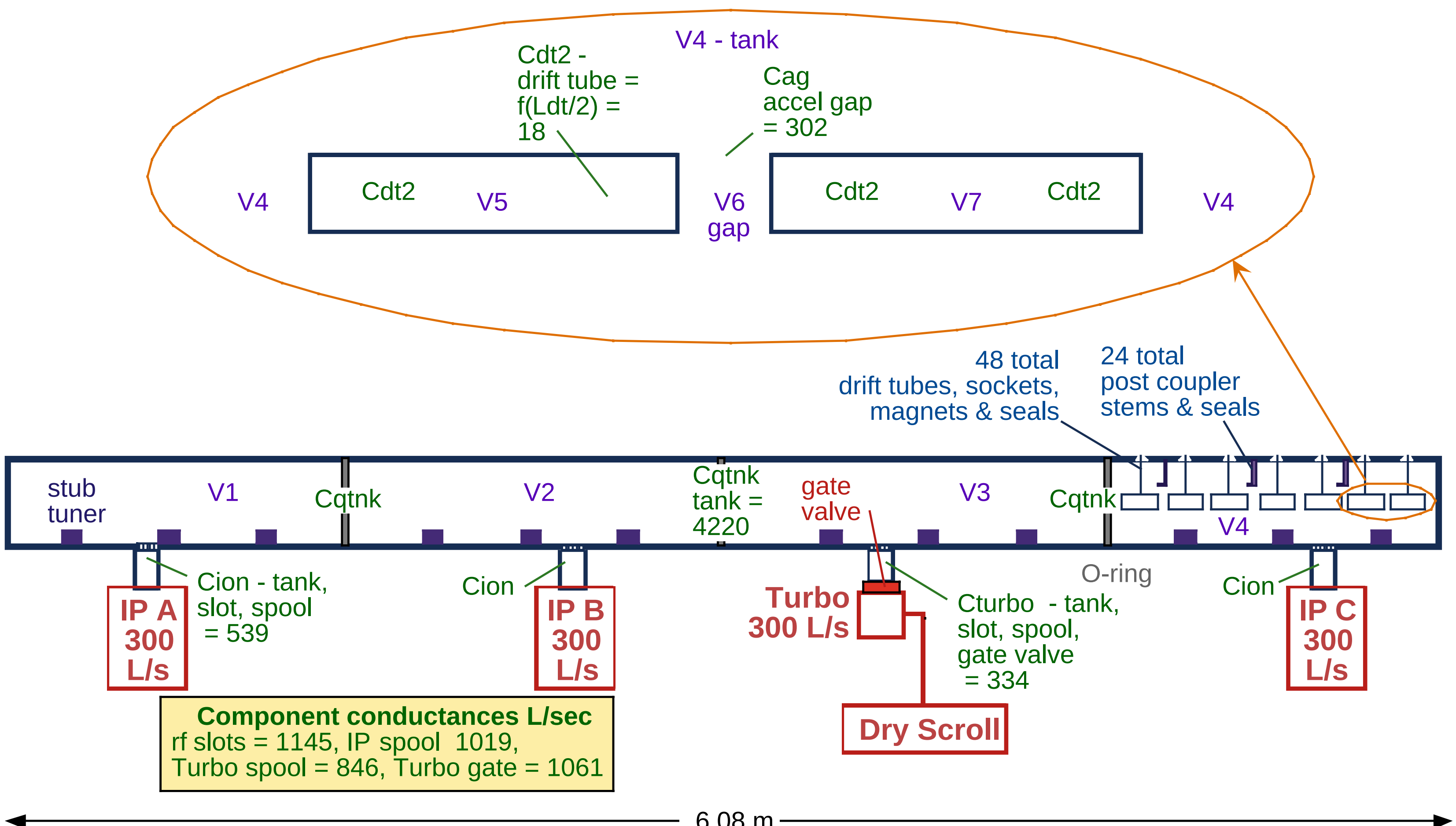
- **Meets the design goals:**

  - **by 2X during normal operation (3 IPs)**
  - ***by 1X during failure mode (2 IPs)***

System Descriptions

DRIFT TUBE LINAC
Tank 1: Copper-plated, 422 cm long, 43-cm ID: Tanks 2-6: Copper-plated, 608 cm long, 43-cm ID
Tank 1: 60 sockets, drift tubes, and drift tube stems and 30 post-couplers Tanks 2 to 6: 48 to 22 sockets, drift tubes, and drift tube stems, and 24 to 11 post-couplers Tanks 1-6: 12 copper slug tuners, 5 - 43-cm diameter O-rings, and 250 various small O-rings
Stainless steel spool pieces for turbo and ion pumps
PUMPING SYSTEM FOR EACH OF 6 TANKS
One Varian PTS 300 dry scroll roughing pump (5 L/s nominal)
One Varian V300HT turbo pump (300 L/s nominal)
Three Physical Electronics Captorr 300 L/s conventional ion pumps
One 6-inch gate valve for turbo pump
DETAILED SYSTEM PARAMETERS FOR TANK 2
Total copper surface area (tank and internal components) = 123,695 cm^2
Total stainless steel surface area (pump spools) = 3310 cm^2
Total volume = 857 L
Total post-conditioned surface outgassing rate = 4.0×10^{-5} Torr-L/sec
Total seal permeability & outgassing rate = 2.1×10^{-5} Torr-L/sec (53% of post-conditioned total)
Magnet outgassing rate inside of each drift tube = 1.25×10^{-7} Torr-L/sec assumes all drift tubes have a 1.785 inch long permanent magnet
Peak pressure after conditioning and pumping air with 3 ion pumps (normal mode) = 8.0×10^{-8} Torr
Peak pressure after conditioning and pumping air with 2 ion pumps (failure mode) = 1.1×10^{-7} Torr

SNS/DTL Tank 2 layout for volumes and conductances



Features of Numerical Model

- Pressure solved for N sub-volumes
- Solves entire pumpdown history
- Separate time-dependent outgassing rates for pre- and post-conditioned surfaces
- Pressure-dependent pump speeds
- Automatic pump distribution and gate valve selection for parametric studies
- Flag for N_2 or Other gases that changes pump speeds and conductances
- Written with Mathematica and runs on a 266 MHz Power Mac G3 in 20 sec for N = 7 (DTL) up to 2.5 min for N = 82 (CCL)

Pressure history is found at each sub-volume for 100 hours

Model solves for pressure with N coupled differential equations during four times:

- roughing phase to 0.05 Torr for 30 min
- turbo pumping to below 10^{-5} Torr for 10 hours
- ion pumping to base pressure for 89.5 hours
- ion pump fails / turbo on to study transients

GAS LOAD BALANCE

$V_n \, dP_n/dt = \Sigma\, Q_{in} - \Sigma\, Q_{out}$ [Torr-L/sec] for n = 1,N

where Q_{in} = leakage and time-dependent outgassing into volume n

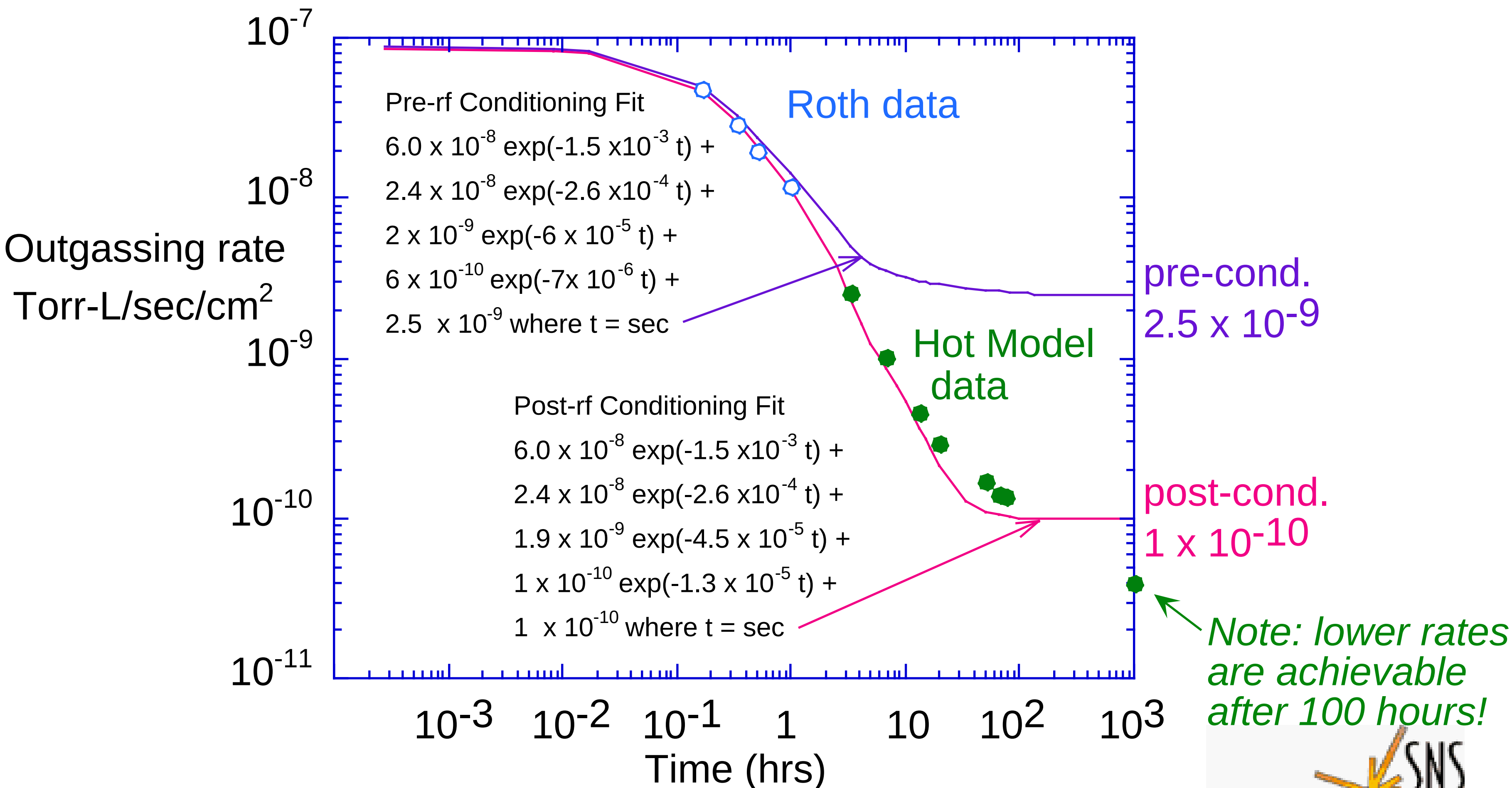
$Q_{out} = C_{nm} (P_n - P_m)$ where m is an adjacent volume

or $Q_{out} = S_p(P_n)\, P_n$

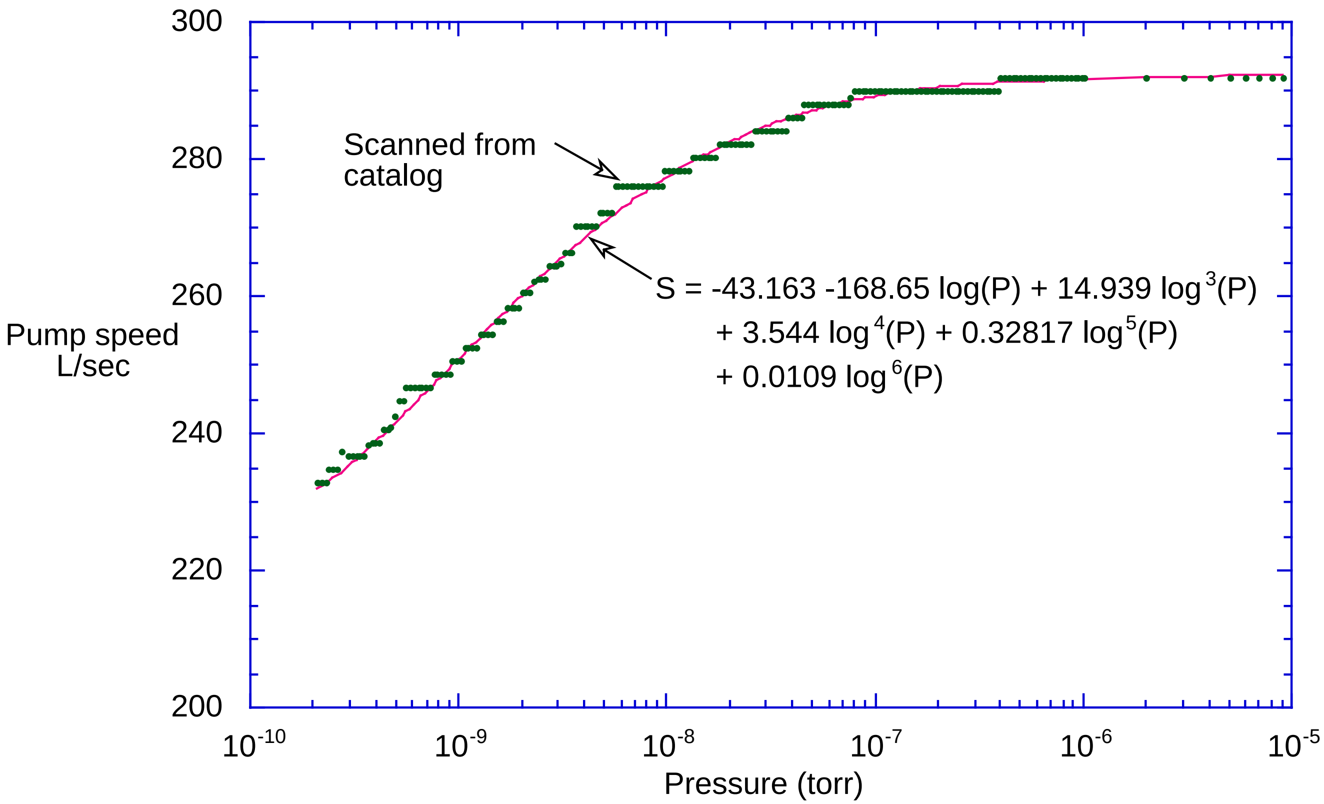
where S_p is pressure-dependent pump speed

Model includes two time-dependent outgassing rates for pre- and post-conditioned surfaces

Rates based on early data from Roth, from APT Hot Model tests, and final rates specified by SNS management



Model includes Gas and Pressure-Dependent Pump Speeds For All Gases - Example



Dependence of pump speed on pressure for a PHI 300 Captorr conventional ion pump. The data was scanned from the vendor catalog and a numerical expression was fit to the data and used in the model.

SNS/DTL- Tank2 Seals and Penetrations

DTL tank 2

Design of seals and penetrations

Locations	Seal Type	Quantities	Seal Material	Nom. Seal dia (in)	Nom. seal size (in)	Nom. Seal dia (cm)	Nom. seal size (cm)	Nom. Comments
Endwalls	Vacuum	4	Viton	18.00	0.188	45.720	0.476	Includes tank section interface
Endwalls	RF	4	silver plated inconel	17.30	0.250	43.942	0.635	Includes tank section interface
Drift tube tank interface	RF / vacuum	48	silver plated inconel	1.44	0.125	3.658	0.318	Combination RF and vacuum seal
Drift tube stem interface	Vacuum	48	silver plated inconel	1.38	0.063	3.493	0.159	
Drift tube lock screw	Vacuum	48	silver plated inconel	0.28	0.063	0.719	0.159	
Post couplers	RF	24	silver plated inconel	1.50	0.125	3.810	0.318	
Post couplers	Vacuum	24	Viton	1.75	0.125	4.445	0.318	
Slug tuners	Vacuum	12	Viton	5.75	0.125	14.605	0.318	
Slug tuners	RF	12	silver plated inconel	4.63	0.125	11.748	0.318	
vacuum spool tank interface	Vacuum	4	Viton	6.25	0.125	15.875	0.318	
vacuum spool tank interface	RF	4	silver plated inconel	6.19	0.188	15.723	0.476	
6" gate valve / turbo pump	Vacuum	1	copper- conflat type	6.00	0.250	15.240	0.635	Nom. 8" conflat flange
vacuum spool pump interface	Vacuum	4	copper- conflat type	6.00	0.250	15.240	0.635	Nom. 8" conflat flange
Iris waveguide tank interface	Vacuum	1	Viton	19.25	0.125	Not a diameter	0.318	Rectangular shaped o-ring
Iris waveguide tank interface	RF	2	silver plated inconel	6.75	0.125	Not a diameter	0.318	Straight seal
Waveguide window	RF / vacuum	1	alum	55.00	0.157	Not a diameter	0.399	Rectangular shaped seal
Vat series 08 gate valve	Vacuum	2	Viton	3.50	0.125	8.890	0.318	Used on beamline axis
Endwall to gate valve	Vacuum	1	Viton	3.00	0.125	7.620	0.318	

Locations	Seals have a 0.5 multiplier	Surface area in cm^2	Outgas rate Torr-l/sec-cm^2	Leak Rate Torr-l/sec-mm	Outgas Load Torr-l/sec	Leak Load Torr-l/sec	Total Outgas and Leak Load Torr-l/s
Endwalls	0.500	0.000	1.14E-08	1.04E-10	0.00E+00	0.000E+00	0.000E+00
Endwalls	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	0.000E+00	0.000E+00
Drift tube tank interface	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	0.000E+00	0.000E+00
Drift tube stem interface	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	0.000E+00	0.000E+00
Drift tube lock screw	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	0.000E+00	0.000E+00
Post couplers	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	0.000E+00	0.000E+00
Post couplers	0.500	0.000	1.14E-08	1.04E-10	0.00E+00	0.000E+00	0.000E+00
Slug tuners	0.500	0.000	1.14E-08	1.04E-10	0.00E+00	0.000E+00	0.000E+00
Slug tuners	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	0.000E+00	0.000E+00
vacuum spool tank interface	0.500	0.000	1.14E-08	1.04E-10	0.00E+00	0.000E+00	0.000E+00
vacuum spool tank interface	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	0.000E+00	0.000E+00
6" gate valve / turbo pump	0.500	0.000	1.26E-09	0.00E+00	0.00E+00	0.000E+00	0.000E+00
vacuum spool pump interface	0.500	0.000	1.26E-09	0.00E+00	0.00E+00	0.000E+00	0.000E+00
Iris waveguide tank interface	0.500	0.000	1.14E-08	1.04E-10	0.00E+00	5.085E-08	5.085E-08
Iris waveguide tank interface	0.500	0.000	5.00E-10	3.70E-10	0.00E+00	6.344E-08	1.269E-07
Waveguide window	0.500	0.000	6.00E-10	2.00E-08	0.00E+00	2.794E-05	2.794E-05
Vat series 08 gate valve	0.500	0.000	1.14E-08	1.04E-10	0.00E+00	0.000E+00	0.000E+00
Endwall to gate valve	0.500	0.000	1.14E-08	1.04E-10	0.00E+00	0.000E+00	0.000E+00
							2.812E-05

Beam Diagnostics	Quantity	
BPM	2	4.680E-08
Toroid	1	1.180E-06
Wire Scanner	0	0.000E+00
Faraday cup	0	0.000E+00
Harp	1	2.040E-07
		1.431E-06

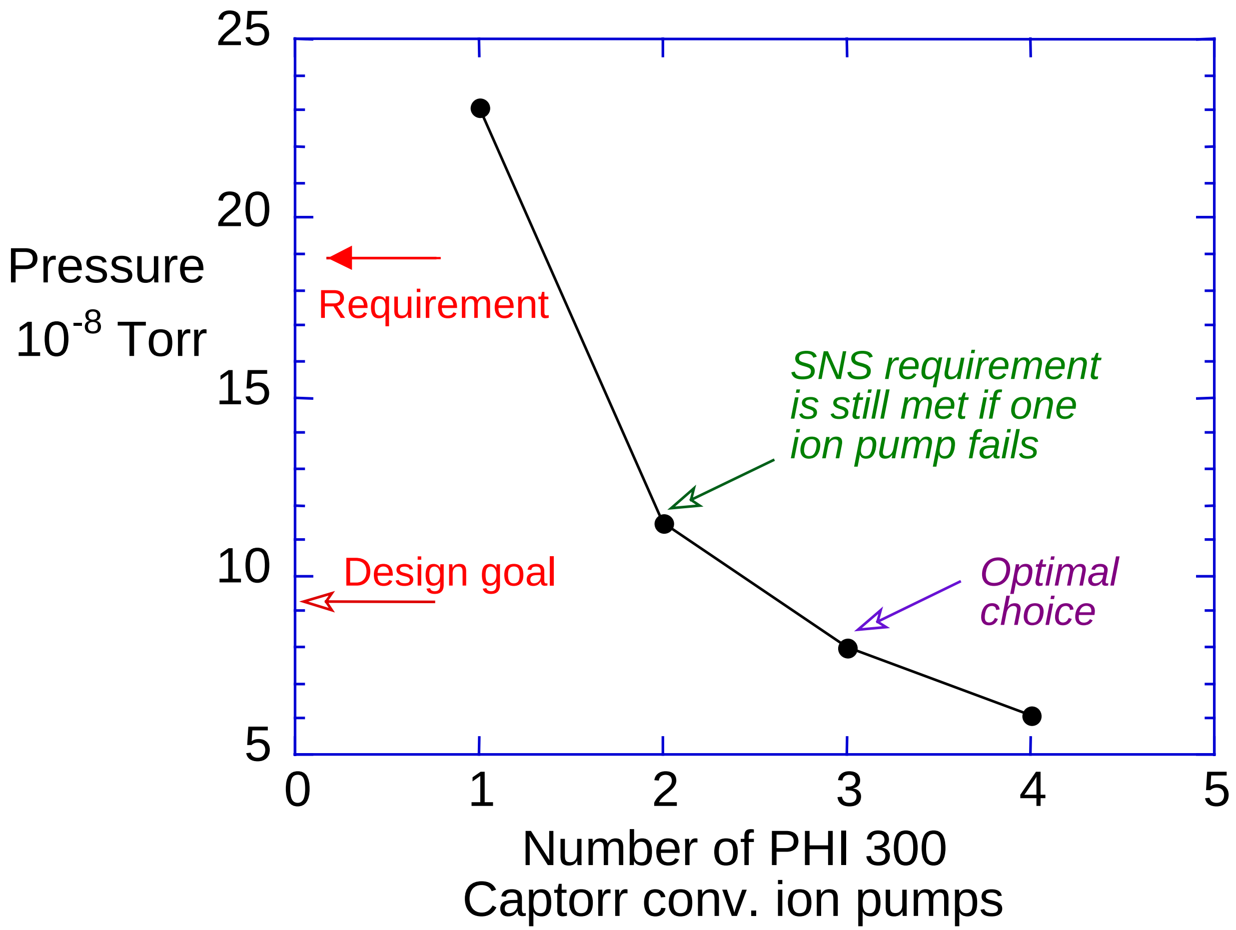
SNS/DTL- Parameter Summary of Tank 2

Sub-volume Location in Layout = Component	Area (cm^2)	Volume (lit)	Conductance (lit/se
Tank quadrant	20,546	221	4220
Socket total (48 total)	6,872	2.93	
Drift tube total (48 total using longest tube)	17,856	24.4	
Drift tube stems total (46 total)	7,508	3.07	
Post coupler total (24 total)	1,488	0.46	
Slug tuner total (12 total)	4,711	12.4	
V1 – net first quadrant	32,248	213.5	
V2 – net second quadrant	30,796	213.5	
V3 – net third quadrant	31,713	216.5	
V4 – net fourth quadrant	32,248	213.5	
V5,V7 = Test drift tubes	99	0.06	
V6 = gap between V5 and V7	0	0.02	
Ion pump spool each (3 total)	598	2.17	1020
Turbo pump spool (1 total)	896	3.24	846
Turbo gate valve (1 total)	619	2.29	1061
Total copper	123,695		
Total stainless steel	3,310		
Total	127,005	857.5	
Total seal leak+outgassing rate = 2.1 x 10^{-5} Torr-L/sec (54% of total)			
Total magnet outgassing rate = 6.0 x 10^{-6} Torr-L/sec over a total length of 218 cm (15% of total)			
Total final gas load = 4.03 x 10^{-5} Torr-L/sec			

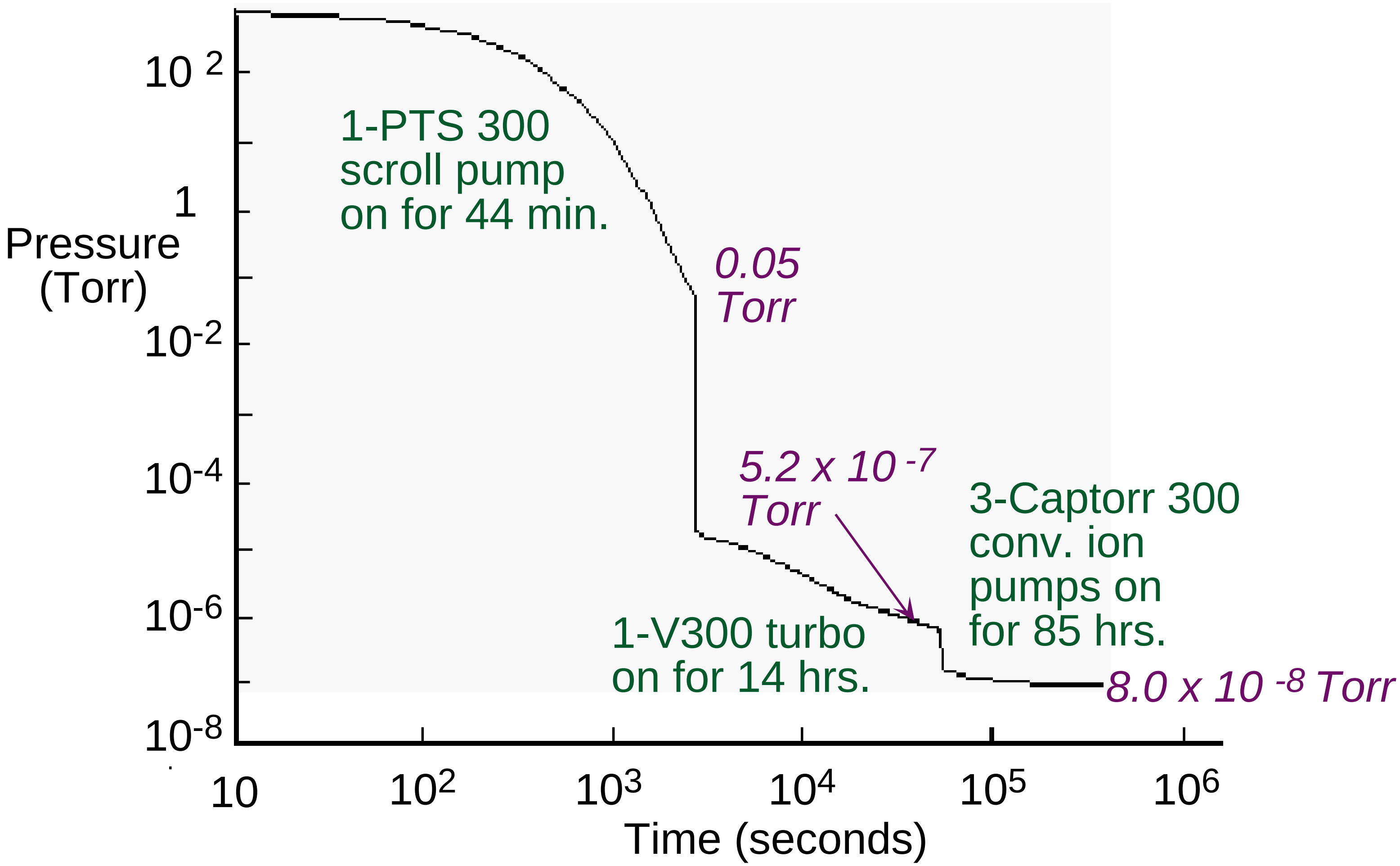
Cslot, rf slot area between tank and pump spools	1146
Cdt, drift tube	18
Cag, one accel gap	302
Cturbo = slot, spool, gate valve, quarter tank	334
Cion = slot, spool, quarter tank	539

TABLE. 3.5. Volumes, areas, outgassing rates and conductances for each component in the DTL Tank 2 numerical model. (Conductance values in molecular flow are listed.)

SNS/DTL- 3 ion Pumps Achieve Design Goal



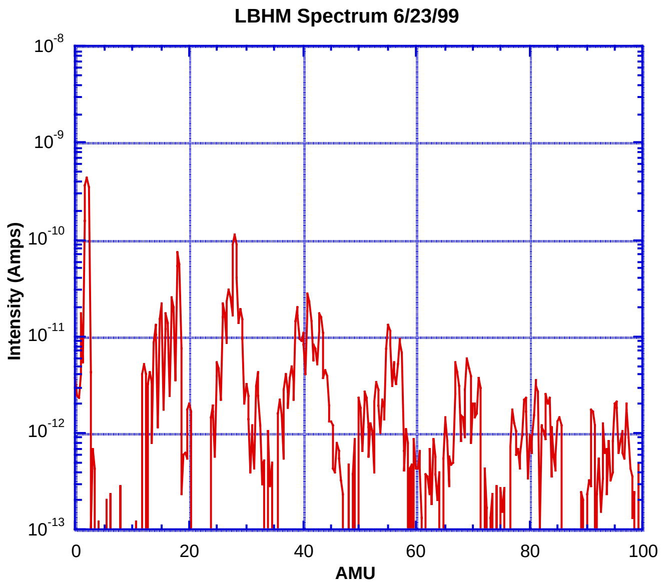
SNS/DTL- Pressure History

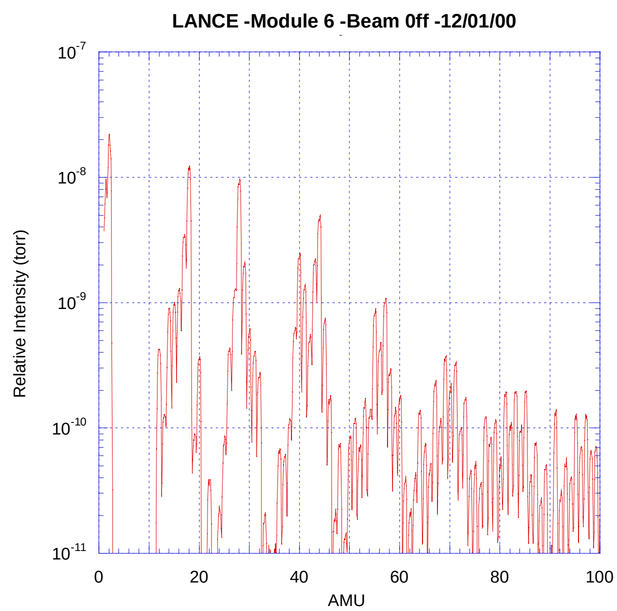


SNS/DTL- Mixed-Gas Analysis

TABLE 3.6. Measured gas mixes in APT/LEDA hot model, assumed gas mix for numerical model, proton scattering weighting factors.

Gas	AMU	APT/LEDA Hot Model Gas Species Data % Of Composition [%]	Assumed DTL Model Gas Composition, C [%]	Proton Scattering Weighting Factor, W (See Section 1.4)	W×C/100
H_2	2.02	18	20	0.15	0.03
CH_4	16.03	3	-	-	-
H_2O	18.02	20	20	0.66	0.13
N_2	28.02	49	50	1.0	0.50
CO_2	44.01	7	10	1.5	0.15





SNS/DTL- Mixed-Gas Analysis

Gas (amu)	Drift Tube Pressure P (10^{-8} Torr) with 100% Gas P_{gas}	Partial Pressures (10^{-8} Torr) $P_{avg} = P * C$	Weighted Partial Pressures (10^{-8} Torr) $[P] = P_{gas} * C * W$
H_2 2.016	3.04	0.61	0.09
H_20 18.016	7.32	1.46	0.97
N_2 28.02	**8.78**	4.39	4.39
CO_2 44.01	8.78	0.88	1.32
air 28.98	**8.02**		
TOTAL Composite		**7.34**	**6.76**

TABLE. 3.7. Model results for each gas and their partial and weighted partial pressures.

SNS/DTL-Conclusions

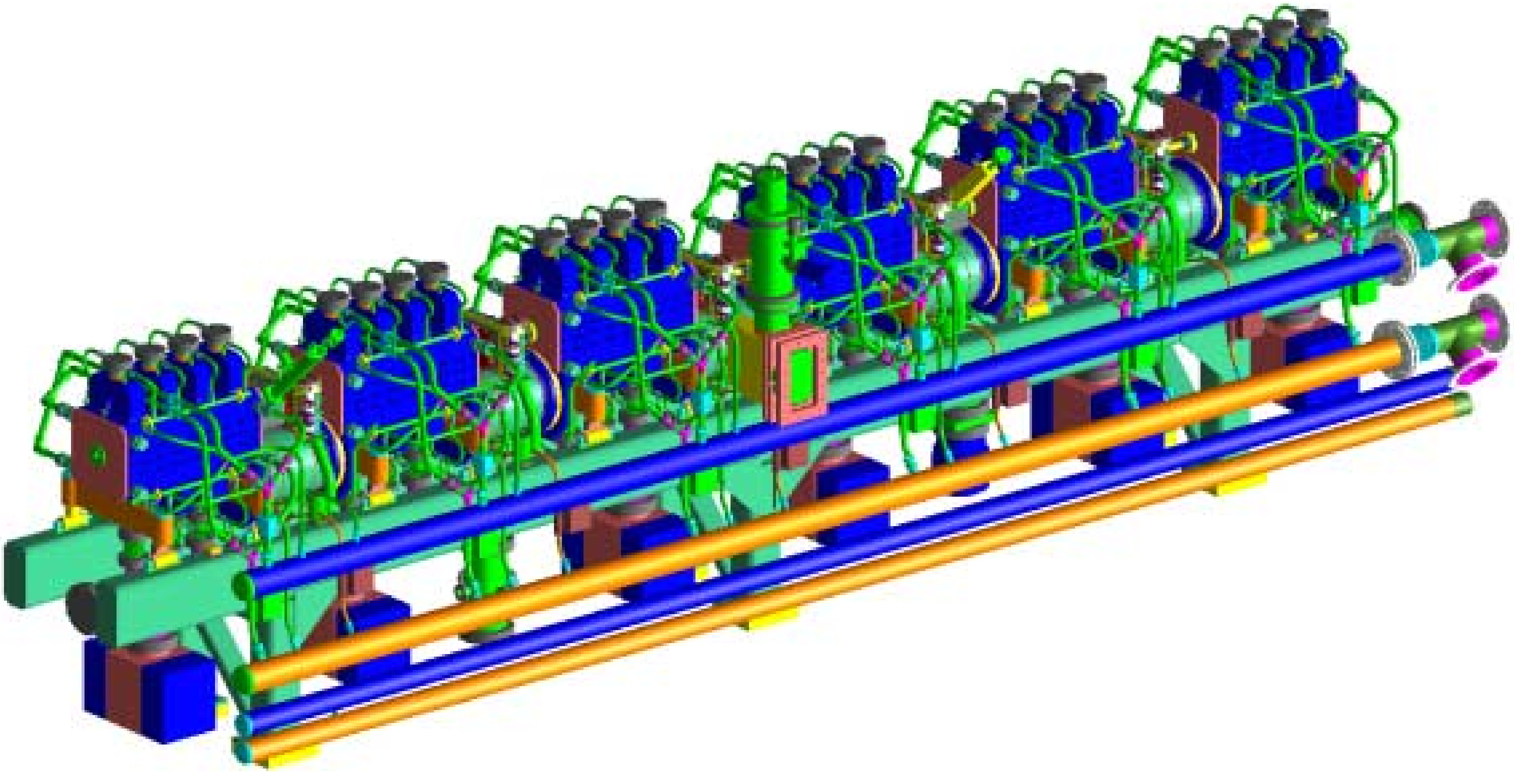
Design Function	FDR Modeling Results
Vacuum Level - Air	Sufficiently provided for drift tube (average pressure of $8x10^{-8}$ Torr.) with comfortable margins of factor 2.
Vacuum Level – Other Gases	Satisfactory results for mixed gases with H_2, H_2O, N_2 and CO_2.
Pump Selection	Practical and economical
Roughing Function	Less than 1 hour (44 minutes)
Turbo Conditioning	14 Hours
Ion Pump Operation	Reaching $8x10^{-8}$ Torr in 85 Hours
Gauging Calibration	Cold Cathode gauge at the tank spool reads 6% lower than the drift tube pressure.

Vacuum Design Requirements for SNS CCL

Parameter		Requirements / Value
Pumping to overcome system outgassing		1.0×10^{-10} Torr-L/sec/cm^2 for SS and Cu (at 100 hrs: post-cond.) 2.5×10^{-9} Torr-L/sec/cm^2 for all (at 100 hrs: pre-cond.)
Beamline pressure Post - rf conditioned Normal: all ion pumps on	***Design*** ***Required***	8.9×10^{-8} Torr (avg.) for mixed gases $< 4.4 \times 10^{-8}$ Torr for mixed gases
Beamline pressure Post - rf conditioned Failure : all but 1 ion pump on	***Design*** ***Required***	8.9×10^{-8} Torr (avg.) for mixed gases $< 8.9 \times 10^{-8}$ Torr for mixed gases

CCL Vacuum System Requirements and Values specified by SNS for beam energies between 87 and 185 MeV.

SNS/CCL Vacuum Pumping System



SNS/CCL Vacuum System Design Features

- **Design Considerations**

  All outgassing are taken into account:

  Metal Surfaces
  Seals
  All components and penetrations

- **High-Vacuum Pumping Scheme**

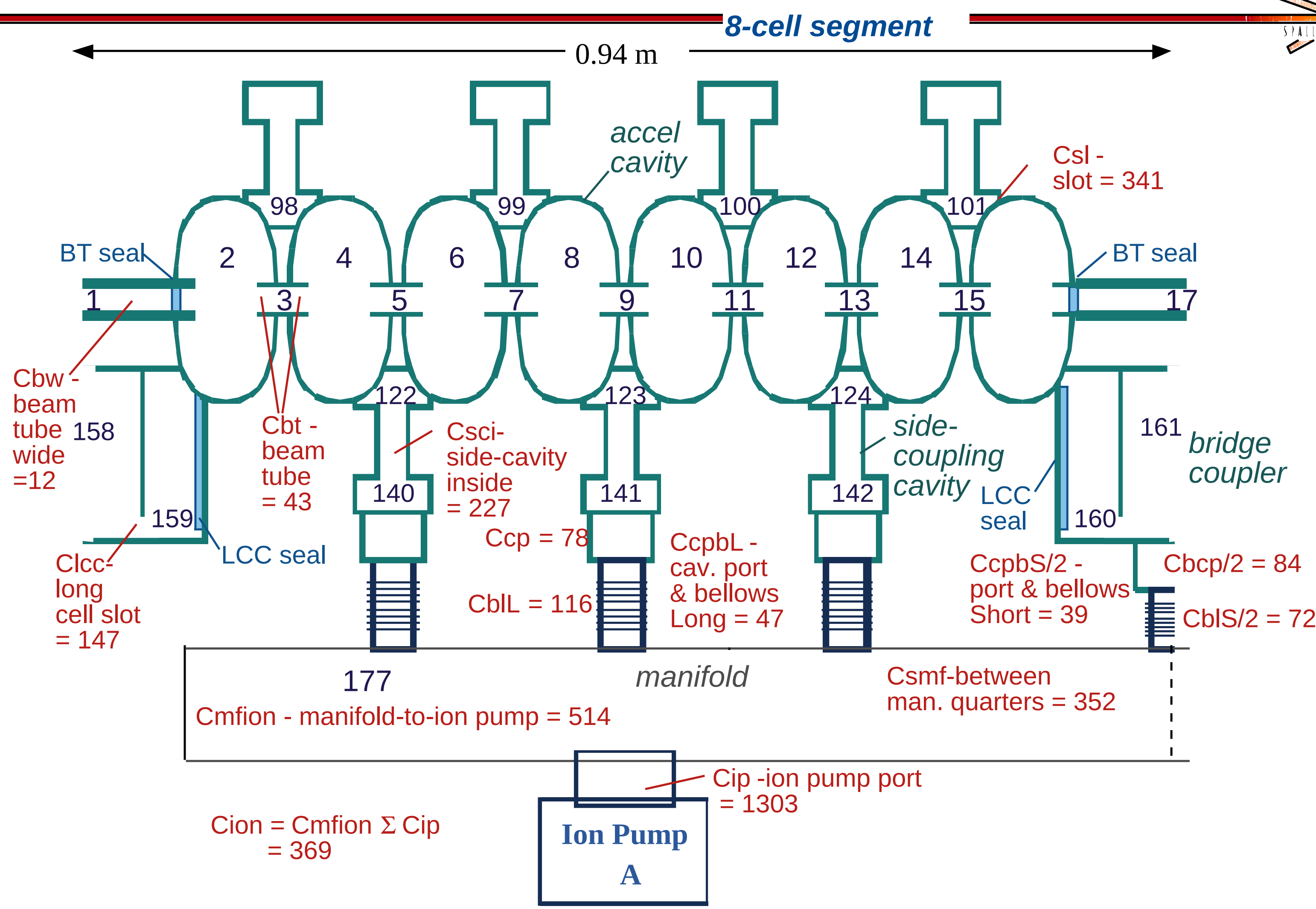
  Manifolding with IPs

- **Meets the design goals:**
  - **by 2X during normal operation (5 IPs)**
  - ***by 1X during failure mode (4 IPs)***

SNS/CCL Vacuum System Design – Module 1

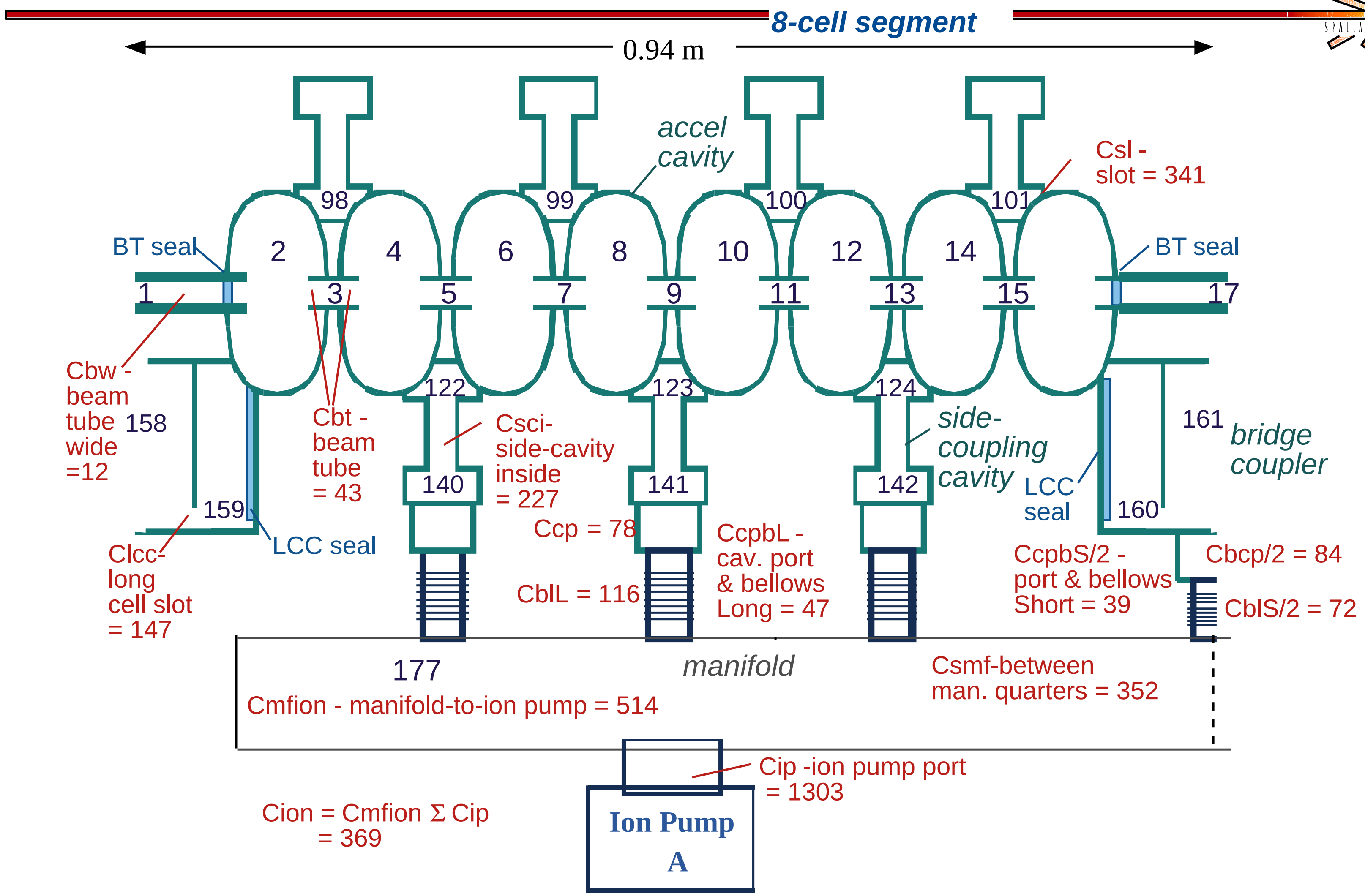
CCL Module 1
OFE Copper, hydrogen brazed - 11.3 m
8 cells/segment, 12 segments
Two stainless steel manifolds attached to 2 pump carts (1 roughing and 1 turbo pump) and 10 ion pumps
Pumping system per manifold (5.63 meters)
One PTS 300 dry scroll roughing pump (5 L/s nominal)
One V300 turbo pump (300 L/s nominal)
Five Physical Electronics Captorr 300 conventional ion pumps (300 L/s nominal)
One 6-inch gate valve for turbo pump
Detailed system parameters for one manifold
Total copper surface area = 159,918 cm^2
Total stainless steel surface area (manifold) = 40,457 cm^2
Total volume = 531 L
Total final gas load = 1.8 $x10^{-5}$ Torr-L/sec (assumes Cu outgassing rate for Cu of 8 x 10^{-11} Torr-L/s/cm^2 and for stainless steel of 1 x 10^{-10} Torr-L/s/cm^2
Total seal leak and outgassing rate = 8.7 x 10^{-7} Torr-L/sec (5% of total gas load)
Average beamline pressure after pumping air with 5 ion pumps (normal mode) = 4.04 x 10^{-8} Torr
Average beamline pressure after pumping air with 4 ion pumps (failure mode) = 5.00 x 10^{-8} Torr

SNS/CCL Model Layout - Volume & Conductance – Module 1



. **Layout of 1st of 6 segments of sub-volumes and conductances in the model of the SNS/CCL**

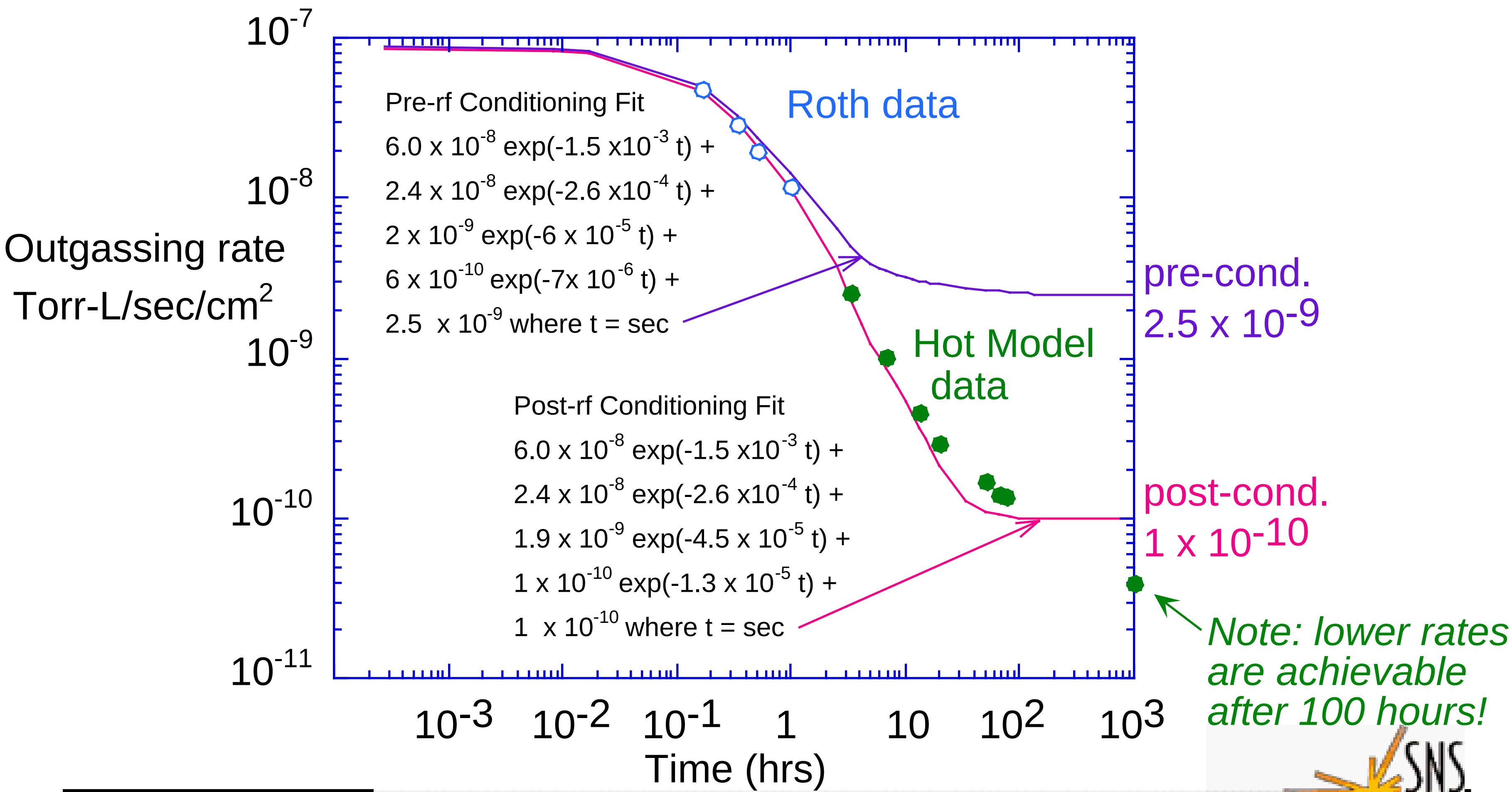
SNS/CCL Model Layout - Volume & Conductance – Module 1



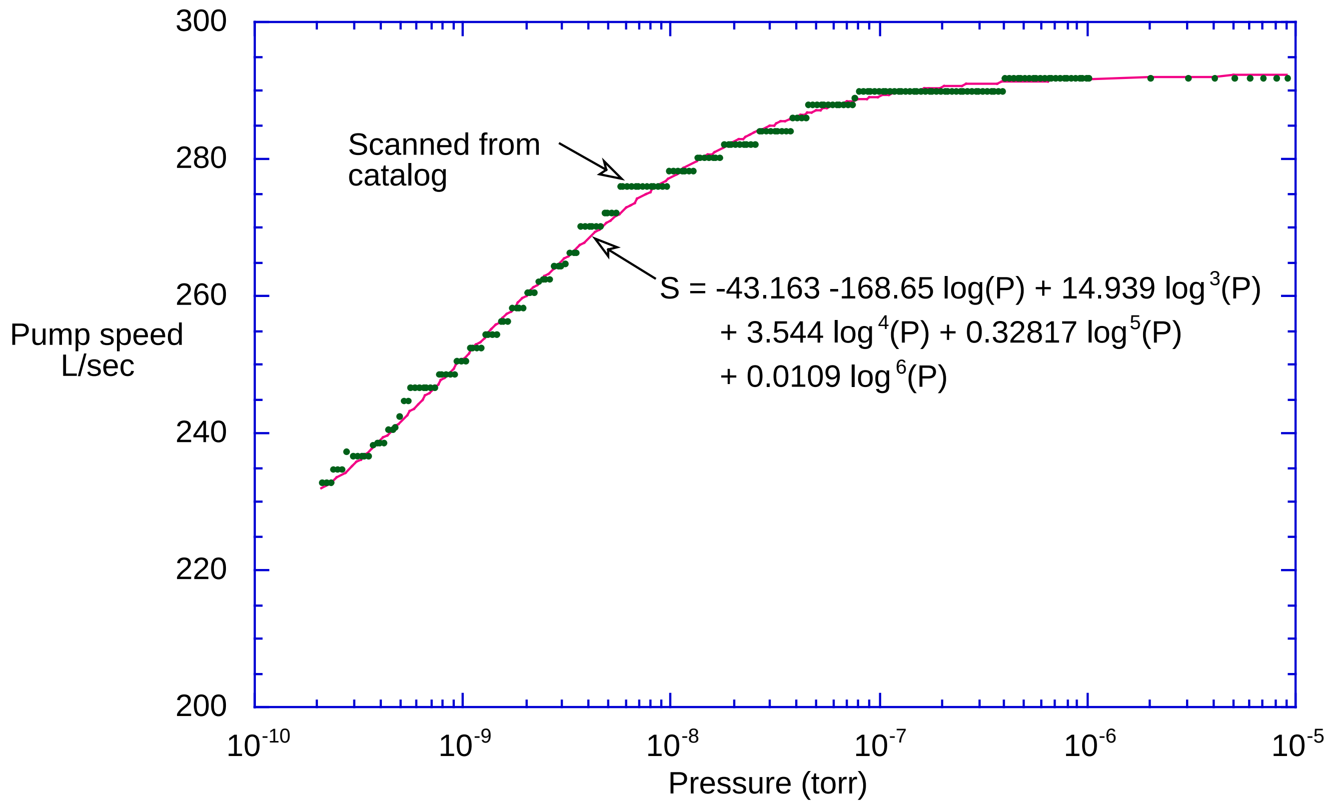
Layout of 2nd of 6 segments of sub-volumes and conductances in the model of the SNS/CCL

Model includes two time-dependent outgassing rates for pre- and post-conditioned surfaces

Rates based on early data from Roth, from APT Hot Model tests, and final rates specified by SNS management



Model includes Gas and Pressure-Dependent Pump Speeds For All Gases - Example

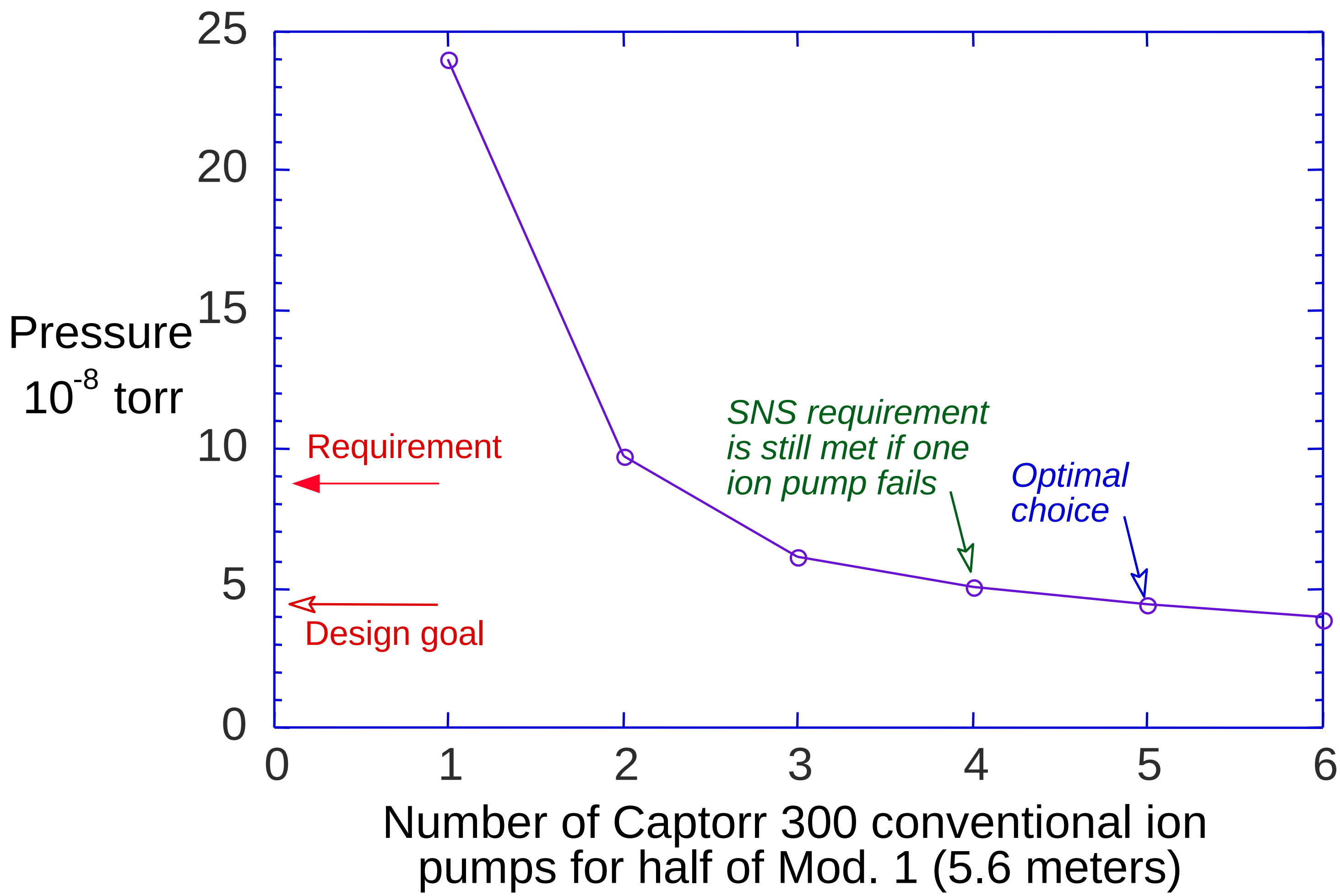


Dependence of pump speed on pressure for a PHI 300 Captorr conventional ion pump. The data was scanned from the vendor catalog and a numerical expression was fit to the data and used in the model.

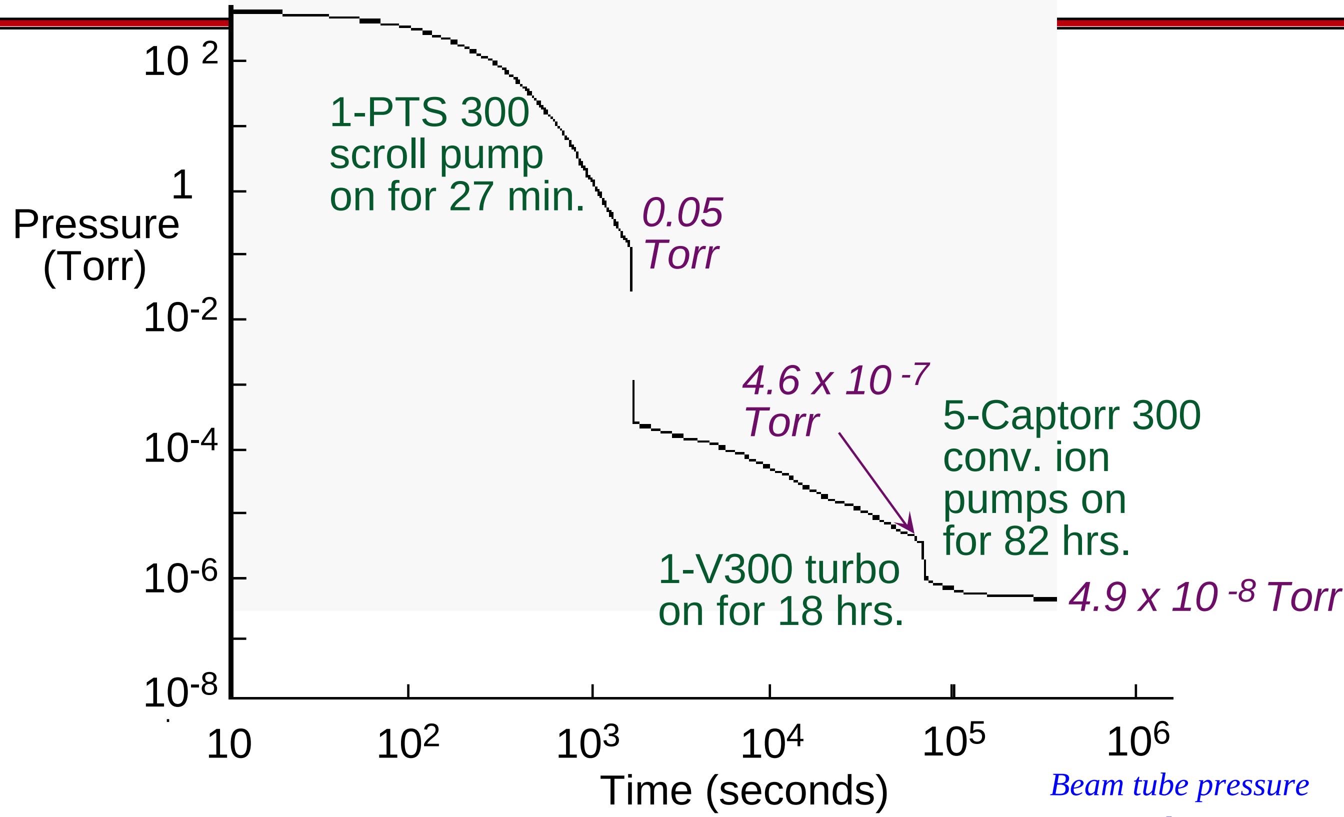
SNS/CCL Vacuum System –Pump Down Results

	Pressure (Torr)
Design Requirement	4.40×10^{-8}
100-hr Ougassing Rates: SS 1×10^{-10} T-L/sec-cm^2 Cu 1×10^{-10} T-L/sec-cm^2	4.83×10^{-8}
100-hr Ougassing Rates: SS 1×10^{-10} T-L/sec-cm^2 Cu 8×10^{-11} T-L/sec-cm^2	4.03×10^{-8}

SNS/CCL Vacuum System Design –Pump Selection



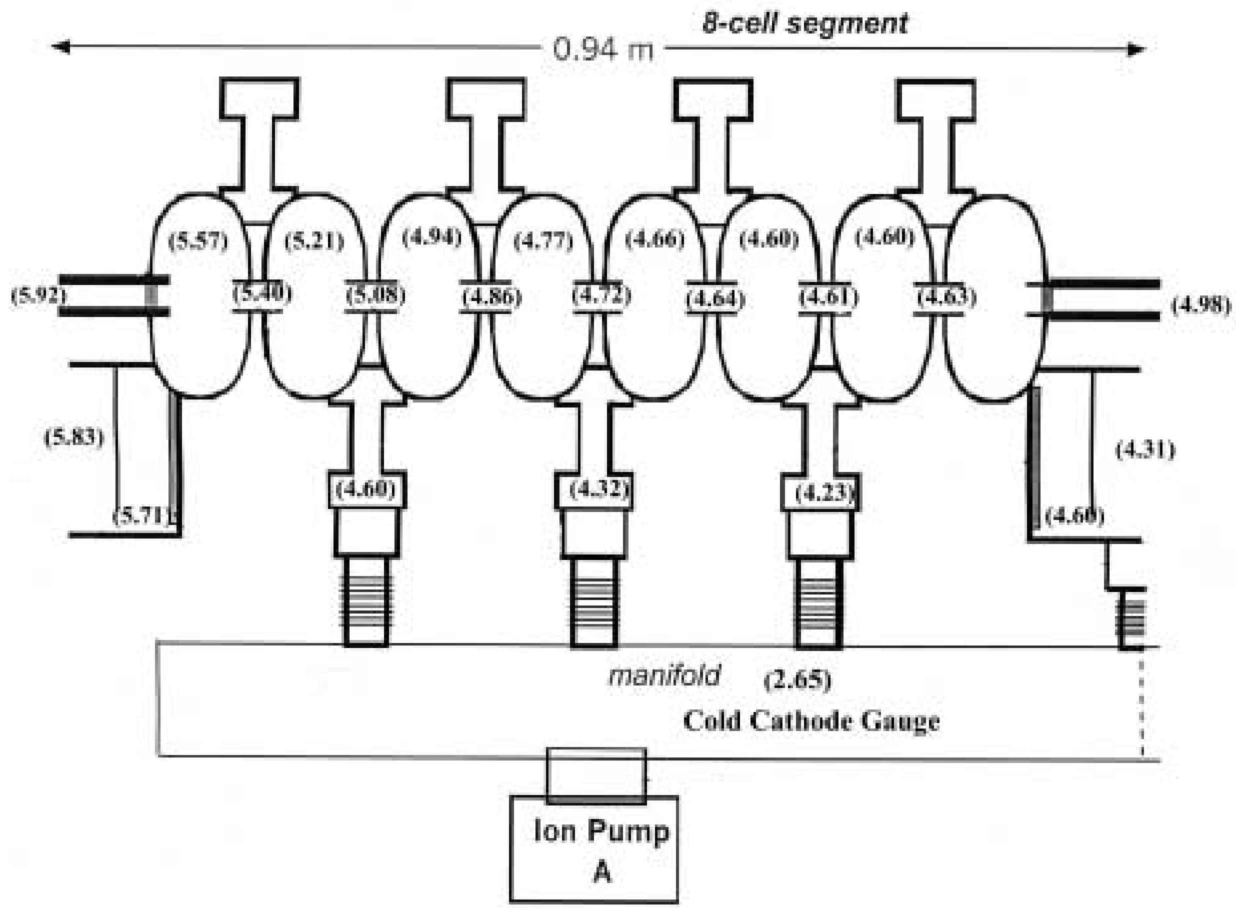
SNS/CCL Vacuum System – Pump Down History



Beam tube pressure averaged over two segments = 4.0 x 10 $^{-8}$ Torr

History of peak beamline pressure (sub-volume 1) from atmosphere to the base pressure for CCL Mod. 1. Pump configuration is for one manifold which services half of a typical CCL module. The final copper outgassing rate is 8 x 10^{-11} Torr-L/sec and the final stainless steel outgassing rate is 1 x 10^{-10} Torr-L/sec.

SNS/CCL Vacuum System Design- Gauge Calibration



Pressure Distribution in 1st half of Module 1. Pressure Reading (x 10^{-8} Torr)

SNS/CCL- Mixed-Gas Analysis

Gas (amu)	AVG. Beamline Pressure P (10^{-8} Torr) with 100% Gas P_{gas}	Partial Pressures (10^{-8} Torr) $P_{avg} = P * C$	Weighted Partial Pressures (10^{-8} Torr) $[P] = P_{gas} * C * W$
H_2 2.016	1.43	0.29	0.04
H_20 18.016	3.76	0.75	0.50
N_2 28.02	**4.60**	2.30	2.30
CO_2 44.01	5.15	0.52	0.77
air 28.98	**4.43**		
TOTAL Composite		**3.86**	**3.61**

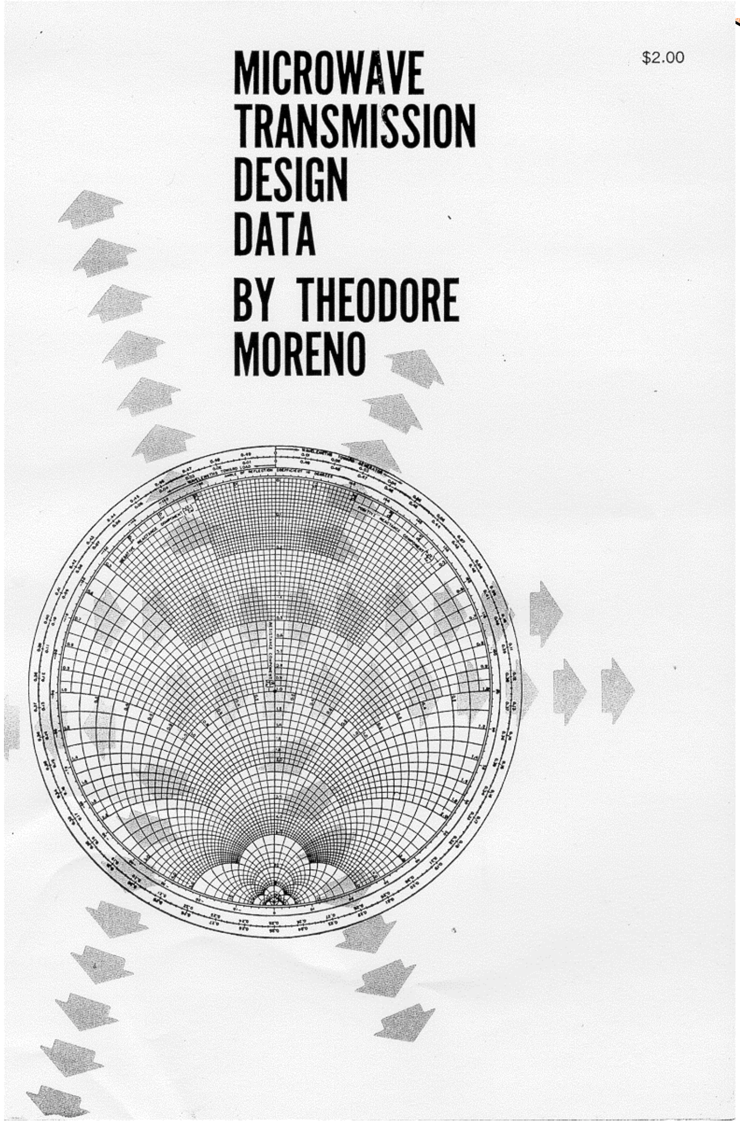
TABLE. 3.12. Model results for each gas and their partial and weighted partial pressures.

SNS/CCL Vacuum System Design- Conclusions

Design Function	FDR Modeling Results
Vacuum Level - Air	Sufficiently provided for beamline (average pressure of 4.4 $x10^{-8}$ Torr.) with comfortable margins of factor 2.
Vacuum Level – Other Gases	Satisfactory results for mixed gases with H_2, H_2O, N_2 and CO_2.
Pump Selection	Practical and economical
Roughing Function	Less than 1/2 hour
Turbo Conditioning	18 Hours
Ion Pump Operation	Reaching $8x10^{-8}$ Torr in 82 Hours
Gauging Calibration	Cold Cathode gauge at the manifold would read nearly100% lower than the beamline pressure.

RF Grills - Attenuation Calculations

- RF Grill Calculations where done by William Roybal.
- Theodore Moreno is the microwave data source for these calculations.
- Notice the cost of the book in the upper right hand corner.



RF Grill Attenuation Calcs - continued

Attenuation equation for a rectangular waveguide. (TE10 mode)

$$\alpha_g := \left[8.69 \sqrt{\left(2 \cdot \frac{\pi}{\lambda_c}\right)^2 - \varepsilon_1 \cdot \left(2 \cdot \frac{\pi}{\lambda}\right)^2} \right] \cdot z$$

T. Morino, "Microwave Transmission Design Data", equation 8-21, page 140

Attenuation equation for a round waveguide (TE11 mode)

$$\alpha_{sc} := \left[8.69 \sqrt{\left(\frac{1.841}{\frac{D_s}{2}}\right)^2 - \left[\frac{(2 \cdot \pi)}{\lambda}\right]^2} \right] \cdot L_s$$

T. Morino, "Microwave Transmission Design Data", equation 7-38, page 120

RF Grill Attenuation Calcs - continued

The relationship between attenuation and power is:

$$db = 10\log\left(\frac{P1}{P2}\right)$$

Solving for P2 (power at the pump) is:

$$P2 := \frac{5\cdot 10^{5}}{\exp\left(\frac{1}{10}\cdot db\cdot \ln(10)\right)}$$

Results (P2 at various points)

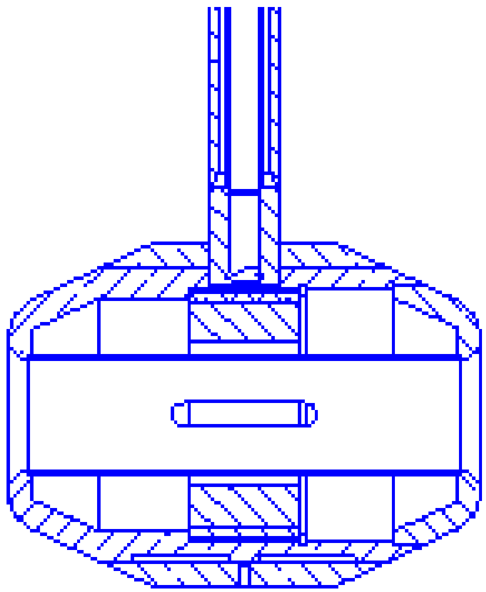
P2@ DTL Ion Pump = 0.050 W
P2 @ DTL Turbo Pump = 0.049W
P2@ DTL NEG Pump = 0.004 W
P2 @ CCL NEG Pump = 0.042 W

Drift Tube Interior Max Outgas Rate Calc.

Drift tube stem is sealed off from DT body

Longest drift tube was selected as worst case

Total gas load of drift tube contents:
Q_total/2=Cond(P_strip - P_out)
Where: Pstrip is the max allowable vacuum pressure and Pout is the vacuum pressure outside of the drift tube.



Total gas load of diagnostics is then:

Q_diagnostic = Q_total - Q_drift_tub

So, the Max outgas rate for any diagnostic is 2.4*10^-6 torr-liters/sec

DTL RF Window Vacuum Calculations

DTL RF Window Vacuum Pumping Assembly

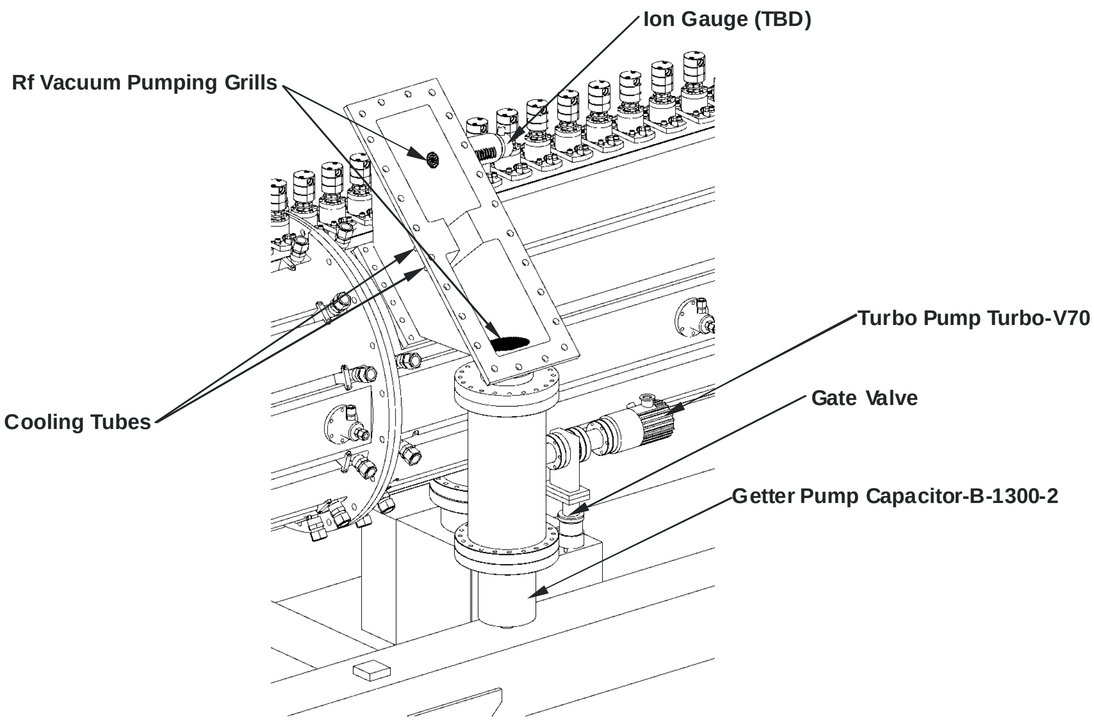
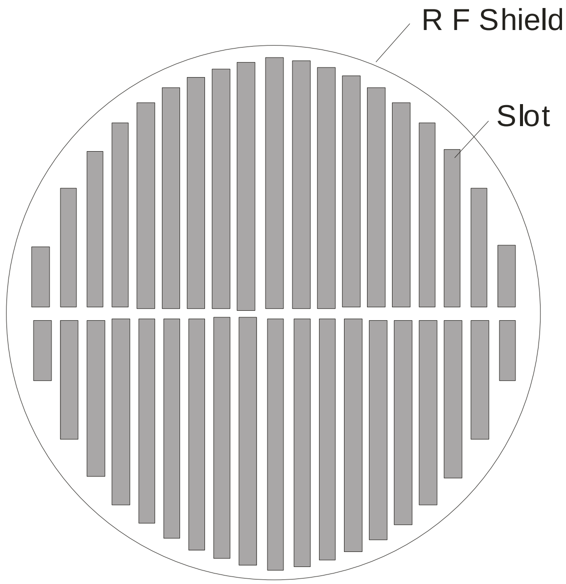


Figure 2.4. Details of the SNS DTL R F window vacuum pumping assembly..

DTL RF Window Grill



R F Grill Diameter = 9.75 cm (3.84")
Number of Slots = 38
Slot Width = 0.318 cm (0.125")
Slot Depth = 0.635 cm (0.25")
Slot Length = 1.27 cm to 4.57 cm (0.5" to 1.8")
Conductance for air = 707 L/s

DTL RF Window Vacuum Calculations - cont.

Total gas load or effective pump speed required ($P_{base}=10^{-7}$ Torr):

$$S_{eff} = (Q_w \times A_w + Q_{wg} \times A_{wg})/P_{base}, = 360 \text{ L/s}$$

Corresponding NEG pump speed required is:

$$S_{NEG} = S_{eff} \times [C_{port}/(C_{port} - S_{eff})]$$

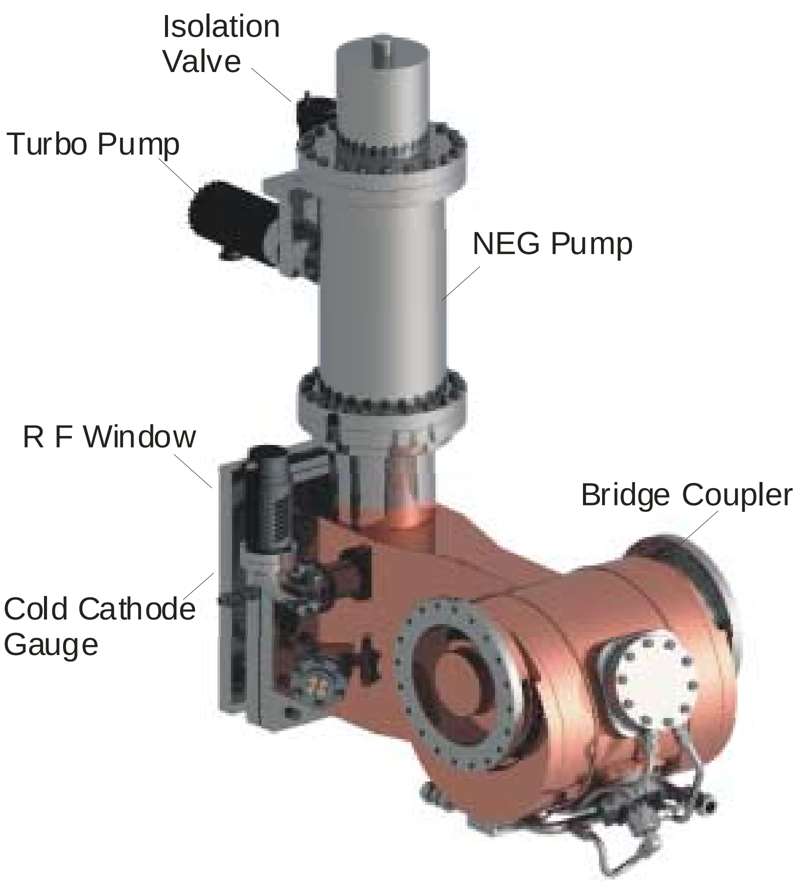
Where the total conductance of the vacuum port is:

$$C_{port} = (C_{rfs}^{-1} + C_{nip1}^{-1} + C_{nip2}^{-1})^{-1} = 242 \text{ L/s}$$

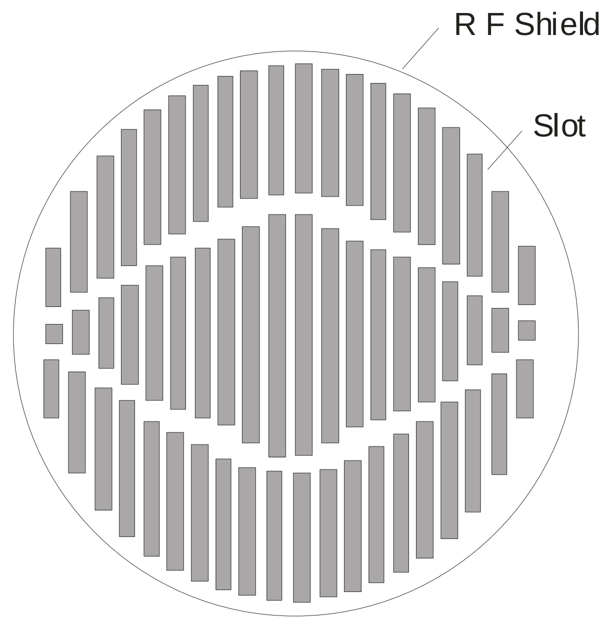
- Since Cport < Seff, the system is conductance limited
- No more room for additional pumping ports
- Recommend using the 1300 L/s NEG pump used on the CCL RF window
- Need to increase RF window conditioning time to lower outgas rate of window or
- pre-condition RF windows to lower initial gas load from 5×10^{-8} to 3.5×10^{-8} Torr L/s/cm^2

CCL RF Window Vacuum Calculations

CCL RF Window Vacuum Pumping Assembly



CCL RF Window Grill



R F Grill Diameter = 12.37 cm (4.87")
Number of Slots = 60
Slot Width = 0.318 cm (0.125")
Slot Depth = 0.635 cm (0.25")
Slot Length Varies
Conductance for air = 630 L/s

CCL RF Window Vacuum Calculations - cont.

Total gas load or effective pump speed required ($P_{base}=10^{-7}$ Torr):

$$S_{eff} = (Q_w \times A_w + Q_{wg} \times A_{wg})/P_{base}, = 168 \text{ L/s}$$

Corresponding NEG pump speed required is:

$$S_{NEG} = S_{eff} \times [C_{port}/(C_{port} - S_{eff})]$$

Where the total conductance of the vacuum port is:

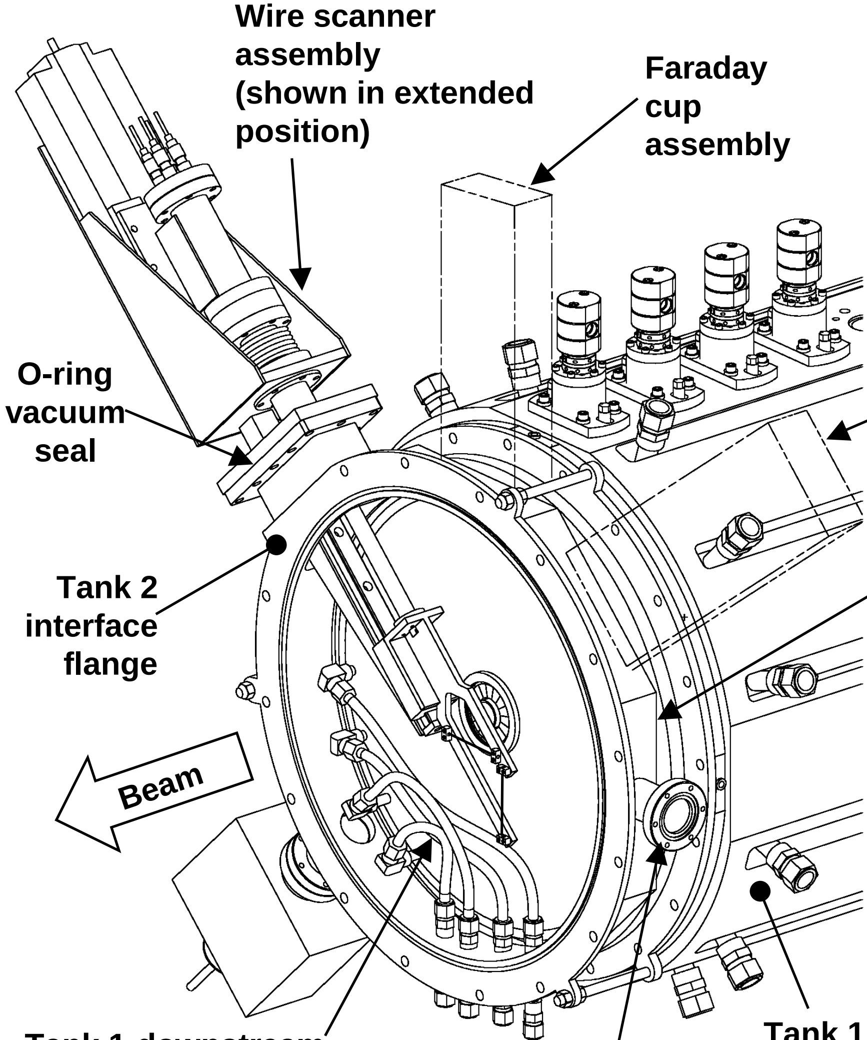
$$C_{port} = (C_{rfs}^{-1} + C_{nip1}^{-1} + C_{nip2}^{-1})^{-1} = 240 \text{ L/s}$$

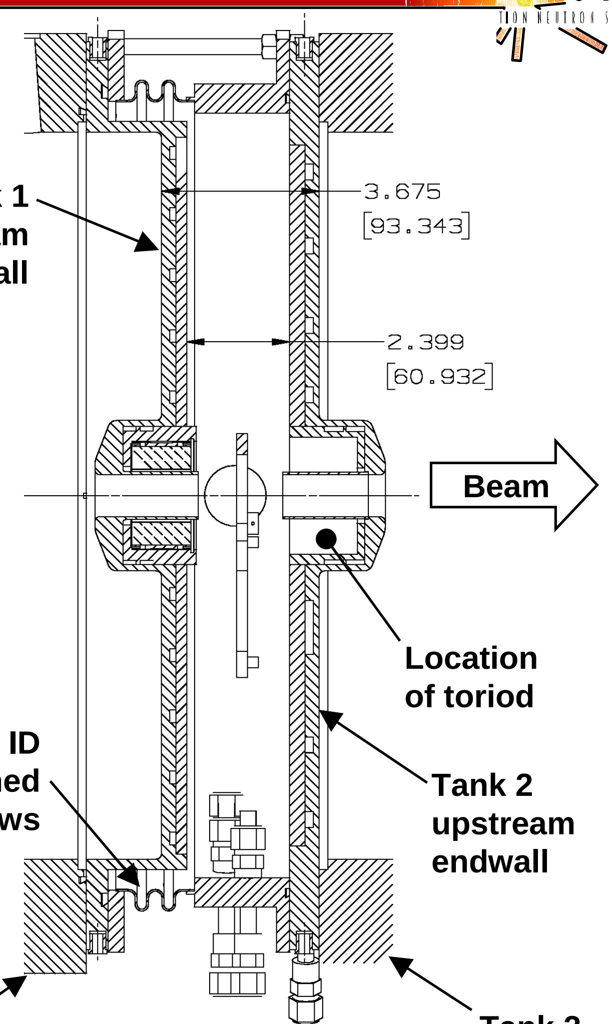
So the required NEG pump speed is:

$$S_{NEG} = 560 \text{ L/s}$$

Recommend using a 1300 L/s SAES NEG pump, off-the-shelf pump used successfully on LEDA RF windows and purchased for CCL hot model.

DTL Intertank Region Outgassing





Section thru tanks 1 and 2 endwalls

DTL Intertank Region Outgassing - cont.

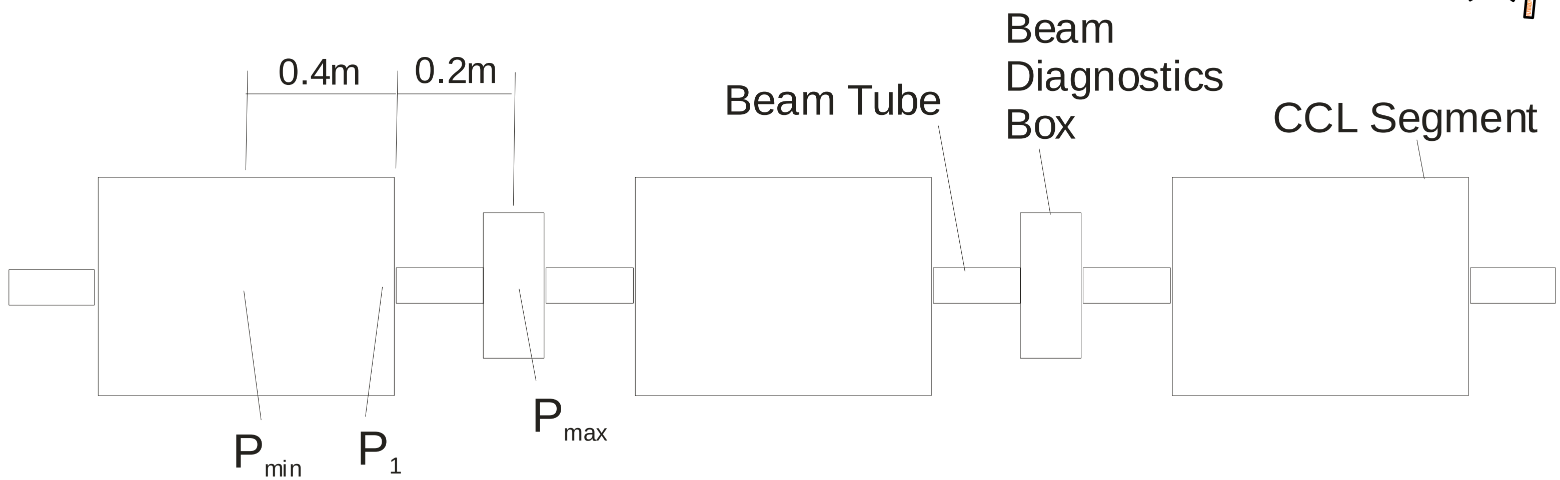
- Dedicated vacuum pump for this space is not required
- Half drift tubes are enough to pump the inter-tank space

$$Qtotal_{diagnostics} := \left[2 \cdot C_{bore\_.mT} \cdot (strip\_pressure - base\_pressure)\right] - Qwalls$$

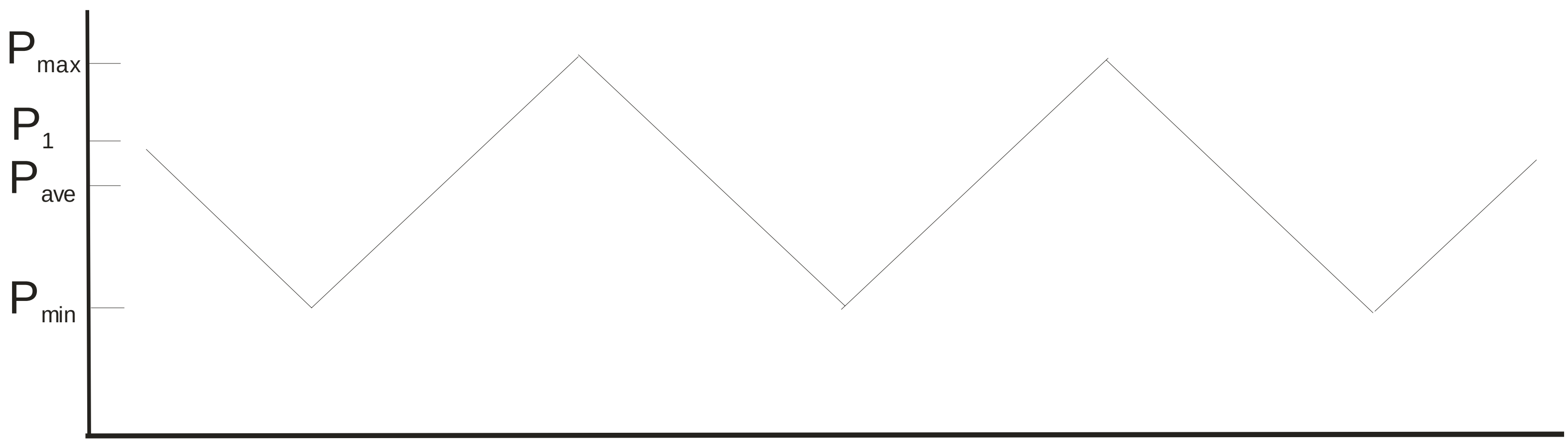
<u>Thus, the max outgassing rate of diagnostics in a DTL intertank region is:</u>

Qtotal_diagnostics = 4.6x10^-6 torr*l/s

CCL Intersegment Diagnostic Outgassing



Assumed and Simplified Pressure Profile



CCL Intersegment Diagnostic Outgassing - cont.

P_{min} is the operating vacuum pressure in the center of a CCL segment, $4.45\text{x}10^{-8}$ Torr

P_{ave} is the vacuum pressure where unacceptable stripping starts, or the average allowable beamline pressure $8.90\text{x}10^{-8}$ Torr

P_1 is the vacuum pressure in the first cavity after the inter-segment region

P_{max} is the maximum allowable vacuum pressure in the beam box, $13.35\text{x}10^{-8}$ Torr

So what is the maximum outgassing rate of the beam box diagnostics that results in this pressure profile?

CCL Intersegment Diagnostic Outgassing - cont.

$$P_{ave} := \frac{1}{2}\left(P_{max} + P_{min}\right)$$

$$P1 := \frac{2}{3}\left(P_{max} - P_{min}\right) + P_{min}$$

$$Qtotal := 2 \cdot C_{mT} \cdot \left[Pmax - \left(\frac{2}{3} Pmax + \frac{1}{3} Pmin\right)\right]$$

Maximum outgas (Q) for any diagnostic is 7.35×10^{-7} torr*l/s

Mechanical Design and Analyses

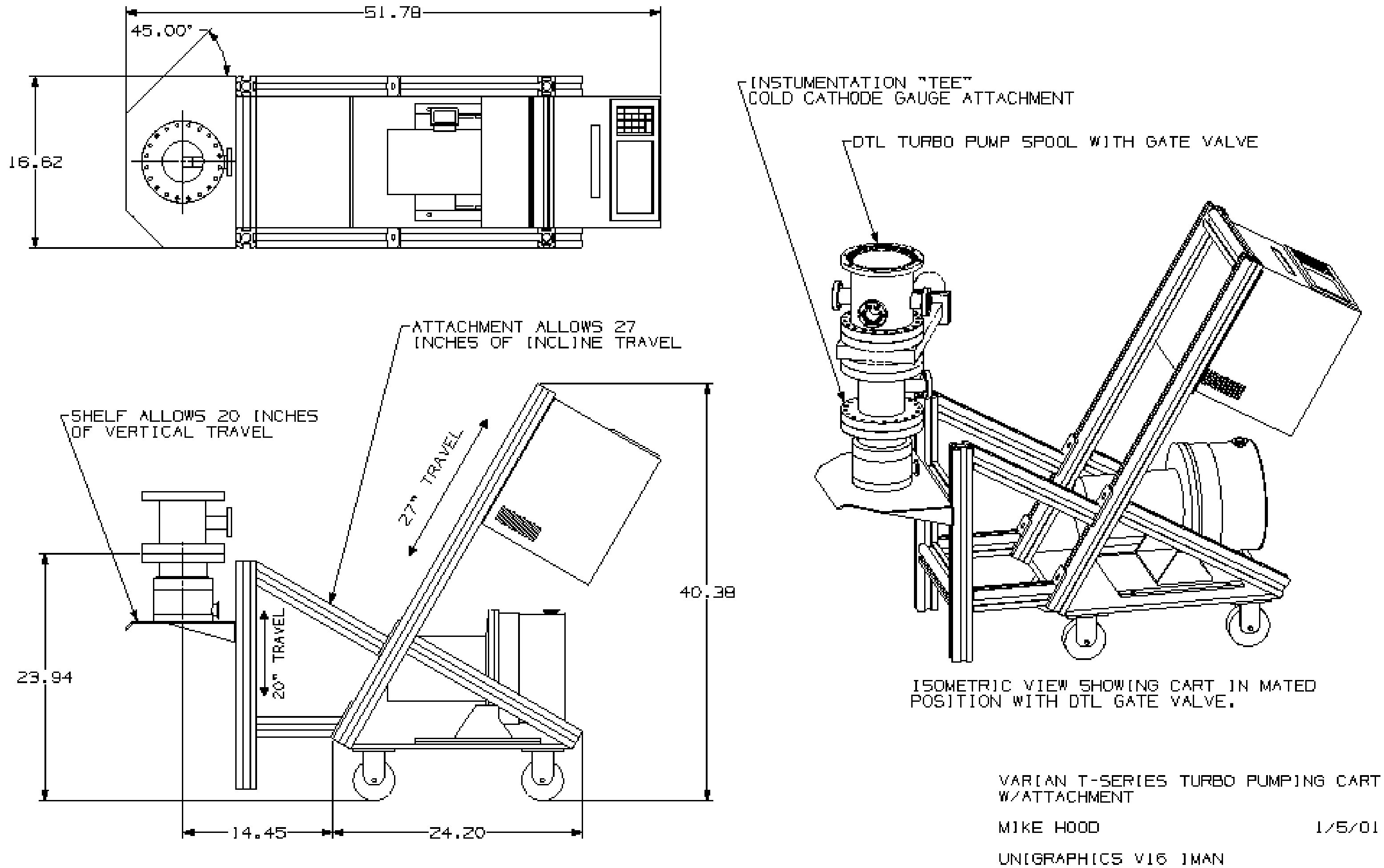
Materials - Radiation Limits

- **Radiation dose rate from operating Linac 300 days/year for 30 years is** 4.3×10^6 Rads

Material	Cumulative Dose Limit (Rad)
Polyvinyl Chloride (PVC)	1×10^8
Polyurethane Rubber (PUR)	7×10^7
Ethylene-Propylene Rubber (EPR)	8×10^7
Styrene-Butadiene Rubber (SBR)	4×10^7
Polychloroprene Rubber (Neoprene)	2×10^7
Chlorosulfonated Polyethylene (Hypalon)	2×10^7
Acrylonitrile Rubber (Buna-N)	2×10^7
Acrylic Rubber	8×10^6
Silicone Rubber (SIR)	9×10^6
Fluoro Rubber	9×10^6
Butyl Rubber	2×10^6
Tefflon (PTFE)	1×10^5
Fluorocarbon (Viton)	1×10^7
Nylon	1×10^7
Plexiglass	1×10^7
Phenolic Resin	1×10^6
Metals	1×10^{10}

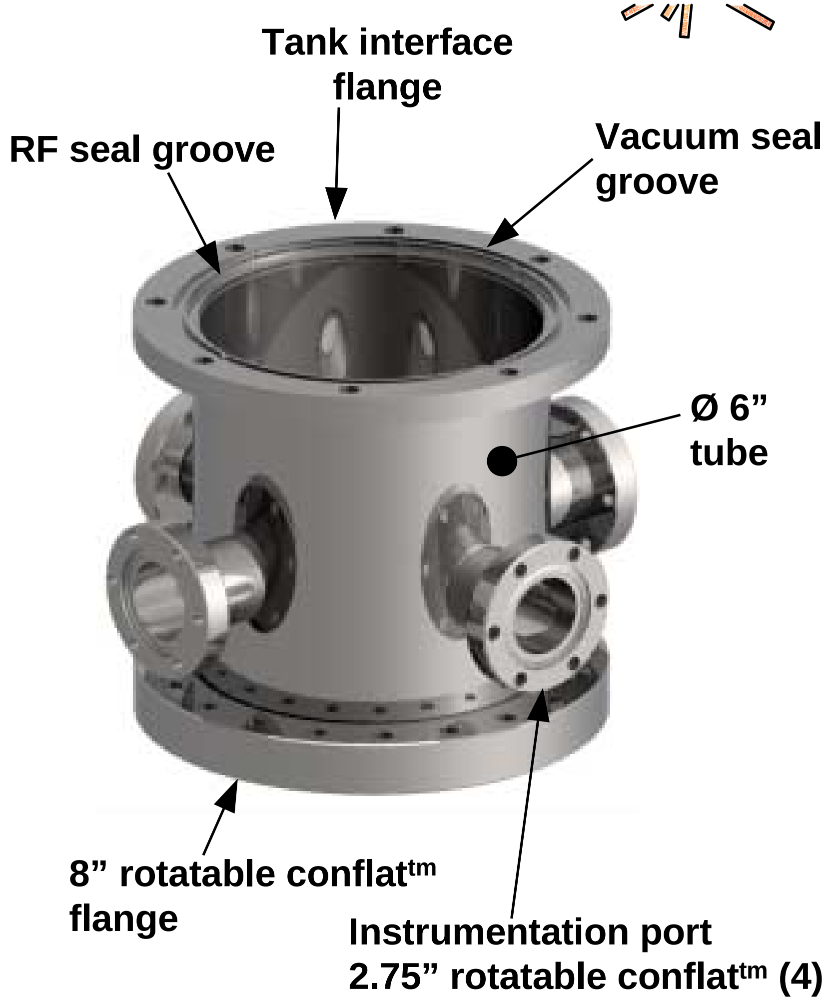
Turbo Cart

Varian turbo cart modified to allow for mounting of the turbo pump to the DTL and CCL pump ports, while maintaining clearance of the support structures.



DTL Vacuum Pump Spools

- **Provides support for vacuum pumps.**
- **Bolt on design eliminates welding on tank sections.**
- **Turbo pump spool provides instrumentation ports for the vacuum system.**
- **Tank-side connection contains both RF and vacuum seal grooves.**
- **304L SST construction with Electro-polished interior.**
- **Spool designs confirmed with vacuum and stress analyses.**

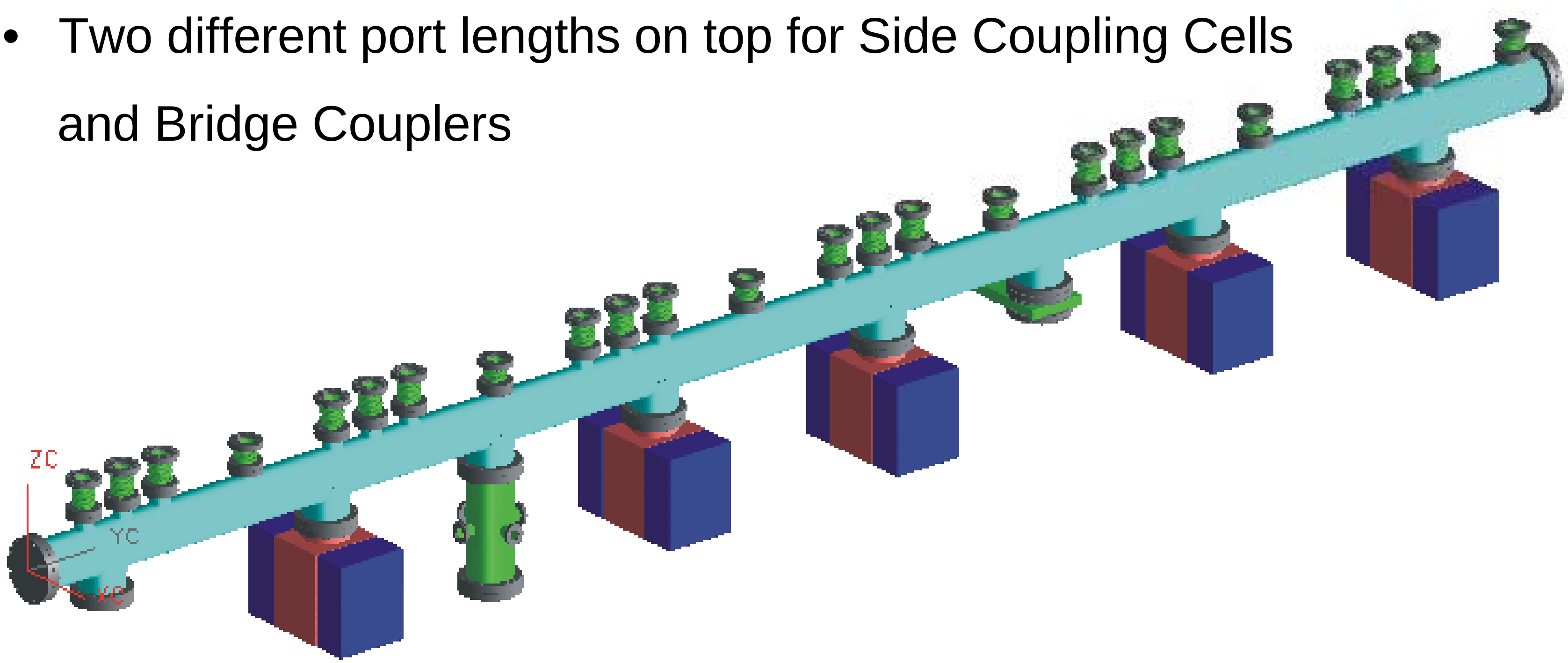


Turbo pump spool shown

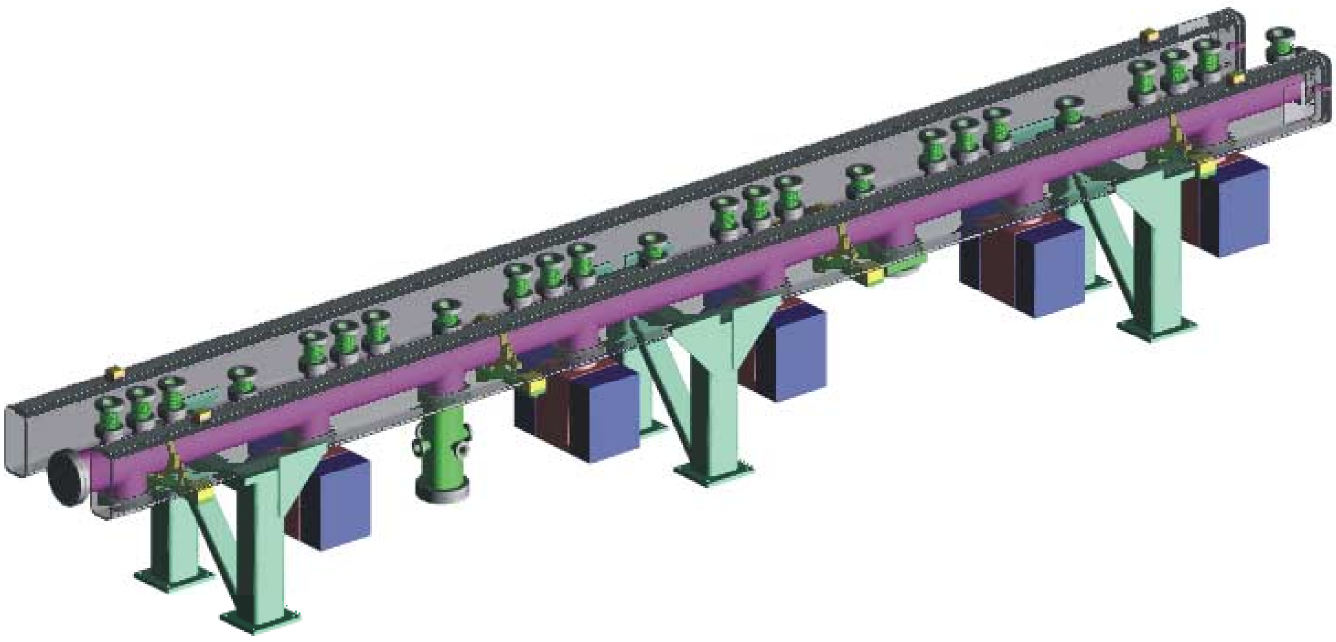
CCL Vacuum Manifold

- 6” OD, electro-polished, stainless steel manifold
- Two independent manifolds per CCL module
- Manifold geometry and mounting verified through vacuum and stress analyses
- Pumps and instrumentation attached to the bottom side ports, bellows, which connect to the CCL, attached to the top ports
- Two different port lengths on top for Side Coupling Cells

  and Bridge Couplers



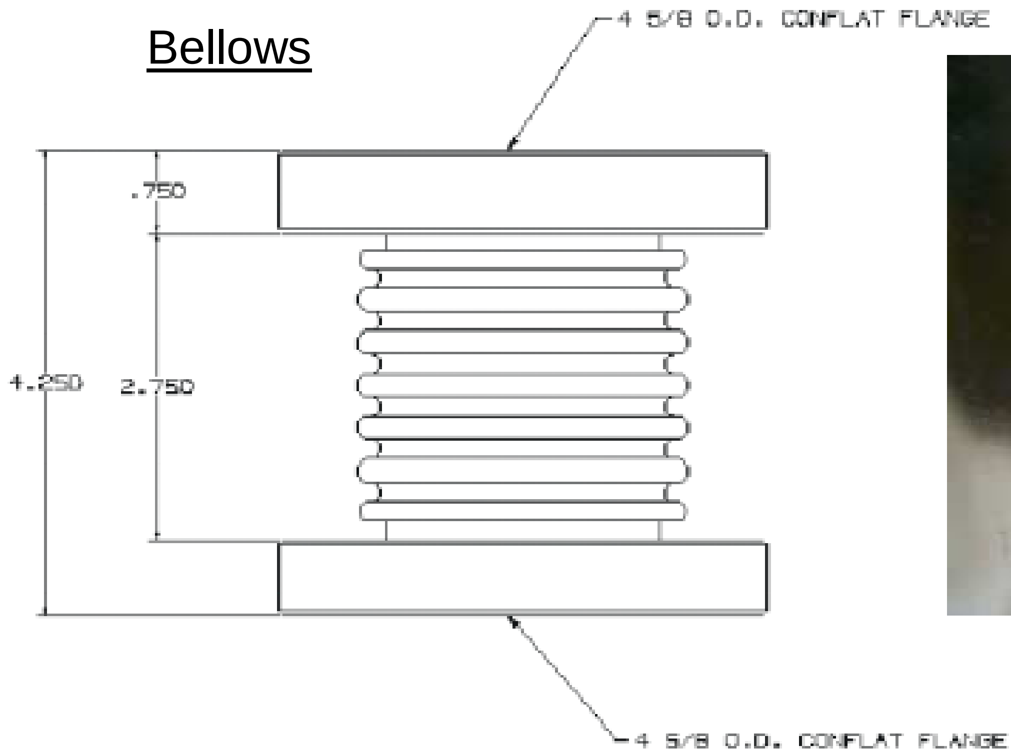
CCL Vacuum Manifold - continued



CCL Vacuum Manifold - continued

- Ports on manifold formed by “T-pulling” a neck, grinding flat, and butt welding the port nipple to the neck
- Hydroformed bellows form flexible connections between the vacuum manifold and the CCL to account for machining and alignment errors.

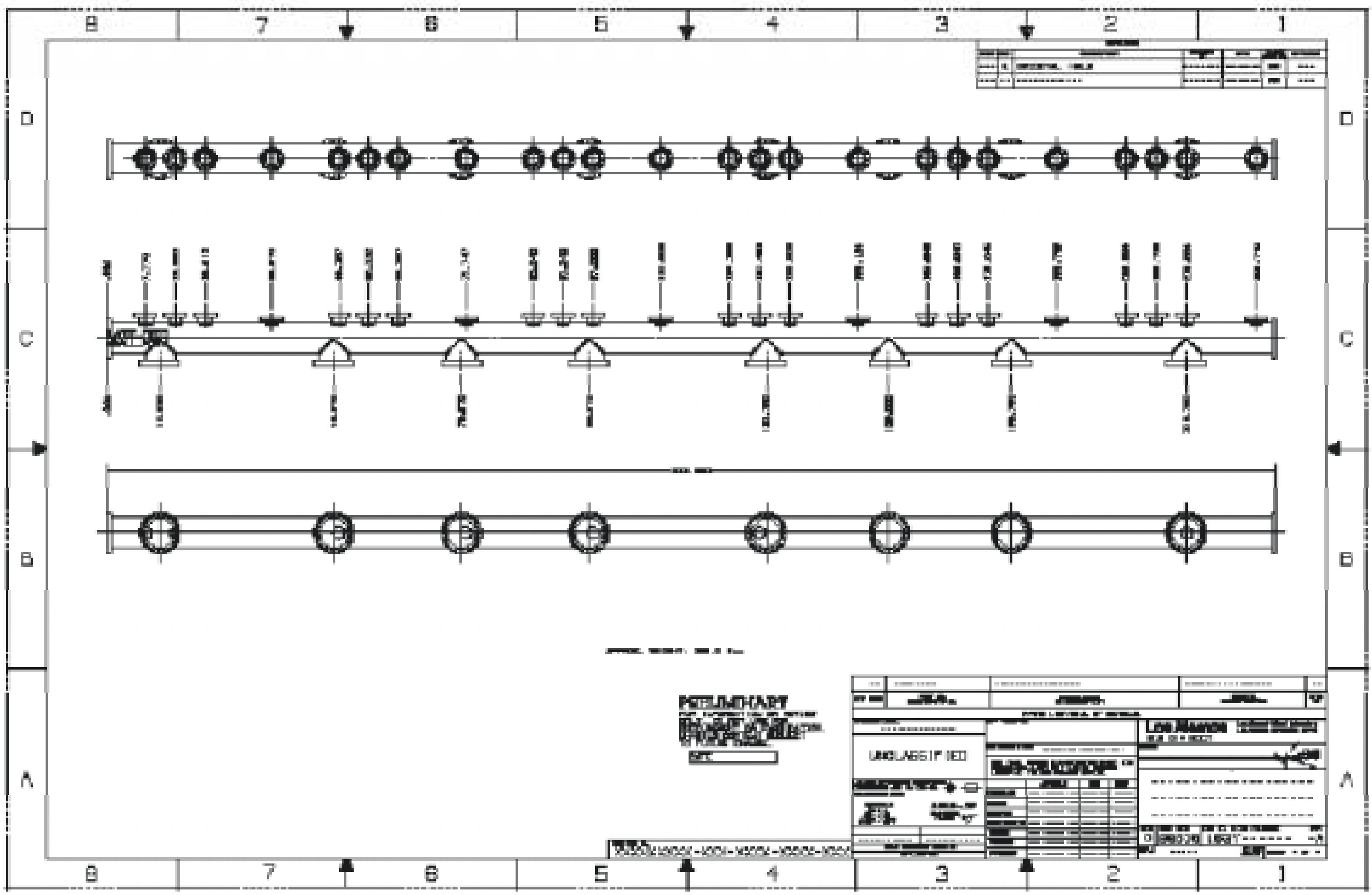
Bellows



T-pulled Neck

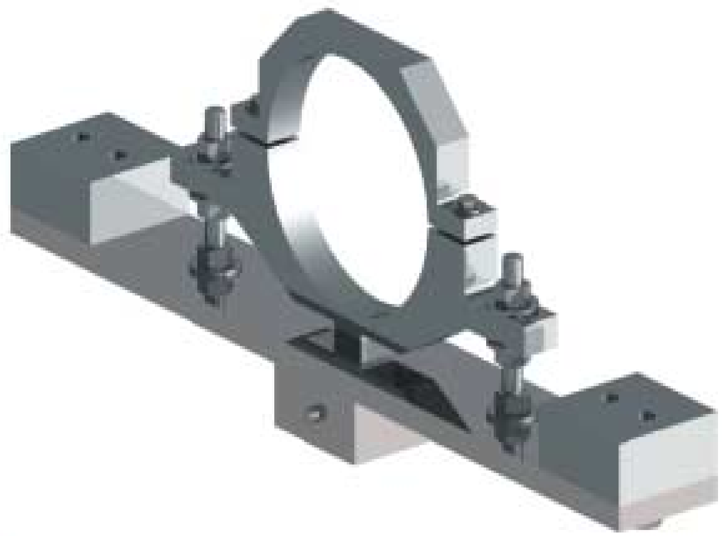
CCL Vacuum Manifold - continued

Detailed Manifold Drawing

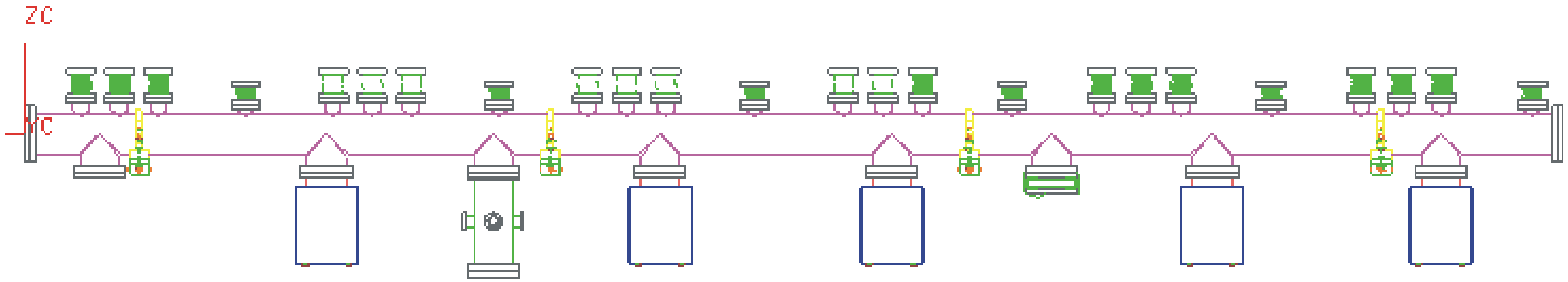


CCL Vacuum Manifold - Mounting & Alignment

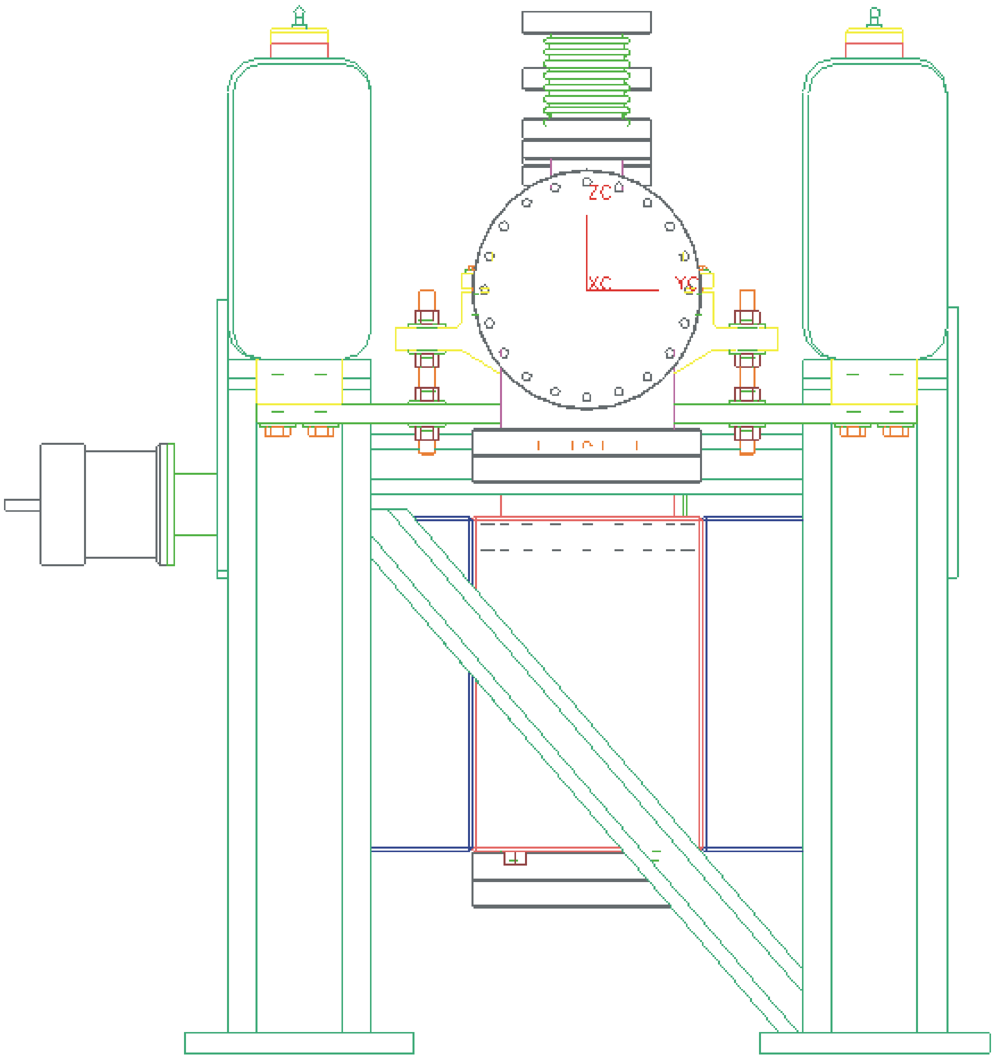
- Each manifold (half of a module), is mounted to the CCL support structure in 4 places
- Two outer-most mounts provide 6 DOF, inner two mounts provides 4 DOF for positioning manifold
- Lateral off-set of bellows is 0.25”, requiring manifold to be aligned to support structure
- Machining and alignment errors of ports on manifold and CCL estimated to be - 0.094” to + 0.138”
- Laser alignment with feducials located on the manifold’s end flange and the support structure



CCL Vacuum Manifold - Mounting & Alignment continued



CCL Vacuum Manifold - Mounting & Alignment continued



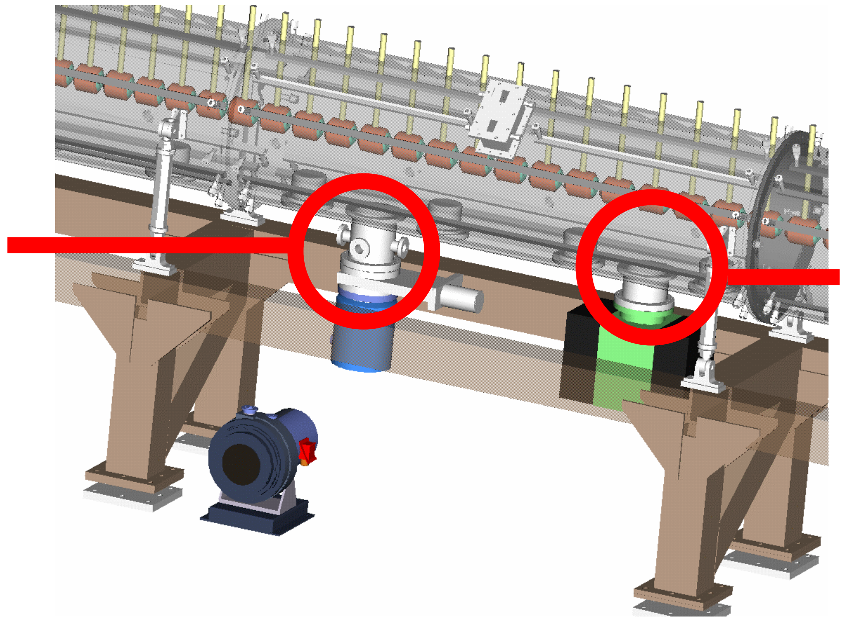
CCL/DTL
MECHANICAL DESIGN

Walter Nederbragt, Mechanical Engineer
Accelerator Technology Engineering Group
Lawrence Livermore National Laboratory

January 19 2001

DTL Requirements

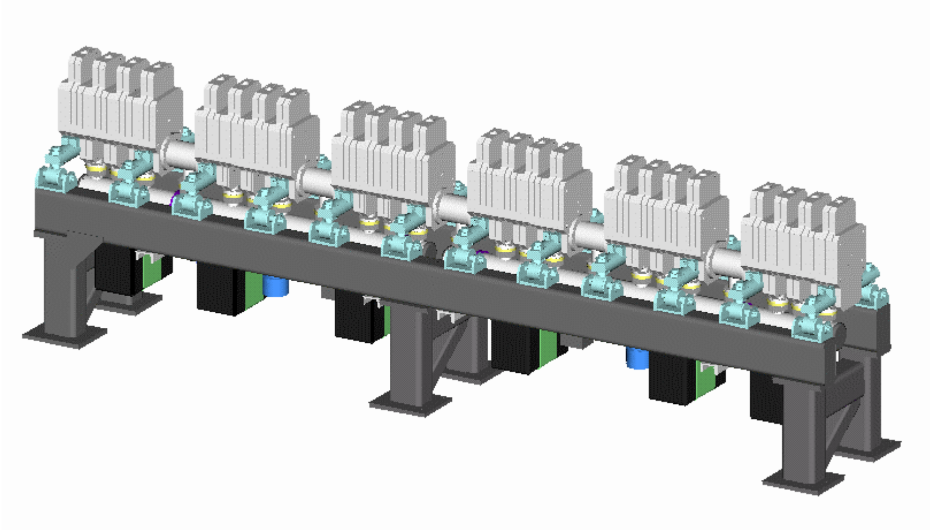
TURBO PUMP CART PORT



ION PUMP PORT

- Support Pumps
- Provide adequate strength under a gravity load & external pressure load
- Survive seismic loading
- Insure that fabrication/installation is possible

CCL Requirements



- Support Pumps
- Provide adequate strength under a gravity load & external pressure load
- Survive seismic loading
- Insure that fabrication/installation is possible (simplify installation where possible)

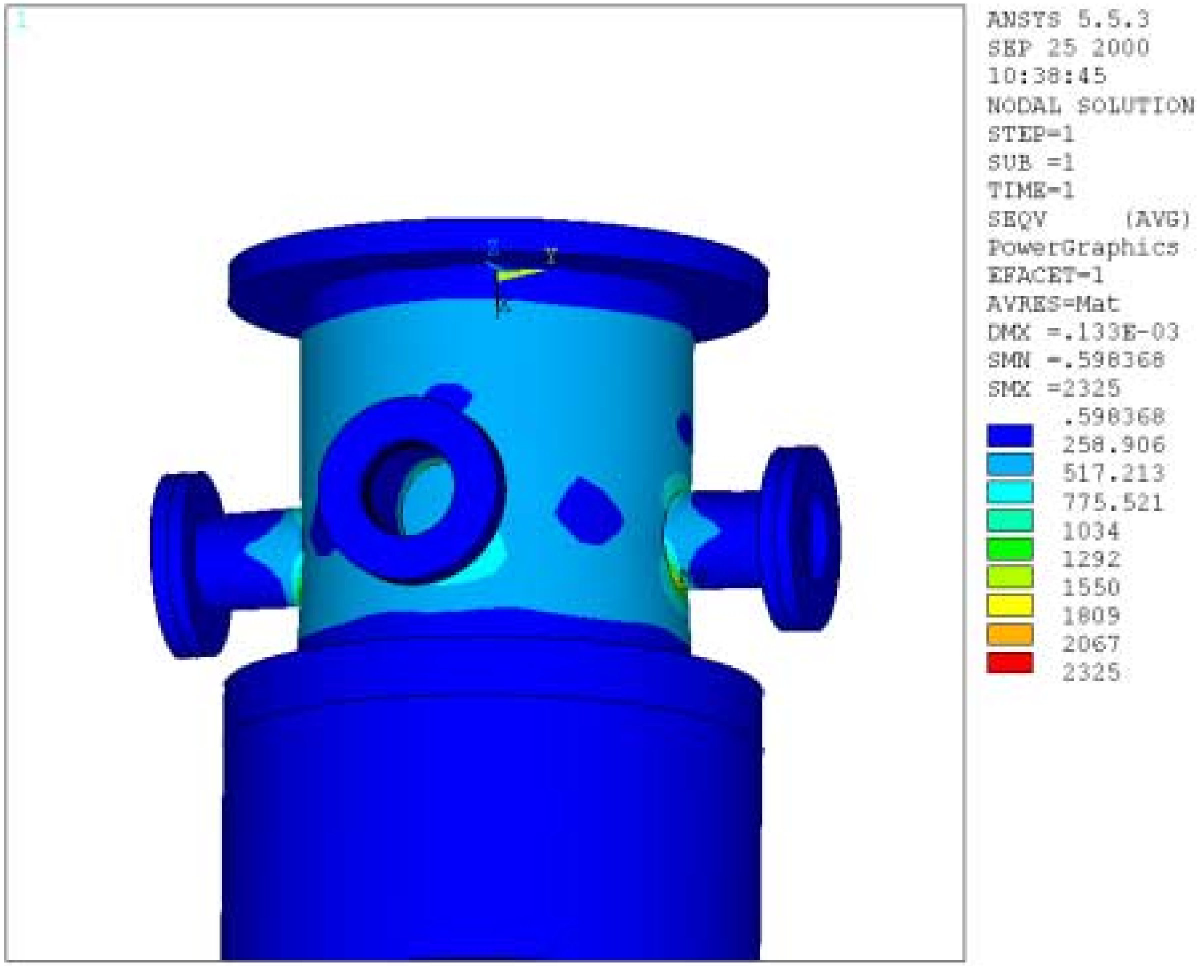
Finite Element Analysis

ANSYS 5.5.3 provided the following analysis:

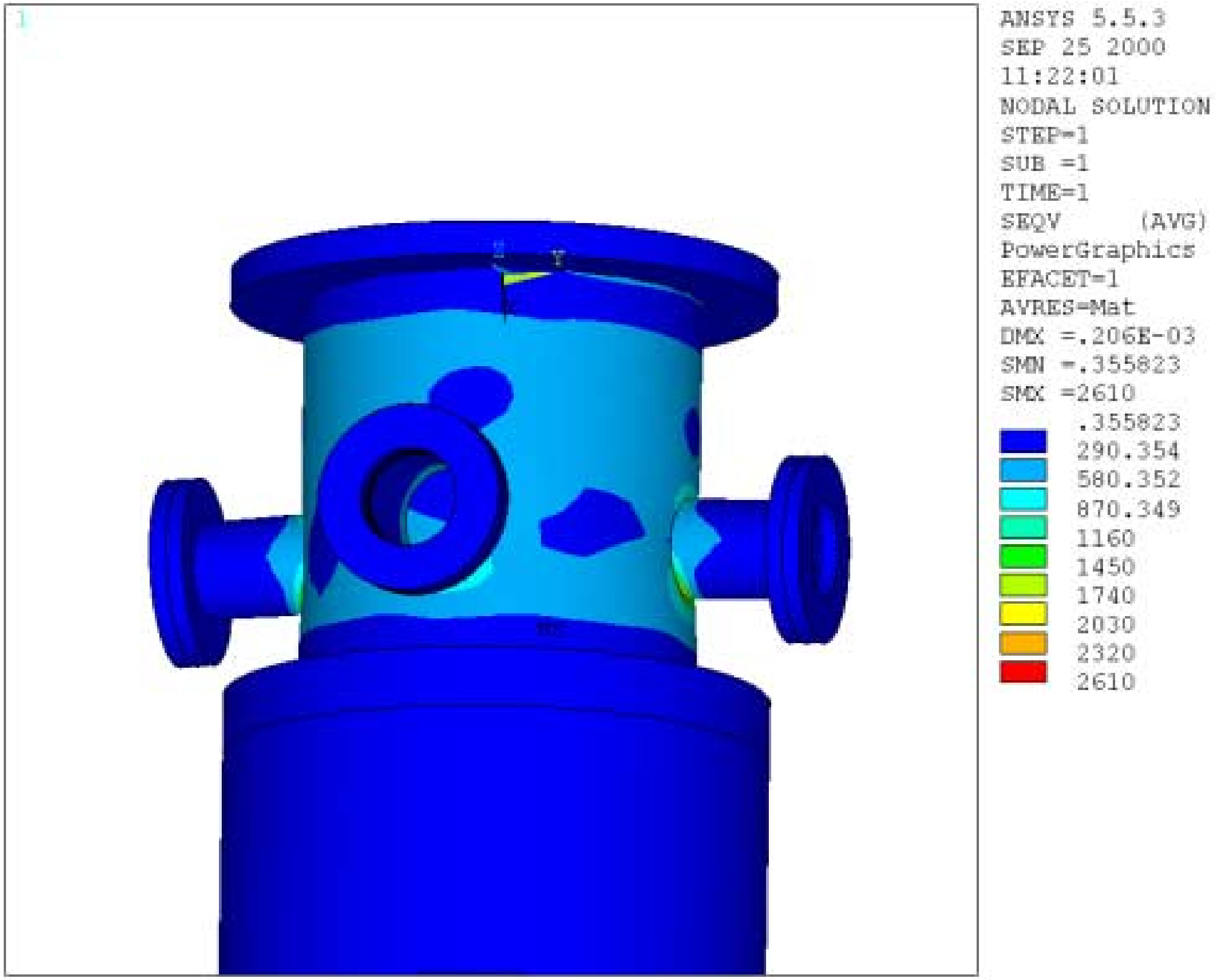
Stress & Deflection Analysis

- Vacuum load
- Gravity load
- Seismic load

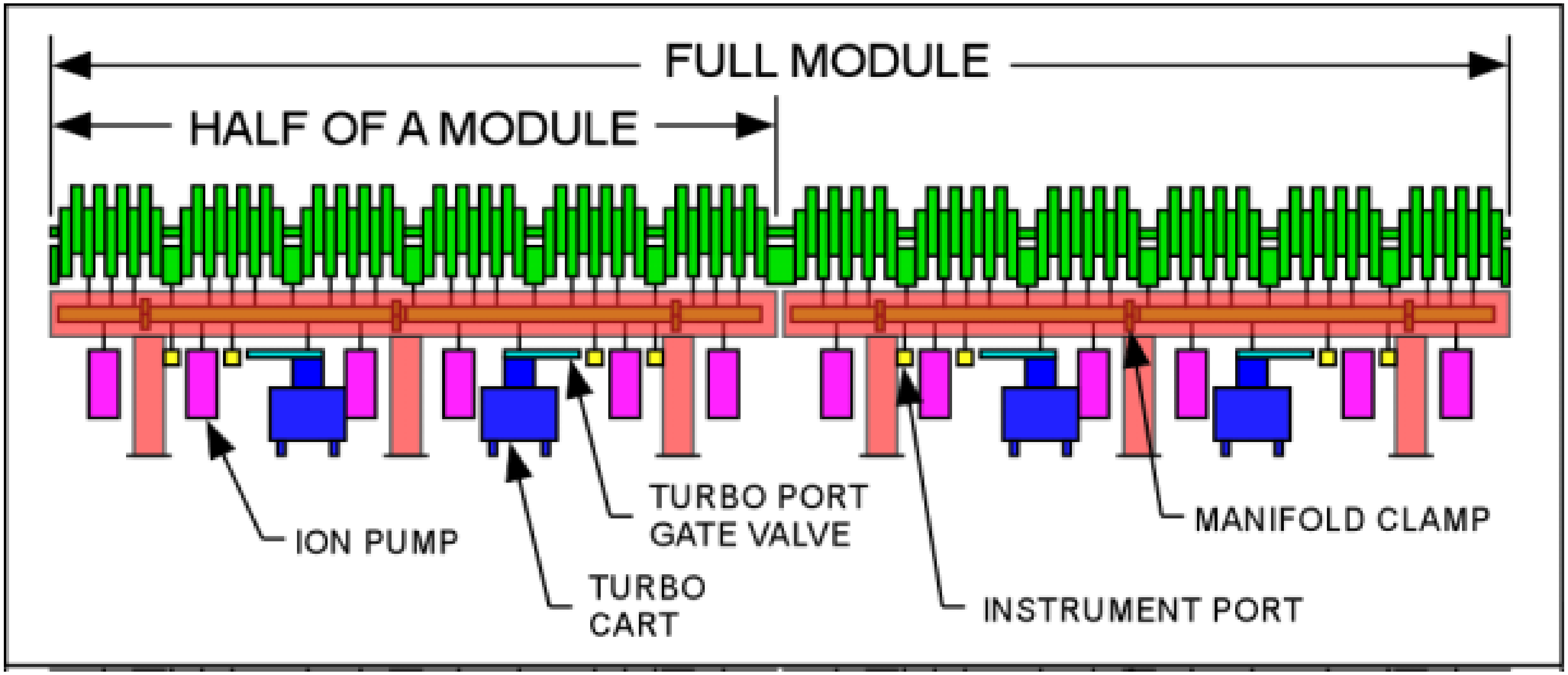
DTL FEA Results – Turbo Pump Spool Piece - Normal Load



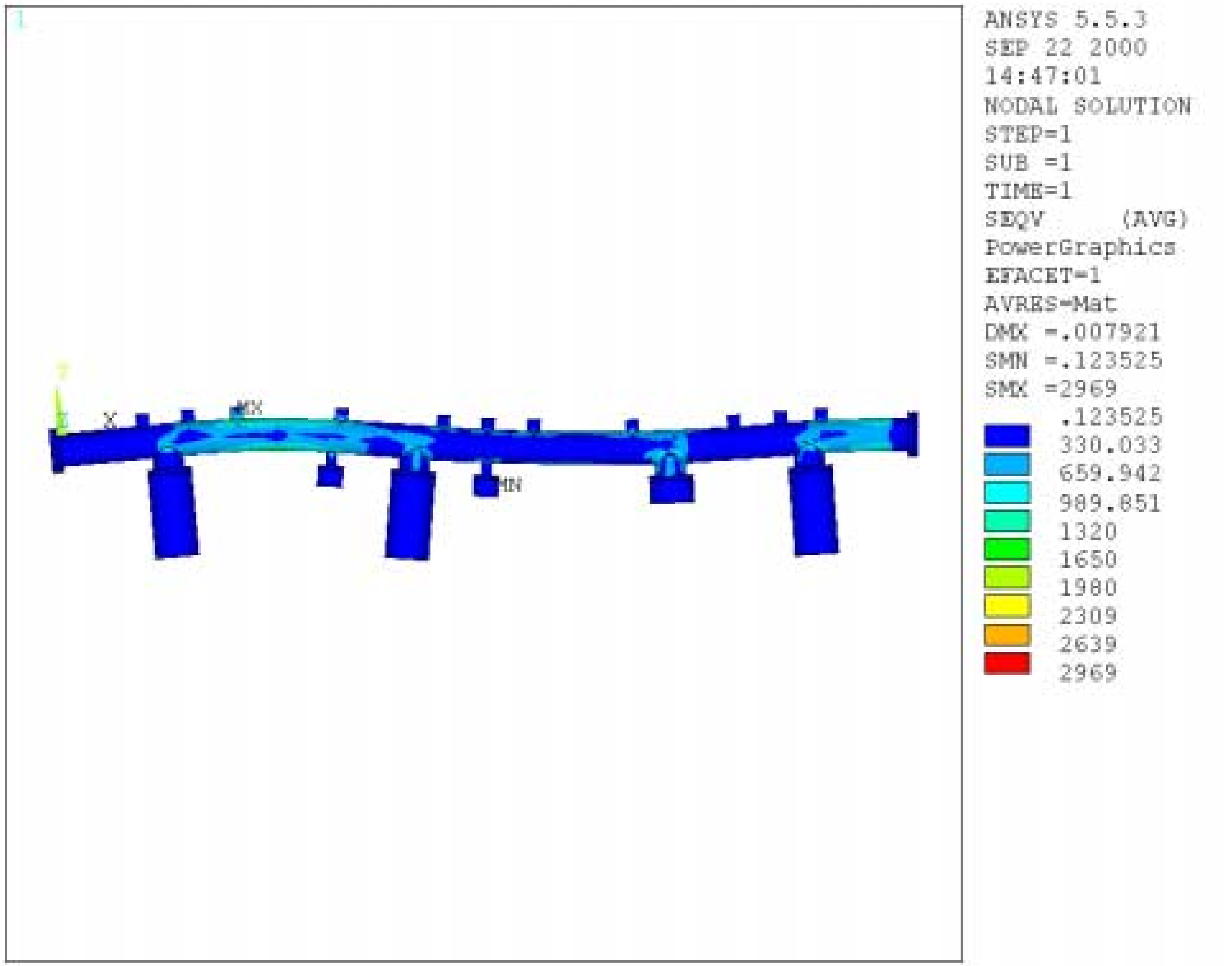
DTL FEA Results - Turbo Pump - Seismic Load



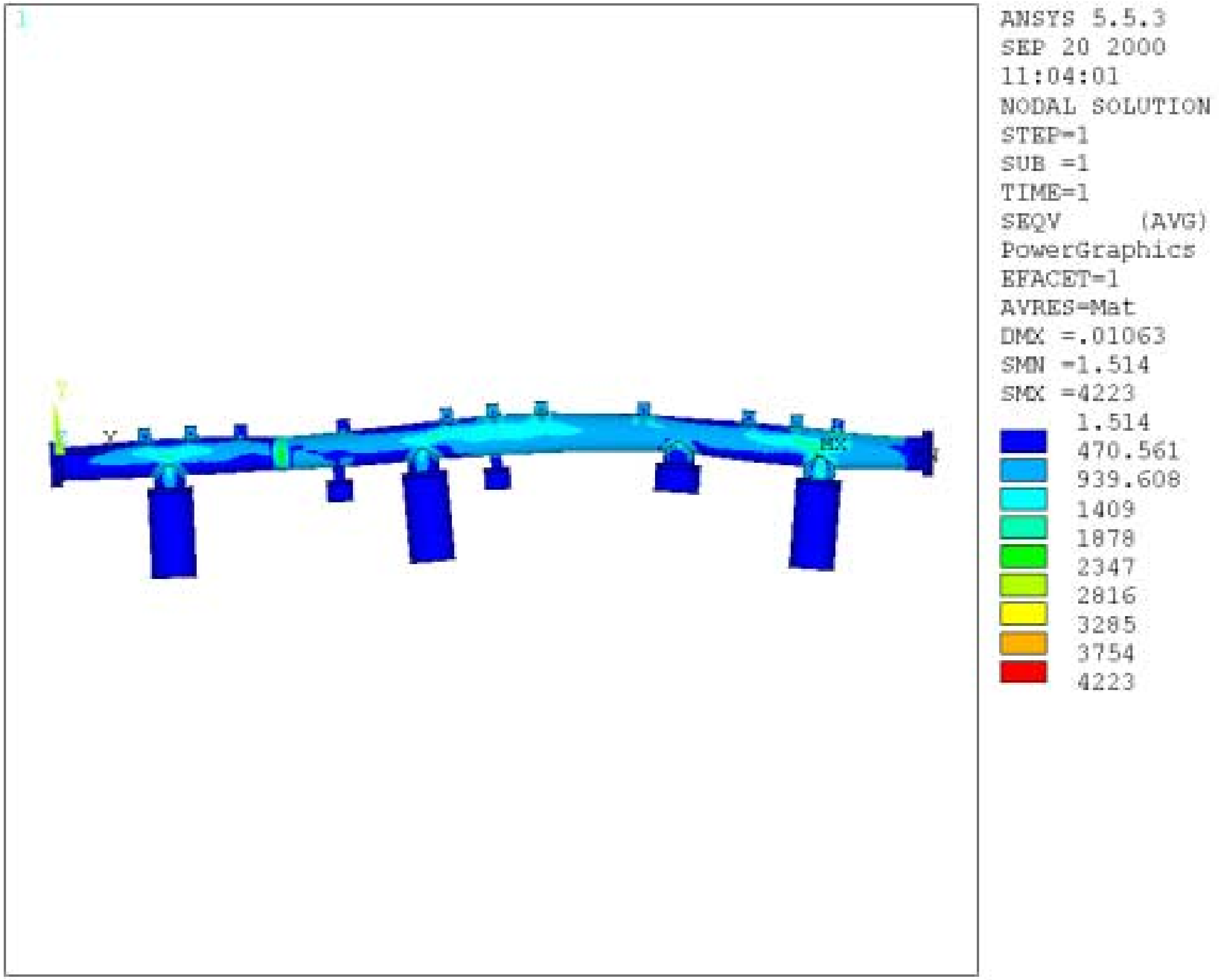
CCL Module - Manifold Model



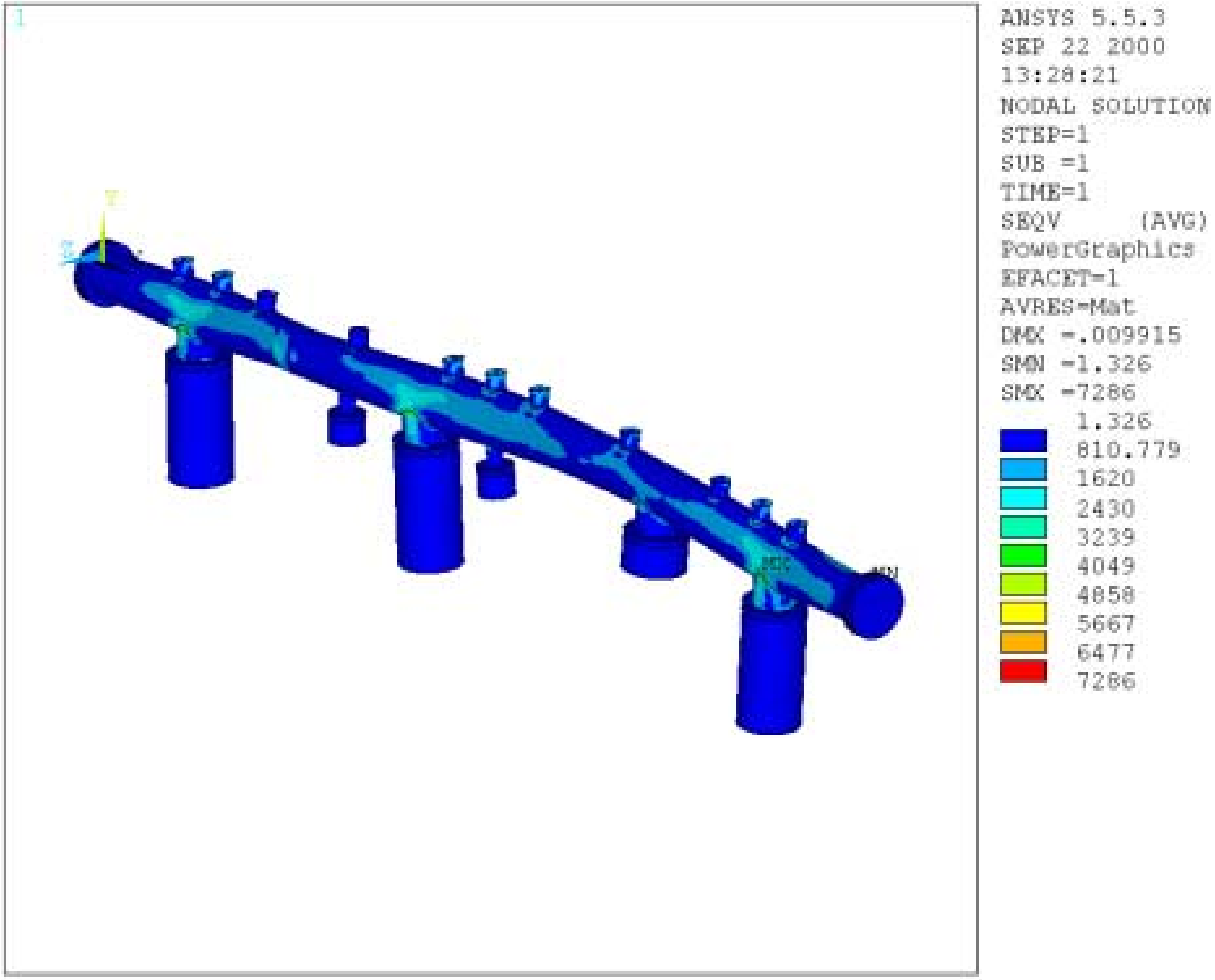
CCL Module Stress Analysis- Gravity Load



CCL Module Stress Analysis- Gravity & Vacuum Load



CCL Module Stress Analysis- Seismic Load



The seismic load consists of a 0.4g axial load, a 0.4g transverse load, and a 0.4g vertical load (1.4g load including gravity).

SNS Facility

Facility Structures

Klystron Gallery

- 30’ wide by 26’ high
- Contains electronics racks & controllers
- Electronics racks distributed along length of gallery
- All cables routed in overhead trays to/from racks and chases

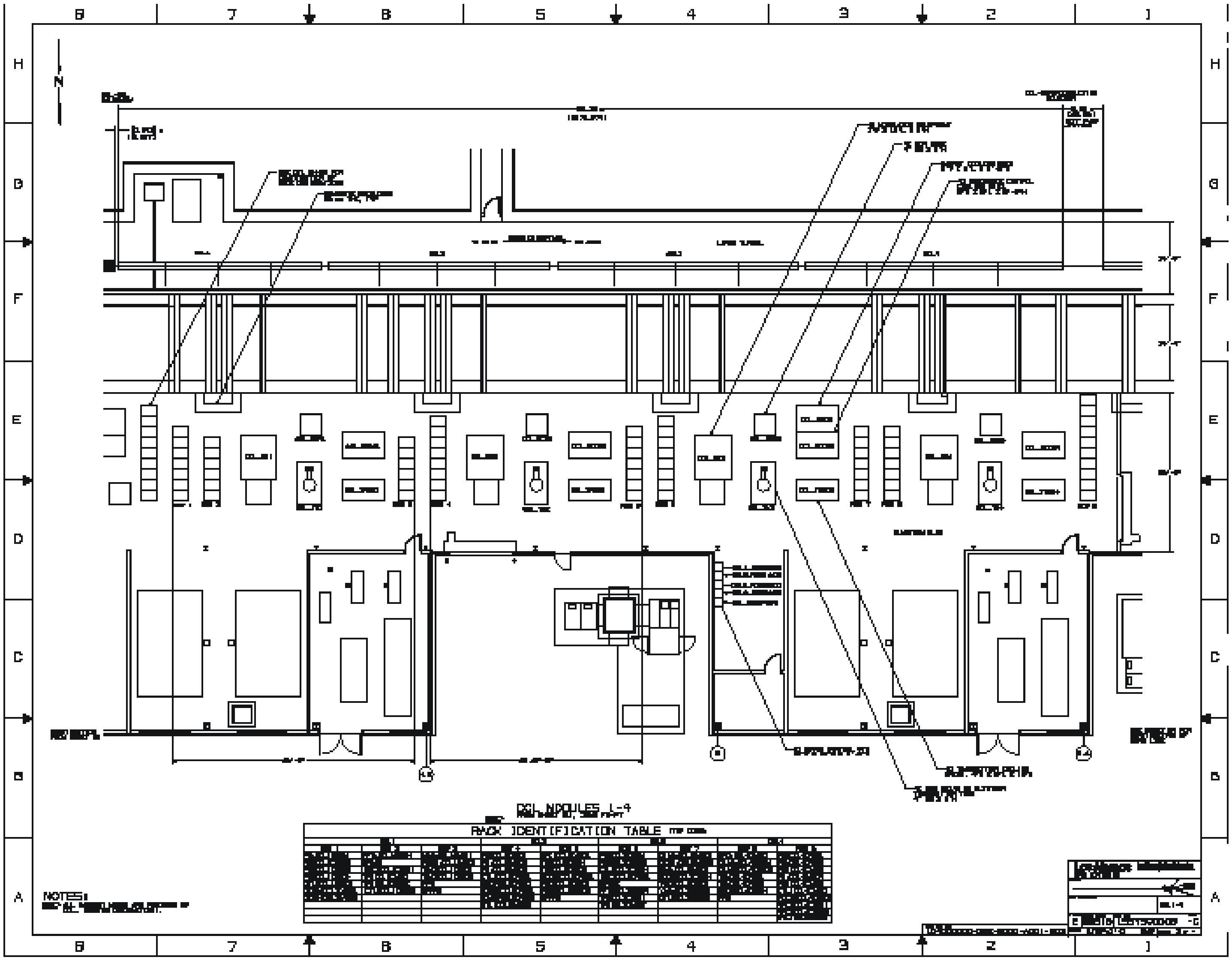
Linac Tunnel

- 14’ wide by 12’ high
- Contains Linac with all vacuum pumps and instrumentation
- Cables routed in overhead trays to/from Linac and chases

Waveguide Chases

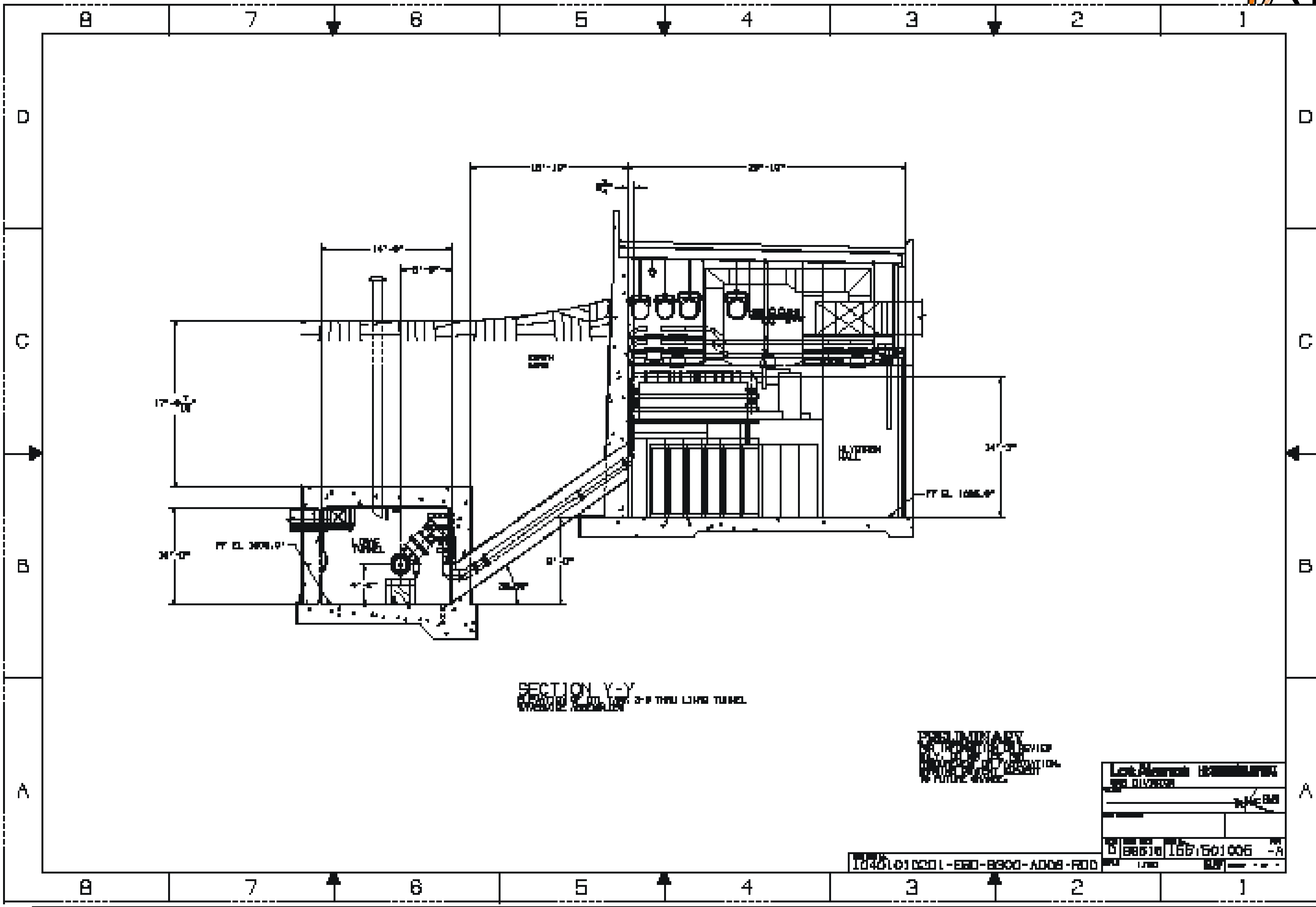
- Chases are angled at 33.5° and run 20’ from gallery to tunnel
- Chases distributed along DTL and CCL
- Chases house conduit for all electrical lines between gallery & tunnel
- Junction boxes on each end of chase for common cables
- Chase design by ORNL

SNS Facility Layout Drawings: Developed with Vacuum System Input

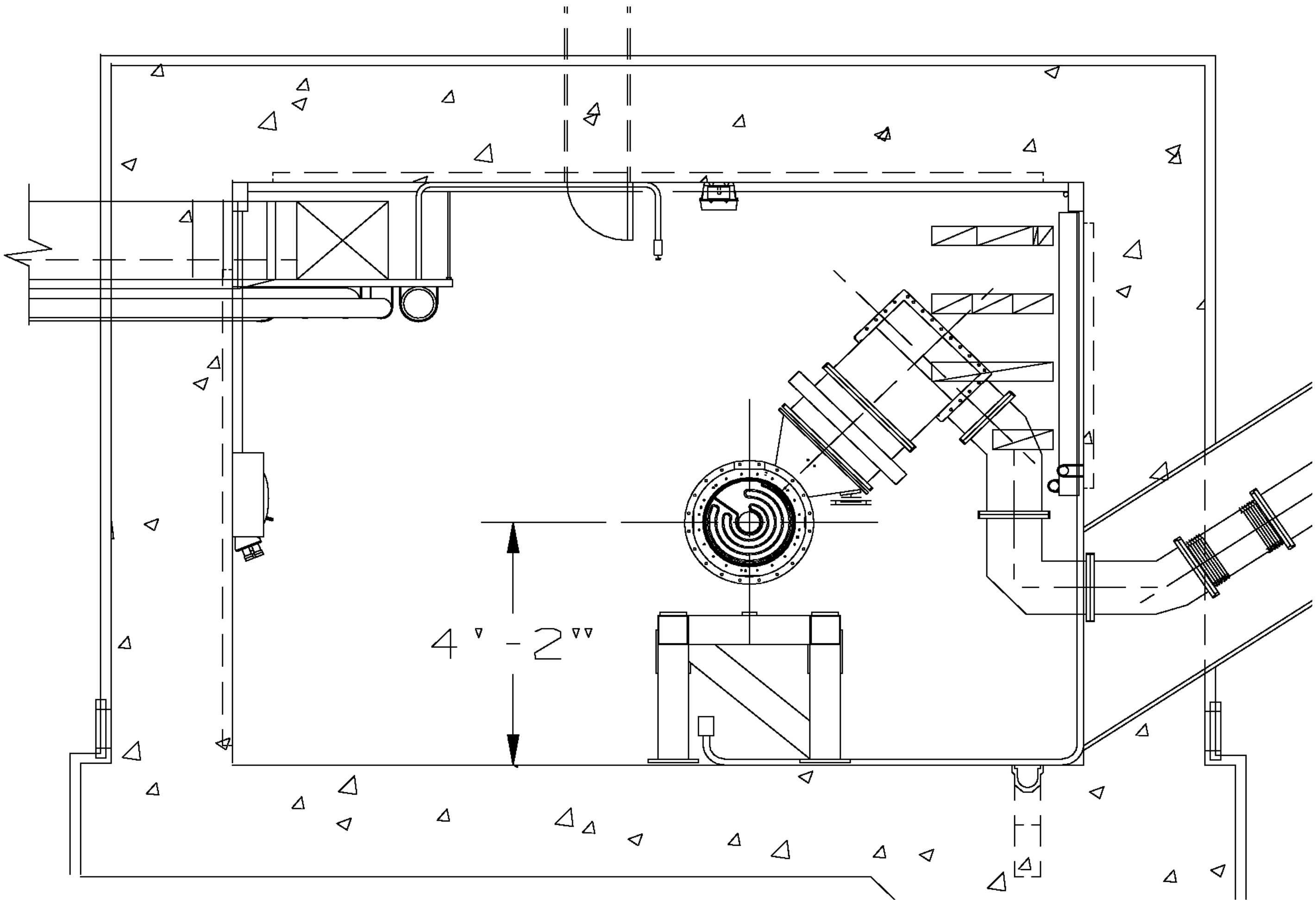


Drawings identify:
- •Rack locations,
- •cable tray routing
- •electrical & compressed air requirements

Facility Cross-section



DTL Tunnel Cross Section



View looking downstream
typical for tanks 3 thru 6

NOTES:

- Limited room beneath and behind the Linac for installation & maintenance activities
- Cable tray routing and J-box locations need to be defined

Final Design Review

Instrumentation and Control

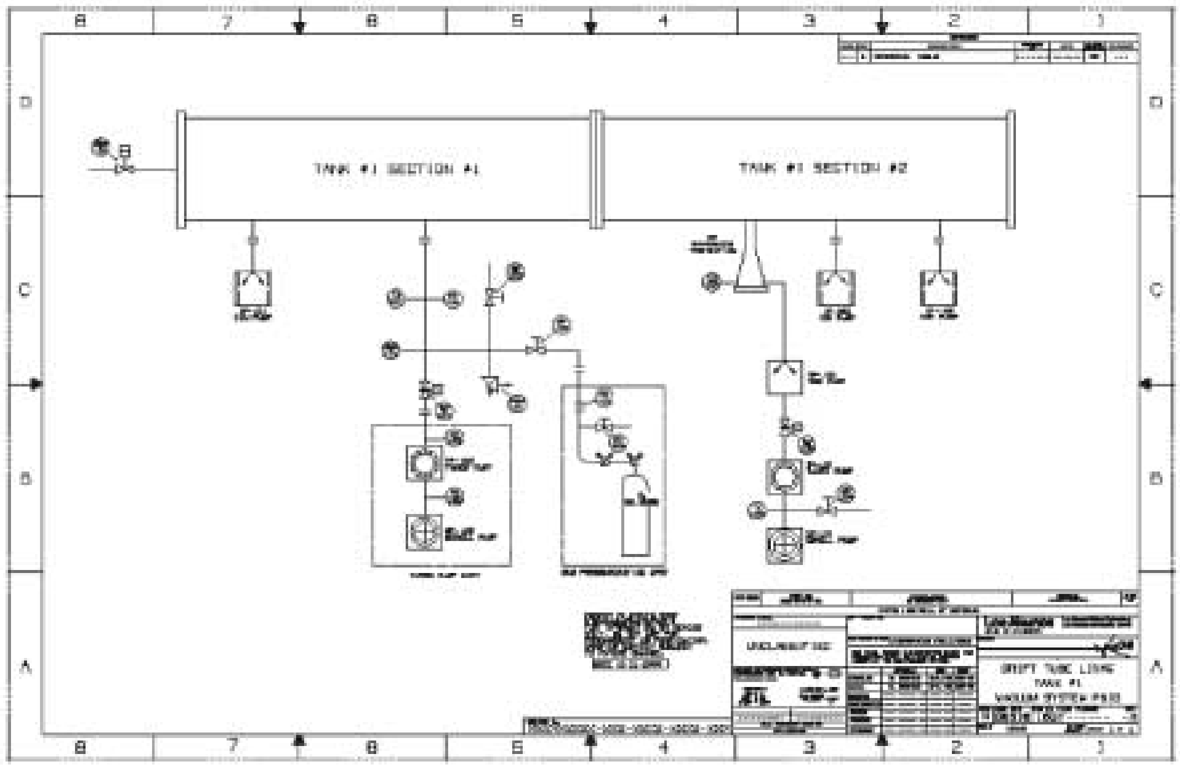
Keith Kishiyama
Electrical Engineer
University of California/Lawrence Livermore National Laboratory
January 19, 2001

Requirements - Instrumentation and Control

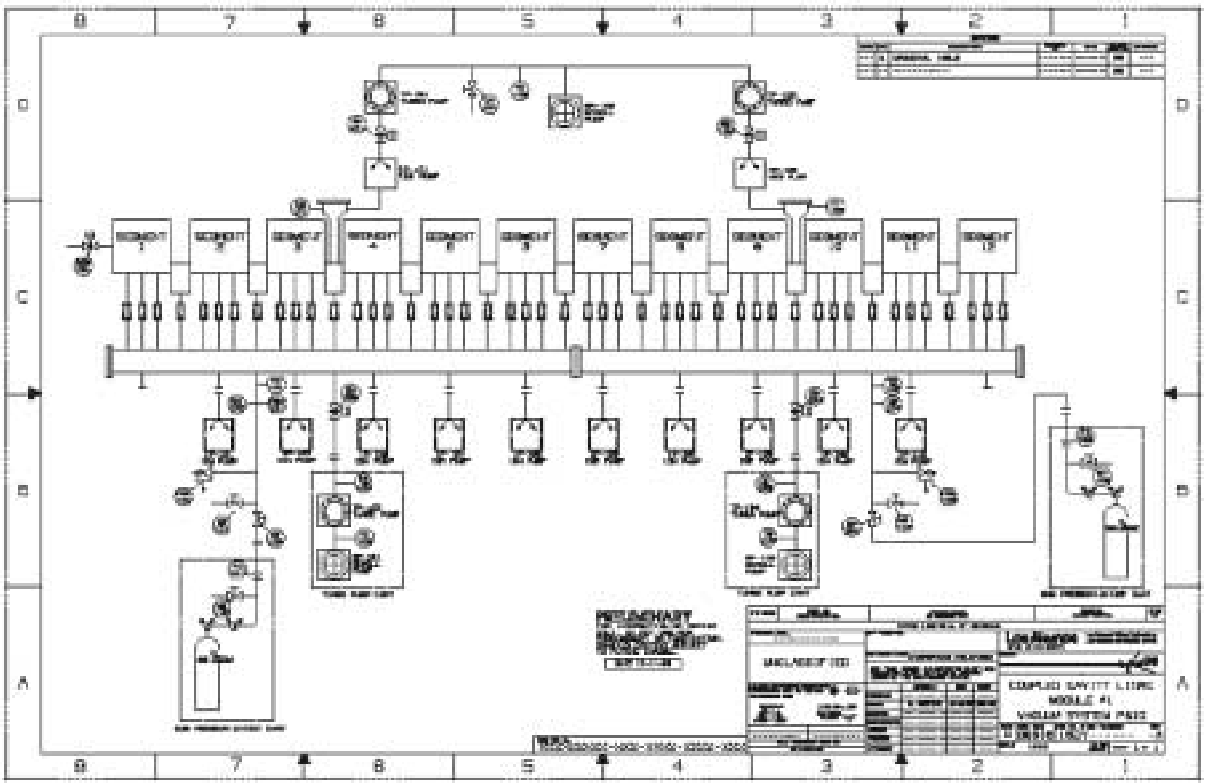
- **Full compliance with SNS standards**
- **Interface to SNS global controls - EPICS**
- **Operate as a stand-alone system for testing/commissioning**
- **Interlocks to protect the vacuum and RF systems**
- **Protect vacuum in the event of a power failure**

SNS DTL and CCL Vacuum Systems

Control system architecture - DTL P&ID



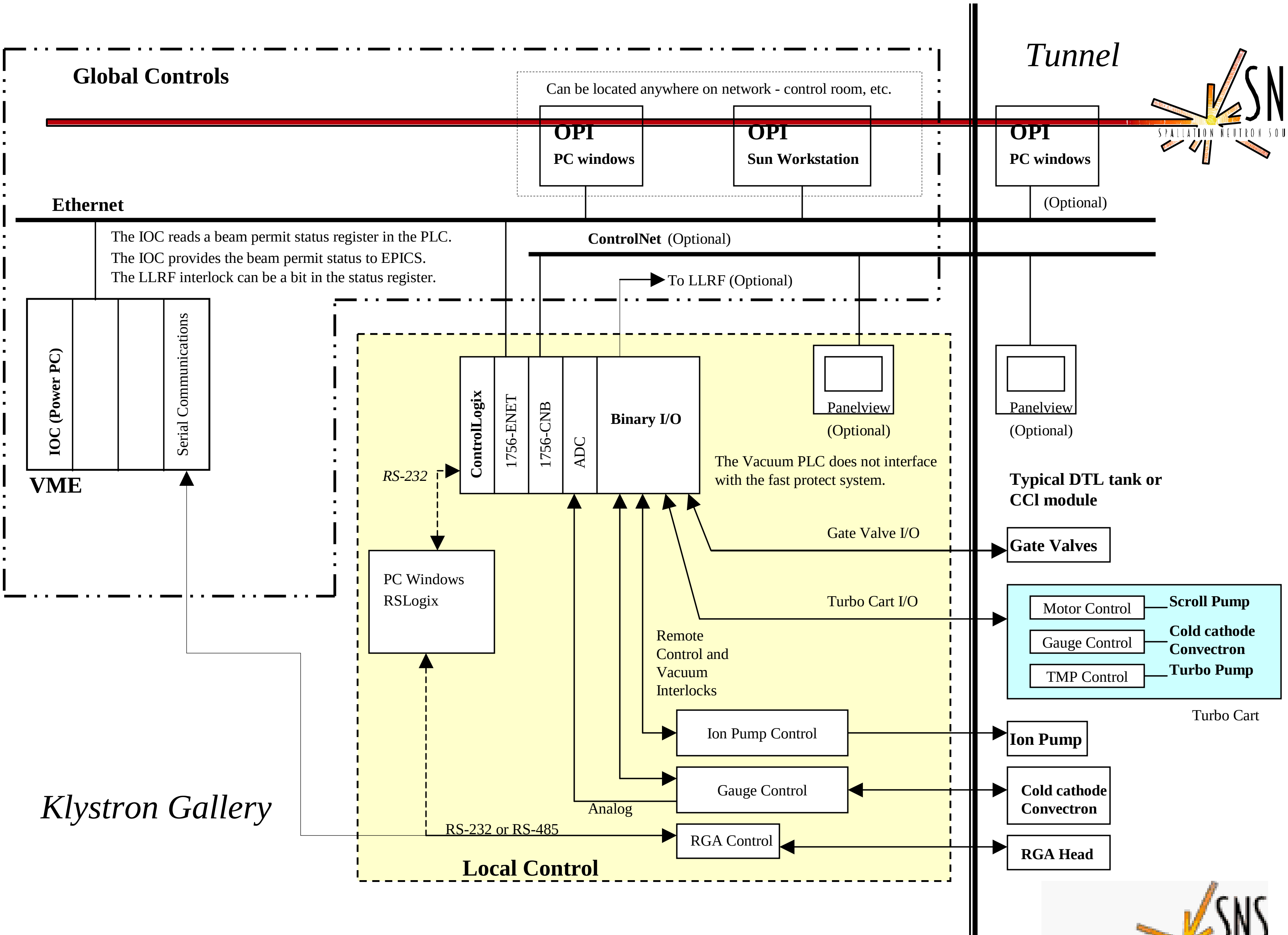
Control system architecture - CCL P&ID



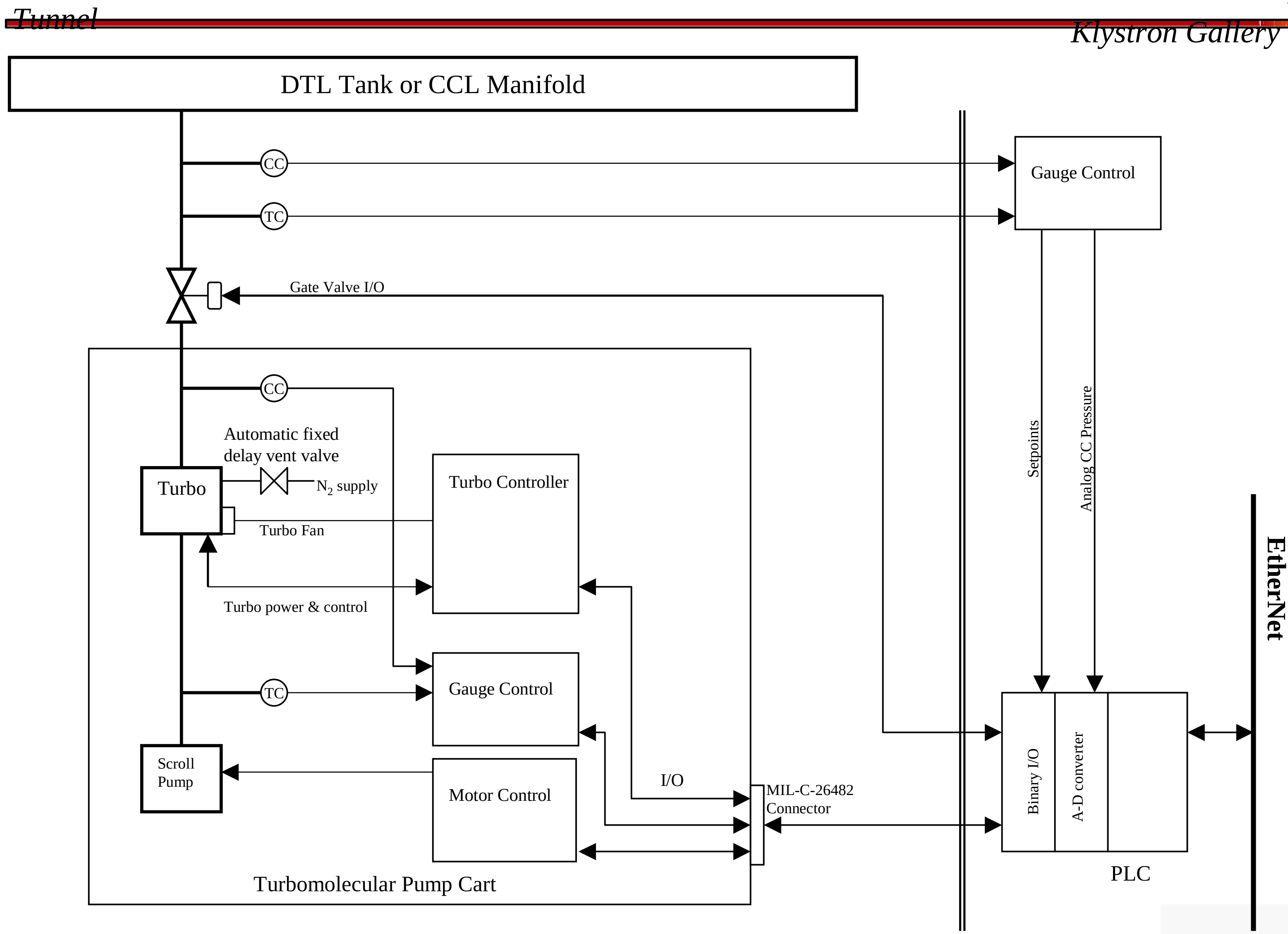
Device and Signal list

Device and Signal Name List for CCL Module 1

System/Subsystem	Device Name	Device	Manufacturer	Model #	Signal Type	Signal name	Location	Module Info (PLC)	Cable/Pair	Comment
CCL_Vac1	SP-101	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-101:Cmd_str				Ladder logic start pump command
CCL_Vac1	SP-101	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-101:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	SP-101	Scroll Pump			24 vac	CCL_Vac1:SP-101:Ctl_run	CCL1 Manifold A	output		Control - Start/stop pump
CCL_Vac1	SP-101	Scroll Pump			24 vdc	CCL_Vac1:SP-101:OL	CCL1 Manifold A	input		Thermal overload
CCL_Vac1	SP-101	Scroll Pump			24 vdc	CCL_Vac1:SP-101:Sts_aux	CCL1 Manifold A	input		Run/Stop status
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_str				Ladder logic start pump command
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_nrm				Ladder logic normal speed command
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_ls				Ladder logic low speed command
CCL_Vac1	TP-103	Turbo pump			relay contact	CCL_Vac1:TP-103:Ctl_run	CCL1 Manifold A	output		Control - start/stop pump
CCL_Vac1	TP-103	Turbo pump			relay contact	CCL_Vac1:TP-103:Ctl_ls	CCL1 Manifold A	output		Control - Normal/low speed
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Sts_run	CCL1 Manifold A	input		Run/stop status
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Sts_ls	CCL1 Manifold A	input		Normal/low speed status
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Fault	CCL1 Manifold A	input		Normal/fault status
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Sp_01	CCL1 Manifold A	input		Operating speed setpoint 1
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Sp_02	CCL1 Manifold A	input		Operating speed setpoint 2
CCL_Vac1	CC-105	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-105:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-105	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-105:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-105	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-105:Ctl_on	Turbo cart	output		Control - CCG on/off
CCL_Vac1	CC-105	Cold Cathode Gauge			0-10v analog	CCL_Vac1:CC-105:P	Turbo cart	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-105	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-105:Sp_01	Turbo cart	input		Ion Gauge pressure setpoint 1
CCL_Vac1	TC-103	Convectron			0-10v analog	CCL_Vac1:TC-103:P	Turbo cart	input		Foreline pressure, 10 milliTorr to 760 Torr
CCL_Vac1	TC-103	Convectron			24 vdc	CCL_Vac1:TC-103:Sp_01	Turbo cart	input		Convectron pressure setpoint 1
CCL_Vac1	CC-103	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-103:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-103	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-103:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-103	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-103:Ctl_on	CCL1 Manifold A	output		Control - CCG on/off
CCL_Vac1	CC-103	Cold Cathode Gauge			0-10v analog	CCL_Vac1:CC-103:P	CCL1 Manifold A	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-103	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-103:Sp_01	CCL1 Manifold A	input		Ion Gauge pressure setpoint 1
CCL_Vac1	TC-101	Convectron			0-10v analog	CCL_Vac1:TC-101:P	CCL1 Manifold A	input		Foreline pressure, 10 milliTorr to 760 Torr
CCL_Vac1	TC-101	Convectron			24 vdc	CCL_Vac1:TC-101:Sp_01	CCL1 Manifold A	input		Convectron pressure setpoint 1
CCL_Vac1	RGA-101	Partial pressure analyzer			RS-232	CCL_Vac1:RGA-101	CCL1 Manifold A			Partial pressure analyzer
CCL_Vac1	PSV-101	Pressure Safety Valve					CCL1 Manifold A			Pressure relief for purge
CCL_Vac1	MV-101	Manual Valve					CCL1 Manifold A			Vent valve to atmosphere
CCL_Vac1	MV-102	Manual Valve					CCL1 Manifold A			Purge gas inlet valve
CCL_Vac1	MV-105	Manual Valve					Gas Press. Cart			Purge line vent valve to atmosphere
CCL_Vac1	FO-101	Flow Orifice					Gas Press. Cart			Flow restriction to prevent over-pressurization
CCL_Vac1	GV-103	Gate Valve			PLC Internal Logic	CCL_Vac1:GV-103:Cmd_opn				Ladder logic open valve command
CCL_Vac1	GV-103	Gate Valve			PLC Internal Logic	CCL_Vac1:GV-103:Cmd_cls				Ladder logic close valve command
CCL_Vac1	GV-103	Gate Valve			24 vdc	CCL_Vac1:GV-103:Sol	CCL1 Manifold A	output		Solenoid to Open/close valve
CCL_Vac1	GV-103	Gate Valve			24 vdc	CCL_Vac1:GV-103:Pos0	CCL1 Manifold A	input		Position indicator
CCL_Vac1	GV-103	Gate Valve			24 vdc	CCL_Vac1:GV-103:Pos1	CCL1 Manifold A	input		Position indicator
CCL_Vac1	SGV-101	Sector Gate Valve			PLC Internal Logic	CCL_Vac1:SGV-101:Cmd_opn				Ladder logic open valve command
CCL_Vac1	SGV-101	Sector Gate Valve			PLC Internal Logic	CCL_Vac1:SGV-101:Cmd_cls				Ladder logic close valve command
CCL_Vac1	SGV-101	Sector Gate Valve			24 vdc	CCL_Vac1:SGV-101:Sol	CCL1	output		Open/close valve
CCL_Vac1	SGV-101	Sector Gate Valve			24 vdc	CCL_Vac1:SGV-101:Pos0	CCL1	input		Position indicator
CCL_Vac1	SGV-101	Sector Gate Valve			24 vdc	CCL_Vac1:SGV-101:Pos1	CCL1	input		Position indicator


Global Controls
Tunnel
Can be located anywhere on network - control room, etc.
OPI
PC windows
OPI
Sun Workstation
OPI
PC windows
(Optional)
Ethernet
The IOC reads a beam permit status register in the PLC.
The IOC provides the beam permit status to EPICS.
The LLRF interlock can be a bit in the status register.
ControlNet (Optional)
To LLRF (Optional)
IOC (Power PC)
Serial Communications
VME
ControlLogix
1756-ENET
1756-CNB
ADC
Binary I/O
Panelview
(Optional)
Panelview
(Optional)
The Vacuum PLC does not interface with the fast protect system.
RS-232
Typical DTL tank or CCl module
Gate Valve I/O
Gate Valves
PC Windows
RSLogix
Turbo Cart I/O
Motor Control
Scroll Pump
Gauge Control
Cold cathode Convectron
TMP Control
Turbo Pump
Turbo Cart
Remote Control and Vacuum Interlocks
Ion Pump Control
Ion Pump
Gauge Control
Cold cathode Convectron
Analog
Klystron Gallery
RS-232 or RS-485
RGA Control
RGA Head
Local Control

SNS DTL &CCL Vacuum Systems



Vacuum System - Software and Control Methodology

- **Device and signal list - used to assign PLC I/O, registers**
- **After I/O and registers are assigned, ready for ladder logic**
  - Ladder logic - sequence of interlocks, setpoints, valve positions
  - Basic structure is similar for most vacuum systems
- **PLC I/O and register map is also used by EPICS**
- **EPICS control of LEDA/RFQ vacuum is fully operational**

Vacuum System Controls

- **SNS standards - hardware**
  - ControlLogix Programmable Logic Controllers
  - Standards in progress: pump controllers, gauge controllers
    - PLC control of turbo and ion pumps via simple contact closure command rather than RS-485/RS-232
- **SNS standards - software**
  - RSLogix, PanelView, RSWire - development environments for PLC provided by vendor
  - PLC programming guidelines - memo from B. Dalesio
  - EPICS - structured environment

Vacuum System Controls - Standalone operation

- **Each tank and module has its own PLC**
- **PanelView operator interface terminals will be used when EPICS is not available**
- **Required in RATS building**
  - Certification operation of pumps, valves, instrumentation
  - Leak checking
- **Laptop computers can be plugged into any Ethernet port to provide a operator interface**
- **The PLC will accept commands from EPICS or PanelView**

Vacuum System Instrumentation

- **Although vacuum pressure can be derived from ion pump current, one ion gauge per tank or manifold is needed to provide robust control of the vacuum system**
- **Cold cathode will be used**
  - lower cost per gauge/channel
  - simple, rugged
  - less accurate

Vacuum System Instrumentation

- **RGA - one per CCL module and DTL tank**
  - Quadrupole type
  - Stand-alone application running under Windows
  - SNS will port 4 key functions to EPICS
    - » Start/initialize RGA
    - » Sequential scan - spectrum from 1 to 100 amu
    - » Random scan - table of selected masses
    - » Close/shutdown
  - Other functions handled by laptop computer

Interlocks

- **Vacuum operations**
  - Protection for equipment
- **Safety**
  - Protection for personnel

Interlocks - Safety

- **Other than the pressure safety of the vacuum vessel, the operation of the vacuum system poses only a few hazards**
  - Ion pumps operate at up to 7000 VDC, 100mA
  - Turbo pumps operate at 56 VAC, 700 Hz
  - Scroll pumps operate at 120 VAC, 60 Hz
  - Electropnuematic valves operate with 125 psi

Interlocks - Vacuum Operations

- **General purpose interlocks**
  - Open or close valves, start or stop pumps, etc
    - Generated from various inputs - PLC, hardware, software
- **Fast ion gauge interlock - RF window protection**
  - Analog output - response less than 20 milliseconds
  - A/D converter
  - Software programmable levels for RF conditioning

Instrumentation and Controls

Global Control System Interface and Responsibilities

for DTL and CCL Vacuum Systems

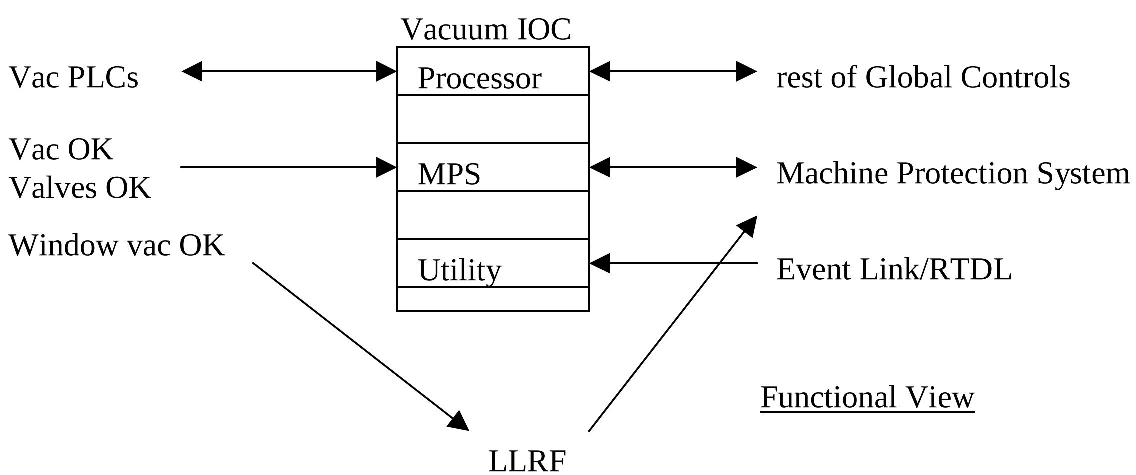
Final Design Review
January 19, 2001

Pilar Marroquin
SNS Linac Controls, SNS-4
665-3172 pilar@lanl.gov

Global Control System

Interfaces

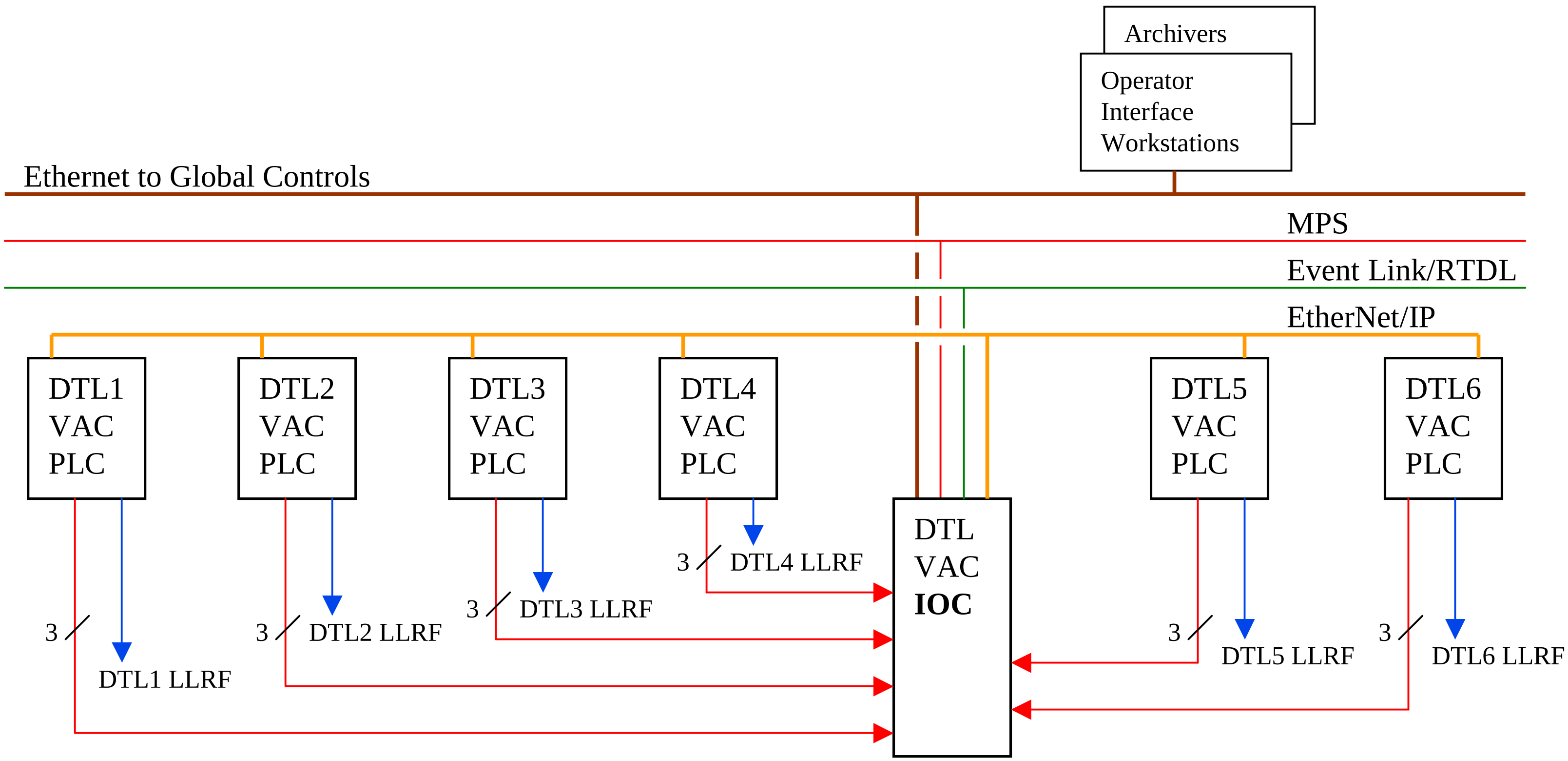
- Vacuum IOCs interface to Global Controls, MPS, Event Link/RTDL
- Global Controls includes plant-wide networks, workstations, archivers, loggers, etc.
- Machine Protection System for equipment protection
- Event Link/RTDL for fast distribution of Timestamp, Modes, Events



IOCs, PLCs, Connections Block Diagram

- 1 IOC for 6 DTL Vacuum Systems
- 1 IOC for 4 CCL Vacuum Systems
- TCP/IP Ethernet from IOC to Global Controls
- EtherNet/IP Ethernet, from IOCs to PLCs

IOCs, PLCs, Connections Block Diagram (cont.)

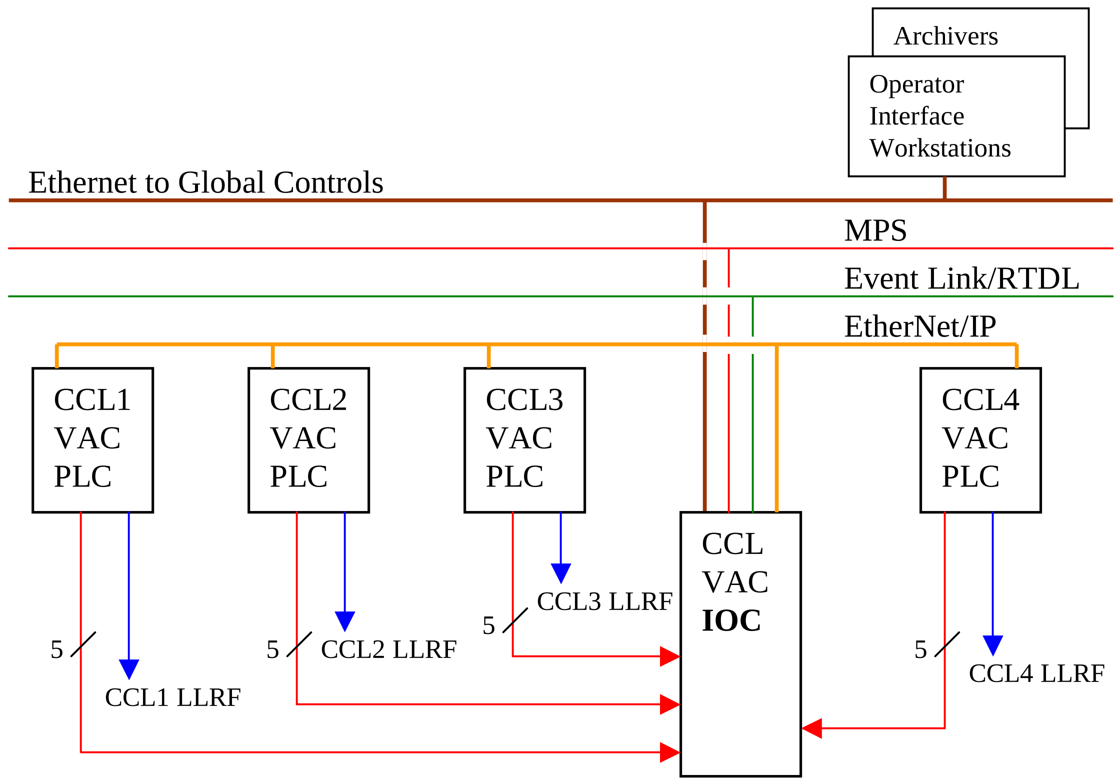


3 signals from each DTL to MPS Beam Permit
Cavity vacuum, Window vacuum, Beamline valve

1 "RF Permit" signal from each DTL to LLRF
Window vacuum

In rack:
ctl:dtl4 cab01

IOCs, PLCs, Connections Block Diagram (cont.)



5 signals from each CCL to MPS Beam Permit
2 Cavity vacuum, 2 Window vacuum, 1 Beamline valve

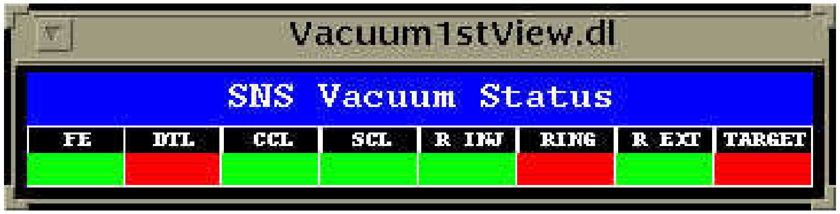
In rack:
ctl:ccl3 cab01

1 "RF Permit" signal from each CCL to LLRF
2 Window vacuums

Global Control System

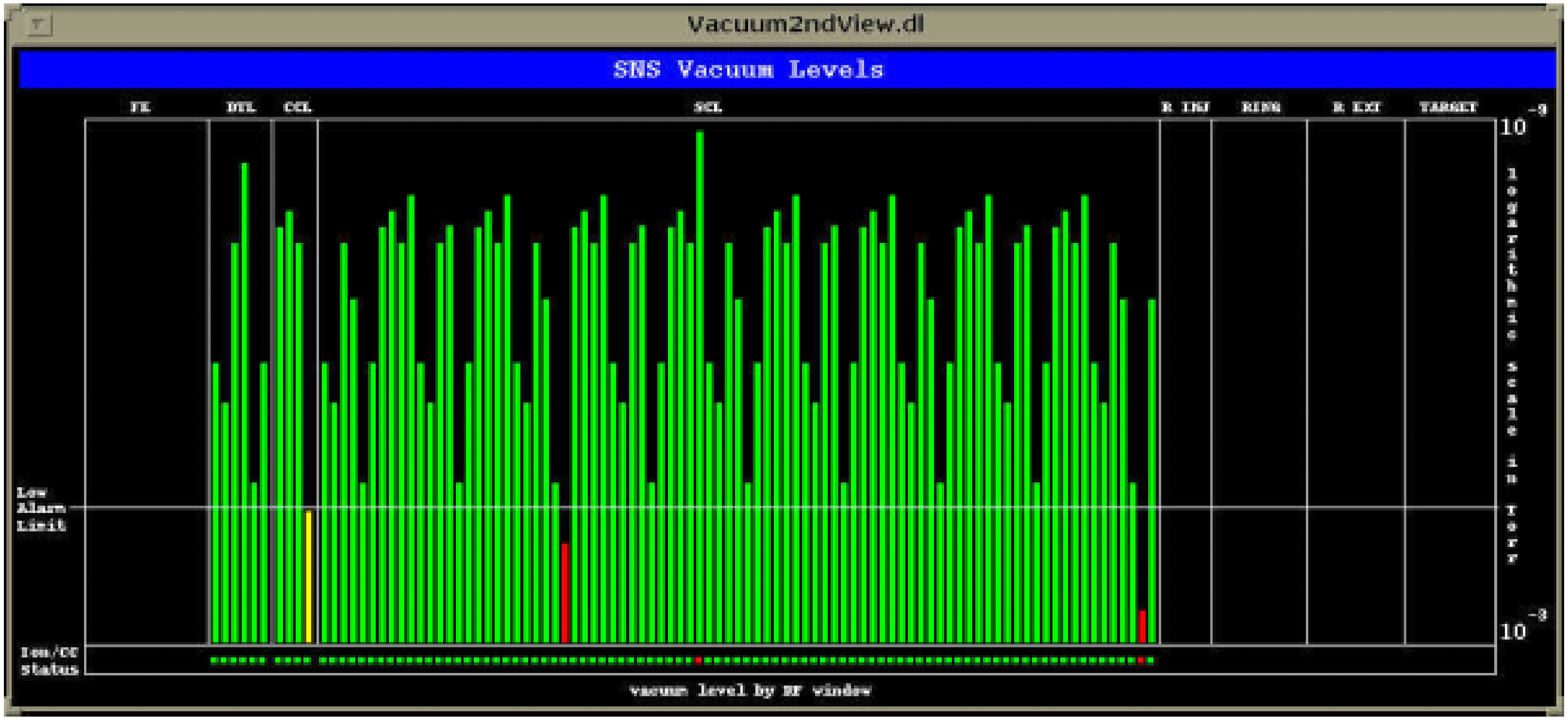
Operator Interface Screens

- Summary top level view
- Bar chart view by RF window vacuums
- Bar chart view by Cavity vacuums
- Detail view, monitoring and control via P&ID screens



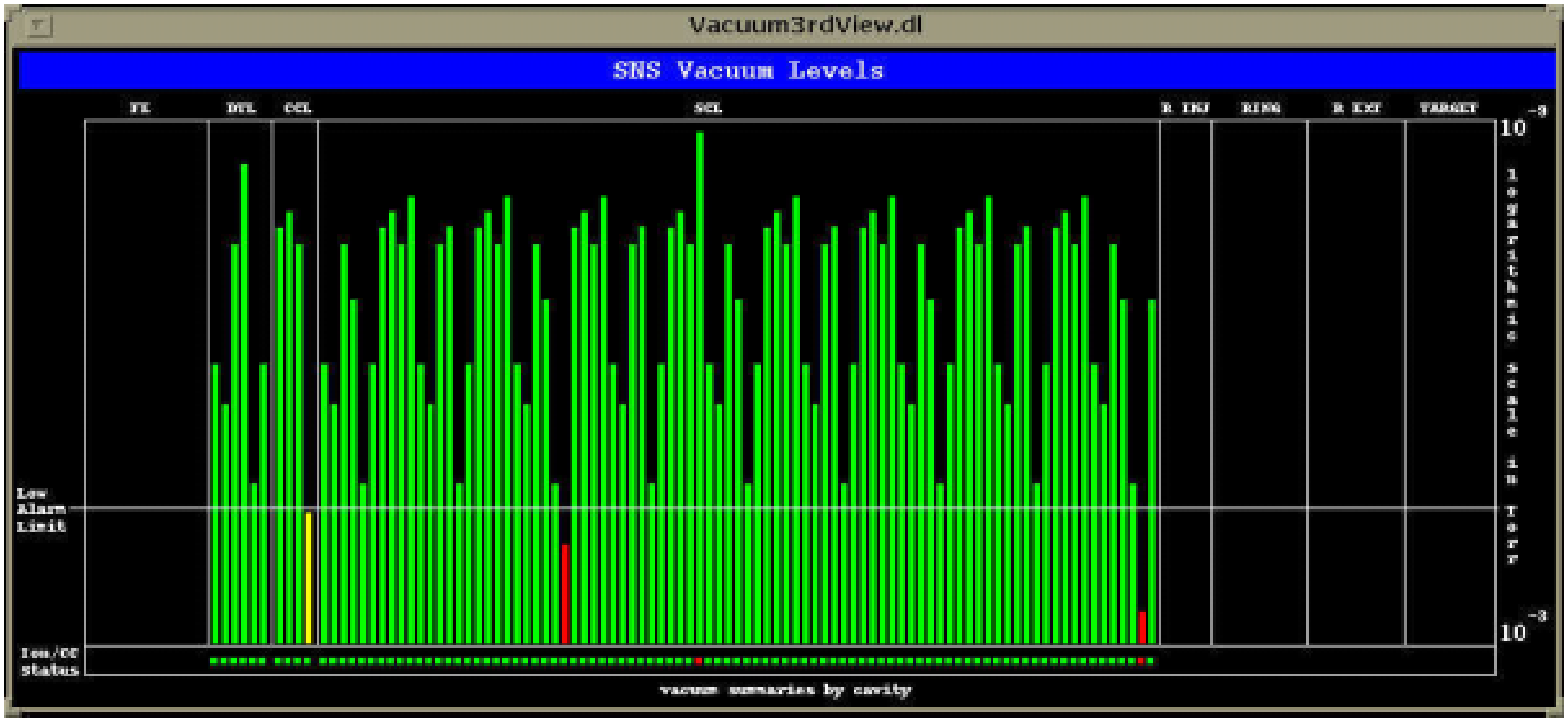
Top level view

Operator Interface Screens (cont.)



View by RF windows

Operator Interface Screens (cont.)



View by Cavities

Hot Model Plans

- 1 IOC to support Vacuum System and RCCS
- Partial prototype system to be developed
- Development of operator interface screens
- Build IOC and develop channel databases
- Test communication drivers and interfaces
- Identify control and monitoring issues at the IOC level
- Deliver configuration when the PLC control system is delivered ~April, 2001

Procurement, Fabrication, & QA

DTL Hardware Costs

Item	Qty	Unit Cost $	Discount %	Total Cost $
Ion Pump, controller, cable 300L/sec	18	$7,895	25	$106,582
Window Turbo Pump & controller, 70 Liter/sec	6	$5,352	25	$24,084
Window NEG pump & controller (capacitor)	6	$6,400	25	$28,800
Dry scroll backing pump	6	$3,000	25	$13,500
Extension cables 100 ft	18	$1,000	25	$13,500
Turbomolecular Pump Cart	6	$19,350	10	$104,490
Pneumatic and Manual Valves				$30,672
Miscellaneous fittings, gaskets & fasteners	6	$3,500	20	$16,800
Pressure Relief Valve	6	$270	10	$1,620
Gas throttling device	6	300	10	$1,620
Gas bottle & regulators	1	$1,000	0	$1,000
Gauges & Controllers				$25,672
Residual Gas Analyzer, 1-100 AMU	6	$8,430	10	$45,522
Equipment Rack, fan, power strip, grounding	7	$2,000	10	$12,600
PLC (plus cards, input & output connect)	7	$18,200	10	$114,800
Local computer & software	1	$5,500	10	$4,950
			Grand Total	**$510,598**

CCL Hardware Costs

Item	Qty	Unit Cost $	Discount %	Total Cost $
Ion Pump, controller, cable, 300 Liter/sec	40	$7,895	25	$236,850
Window Turbo Pump & controller, 70 Liter/sec	8	$3,844	25	$32,112
Window NEG pump , controller(capacitor)	8	$6,400	25	$38,400
Dry scroll backing pump	8	$3,000	25	$18,000
Extension cables 100 ft	24	$1,000	25	$18,000
Turbomolecular Pump Cart	2	$19,350	10	$34,830
Pneumatic and Electric Valves				$41,896
Miscellaneous fittings, gaskets & fasteners	8	$2,000	20	$12,800
Pressure Relief Valve	8	$270	10	$1,944
Gas throttling device	8	300	10	$2,160
Gas bottle & regulators	1	$1,000	0	$1,000
Misc. Hoses, fittings, gaskets	1	$12,000	20%	$9,600
Flanges, bellows, seals, etc				$154,058
Vacuum Manifold w/nipples, 6 in Tube	8	$8,000	0	$64,000
Gauges & Controllers				$35,521
Residual Gas Analyzer, 1-100 AMU	4	$8,430	10	$30,348
Equipment Rack, fan, power strip, grounding	8	$2,000	10	$14,400
PLC (plus cards, input & output connect)	4	$18,000	10	$72,000
Valve interface/indicator box	4	$200	0	$800
Local computer & software	1	$5,500	10	$4,950
			Grand Total	**$824,669**

Procurement Process

- **Detailed performance specification sheets and engineering drawings developed for all vacuum hardware (I.e., pumps, instrumentation, controllers, valves, manifolds, etc.)**
- **Proposed Vendors obtained from LANL/ORNL generated short-list**
- **ORNL establishes BOAs for standard types of equipment (pumps, instrumentation, controllers).**
- **LANL establishes contracts for manifolds, bellows, CCL intersegment hardware, etc.**

Vendor selection will be competitive and proposals reviewed and judged by the following criteria:

- Cost
- Fabrication & testing facilities
- Past performance/references
- Manufacture & delivery plan
- Subcontracting plans
- QA program
- Ability to meet staggered delivery schedule
- On-site survey of facilities

Procurement Quality Assurance

Statements of Work generated for each procurement. QA components include:

- Vendor-supplied QA program
- Vendor facilities - references and on-site inspections. UC personnel to witness any/all inspections and tests
- Qualification and certification of personnel for manufacturing, testing, inspection, & certifications
- Design review prior to production
- Inspection and testing procedures/reports supplied by vendor and signed off
- Engineering drawings supplied in electronic & paper by vendor
- Certifications of calibration and conformance signed & supplied by vendor for each shipment
- Failure/nonconformance reporting by vendor & corrective action plan
- Manuals supplied by vendor for storage guidelines, installation and testing procedures, operating instructions, maintenance, safety, trouble shooting, warranty and contact information.
- Warranties to take affect from initial time of operation - not delivery
- Packaging, labeling, and shipping requirements
- Testing and certification plans at the RATS building

Assembly, Installation, & Certification

DTL Assembly & Installation Tasks

Assembly in RATS Building

- Mount spool pieces
- Mount vacuum pumps, valves, & instrumentation to spool pieces and RF window waveguide
- Assemble & wire electronics rack with pump & gauge controllers, PLC, & touchscreen
- Connect pumps to controllers
- Connect pneumatic valves to pressurized gas source
- Certify operation of equipment
- Leak check DTL tank
- Certify assembly completion

Installation in Linac Tunnel & Klystron Gallery

- Remove main pumps for transport to Linac tunnel, cover ports
- Re-attach main pumps in tunnel
- Route all cabling through trays and waveguide chases. Connect junction boxes
- Connect power/communication cables to pumps & instrumentation
- Connect gas pressurization sources to valves
- Leak check DTL tank
- Install controls system rack & connect to cables & global controls
- Perform vacuum system check-out

CCL Assembly & Installation Tasks

Assembly in RATS Building

- Attach vacuum manifold mounts to support structure
- Position and align vacuum manifolds in each module half
- Mount vacuum pumps, valves, & instrumentation to manifolds and RF window waveguides
- Connect bellows between RF structures and manifold
- Assemble & wire electronics rack with pump & gauge controllers, PLC, & touchscreen
- Connect pumps to controllers
- Connect pneumatic valves to pressurized gas source
- Certify operation of equipment
- Leak check CCL module

Installation in Linac Tunnel & Klystron Gallery

- Remove main pumps for transport to Linac tunnel, cover ports
- Re-attach main pumps in tunnel
- Route all cabling through trays and waveguide chases. Connect junction boxes
- Connect power/communication cables to pumps & instrumentation
- Connect gas pressurization sources to valves
- Leak check CCL module
- Install controls system rack & connect to cables & global controls
- Perform vacuum system check-out

RATS Building Requirements

- Storage space for vacuum components
- Portable clean tent, class 1000
- Portable leak detector
- Portable He & N_2 gas sources
- Vacuum handling and cleaning procedures/equipment
- Standard tools for vacuum equipment assemblies
- Electrical power and compressed air for DTL/CCL vacuum systems
- Trained and certified vacuum technicians for cleaning, assembling, inspecting, leak checking, testing, trouble shooting

Safety & Reliability

Safety - Hazard Analysis & Protective Measures

- NEG Pump - Pyrophoric getter material can combust if exposed to air. Use vacuum interlocks and N_2 pressurization to minimize risk.
- NEG Pump - Pump can sorb several liters of H_2. Use regeneration cycle to slowly dissipate H2 and dilute with scroll pump ballast.
- Ion Pump - 7000 VDC. High voltage connectors on pumps have retainers. Connectors on controller protected by locked cabinet.
- Turbo and Scroll Pumps have built-in overload protectors
- Valves will fail in the closed position to protect vacuum environ.
- Gas Pressurization - throttling device and relief valve to prevent overpressurization and failure. Manual vents to atmoshpere.
- Electronics removed from radiation environ. & rad hard cables used.
- RF Grills used to prevent RF leakage to pumps and gauges
- Electronics Racks - Locks on rack door and touchscreen
- Operational hazards and protective measures - Listed in Reports

Personnel Safety

- ORNL Safe Operating Procedures and Hazard Control Plans needed for assembly, installation, testing, and commissioning
- All electrical policies must be compliance with DOE and ORNL ES&H requirements
- MSDS sheets for vacuum related material on file
- Vacuum personnel will be trained and certified in standard vacuum cleaning, handling, and operating procedures
- Radiation protection plans for handling contaminated vacuum hardware must be in place @ ORNL
- LANL will provide ORNL with assembly, installation, operation, & maintenance manuals/guidelines

Reliability

- Reliability, Availability, Maintenance, and Inspectability (RAMI) program developed for SNS but then replaced by "Best Engineering Practices"
- RAMI identified an SNS availability of 85% and a LINAC availability of 99% (vacuum = ?)

Best Engineering Practices for the DTL/CCL Vacuum

- Previous accelerator vacuum system designs incorporated (LANSCE, APT, LEDA, APS)
- PDR and FDR committees made up of accelerator vacuum experts from SLAC, APS, RHIC, CEBAF, LANSCE, DAHRT, & APT/LEDA.
- Ion pumps used for continuous operation (high reliability)
- Valved turbo cart ports for conditioning and back-up
- Redundancy in vacuum pumps (designed pressure margin = 2)
- Tank & module isolation valves, redundant gauges, UPS, N2,

Project Summary and Schedule

Design Task Summaries

Completed Activities

- Hardware layouts, P&IDs, & specification sheets
- Vacuum analyses for DTL tank, CCL module, drift tubes, RF windows, beam diagnostics
- Mechanical designs and analyses, assembly drawings
- Control system architecture & safety/hazard assessments
- Procurement specs & plans, and QA plans
- Assembly & Installation plans

On-going Activities

- Detail drawings of CCL vacuum manifold
- Checking/correcting drawings
- Programming of prototype control system
- Wiring and rack layout diagrams
- Identifying/satisfying all global control interface requirements
- Development of assembly, installation, testing, & operations manuals
- Finalizing procurement specs with ORNL/SNS

DTL Vacuum Cost Summaries

Labor Costs

Activity	Total Man-hours	Baseline Costs ($k)	Expenditures to Date ($k)	Additional Expenditures Expected ($k)	Total Expenditures ($k)	Overrun (-) or Savings (+)($k)
Preliminary Design	1598	175.0	175.0	0.0	175.0	0
Final Design	3916	439.1	295.0	100.0	395.0	44.1
Procurement Development	400	23.6	0.0	23.6	23.6	0.0
Documentation	100	0.0	0.0	6.6	6.6	-6.6
Fabrication	160	9.4	0.0	9.4	9.4	0.0

Hardware Costs

Equipment	Baseline Costs ($k)	New Costs base on Final Design ($k)	Variance ($k)	Reason for Variance
Vacuum Pumps	293.2	315.2	-22.0	RF window pumping
Plumbing	22.8	60.5	-37.7	Evolving design of Linac and hardware changes
Instrumentation	46.4	83.3	-36.9	The additional instrumentation on the RF window is needed for safety interlocks with the RF power.
Control System	151.4	154.8	-3.4	Design enhancements and assembly/installation/commissioning requirements - individual vacuum control systems. Costs of the PLCs were dropped previously from WBS 1.9.4.
TOTAL	513.8	613.8	-100.0	

CCL Vacuum Cost Summaries

Labor Costs

Activity	Total Req'd Man-hours	Baseline Costs ($k)	Expenditures to Date ($k)	Additional Expenditures Expected ($k)	Total Expenditures ($k)	Overrun (-) or Savings (+)($k)
Preliminary Design	2284	251.5	251.5	0.0	175.0	0
Final Design	5280	568.9	330.4	160.0	430.4	78.5
Procurement Development	400	23.6	0.0	23.6	23.6	0.0
Documentation	100	0.0	0.0	6.6	6.6	-6.6
Fabrication	320	18.9	0.0	18.9	18.9	0.0

Hardware Costs

Equipment	Baseline Costs ($k)	New Costs base on Final Design ($k)	Variance ($k)	Reason for Variance
Vacuum Pumps	325.4	405.4	-80	RF window pumping
Plumbing	193.3	311.8	-118.5	Evolving design of Linac and hardware changes
Instrumentation	61.9	77.1	-15.2	The additional instrumentation on the RF window is needed for safety interlocks with the RF power.
Control System	56.8	107.8	-51.0	Design enhancements and assembly/installation/commissioning requirements - individual vacuum control systems. Costs of the PLCs were dropped previously from WBS 1.9.4.
TOTAL	637.5	902.1	-264.6	

Fully Integrated Project Schedule

DTL Vacuum System

Activity	Early Start Date	Early Finish Date
Documentation & Manuals	23-Jan-01	20-Feb-01
Control System Programming	23-Jan-01	01-May-01
Purchase Request to Purchase Order	21-Feb-01	12-Jul-01
Tank 1 Vacuum Fab & Ship	1-Oct-01	31-Oct-01
Tank 2 Vacuum Fab & Ship	1-Nov-01	5-Dec-01
Tank 3 Vacuum Fab & Ship	6-Dec-01	14-Jan-02
Tank 5 Vacuum Fab & Ship	15-Jan-02	14-Feb-02
Tank 6 Vacuum Fab & Ship	15-Feb-02	19-Mar-02
Tank 4 Vacuum Fab & Ship	20-Mar-02	18-Apr-02
Tank 1 Controls/Racks Fab/Ship	23-Oct-01	26-Mar-02
Tank 2 Controls/Racks Fab/Ship	27-Mar-02	23-Apr-02
Tank 3 Controls/Racks Fab/Ship	24-Apr-02	21-May-02
Tank 5 Controls/Racks Fab/Ship	22-May-02	19-Jun-02
Tank 6 Controls/Racks Fab/Ship	20-Jun-02	18-Jul-02
Tank 4 Controls/Racks Fab/Ship	19-Jul-02	15-Aug-02
Tank 1 Vacuum Assembly	23-Sep-02	4-Oct-02
Tank 2 Vacuum Assembly	20-Nov-02	5-Dec-02
Tank 3 Vacuum Assembly	3-Feb-03	14-Feb-03
Tank 5 Vacuum Assembly	3-Apr-03	16-Apr-03
Tank 6 Vacuum Assembly	11-Jun-03	24-Jun-03
Tank 4 Vacuum Assembly	8-Sep-03	19-Sep-03
Tank 1 Vacuum Installation	31-Mar-03	23-May-03
Tank 2 Vacuum Installation	27-Aug-03	8-Oct-03
Tank 3 Vacuum Installation	11-Sep-03	23-Oct-03
Tank 5 Vacuum Installation	25-Jun-03	6-Aug-03
Tank 6 Vacuum Installation	25-Jun-03	6-Aug-03
Tank 4 Vacuum Installation	8-Mar-04	30-Apr-04

CCL Vacuum System

Activity	Early Start Date	Early Finish Date
Documentation & Manuals	23-Jan-01	20-Feb-01
Control System Programming	23-Jan-01	01-May-01
Purchase Request to Purchase Order	21-Feb-01	12-Jul-01
Module 2 Vacuum Fab & Ship	1-Oct-01	5-Dec-01
Module 3 Vacuum Fab & Ship	6-Dec-01	14-Jan-02
Module 4 Vacuum Fab & Ship	15-Jan-02	14-Feb-02
Module 1 Vacuum Fab & Ship	15-Feb-02	19-Mar-02
Module 2 Controls/Racks Fab/Ship	1-Oct-01	5-Dec-01
Module 3 Controls/Racks Fab/Ship	6-Dec-01	14-Jan-02
Module 4 Controls/Racks Fab/Ship	15-Jan-02	14-Feb-02
Module 1 Controls/Racks Fab/Ship	15-Feb-02	19-Mar-02
Module 2 Vacuum Assembly	6-Mar-02	26-Jun-02
Module 3 Vacuum Assembly	27-Jun-02	28-Aug-02
Module 4 Vacuum Assembly	29-Aug-02	31-Oct-02
Module 1 Vacuum Assembly	20-Nov-02	31-Jan-03
Module 2 Vacuum Installation	14-Jan-03	12-Mar-03
Module 3 Vacuum Installation	13-Mar-03	9-Apr-03
Module 4 Vacuum Installation	10-Apr-03	7-May-03
Module 1 Vacuum Installation	2-Sep-04	29-Oct-04