# *Spallation Neutron Source*

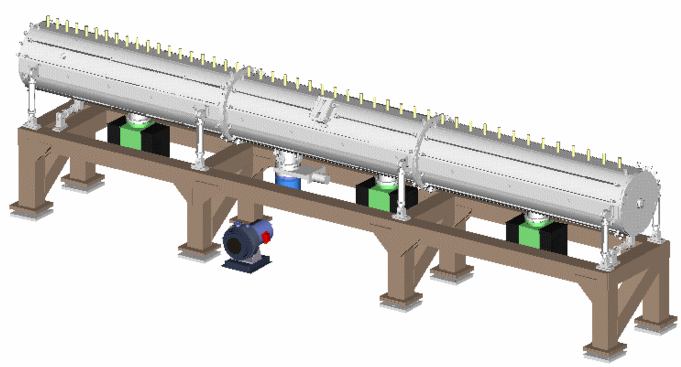
# *Drift Tube Linac Vacuum System*

# *Final Design Report*

(SNS-104020400-DE0001-R00)

by:

J. D. Bernardin, G. Bustos, R. Gillis, K. Kishiyama, R. Meyer Sr.,
W. Morrison, W. Nederbragt, S. Shen, L. Tung



Accelerator Technologies Engineering Group
Lawrence Livermore National Laboratory
and
Mechanical Engineering Group
Spallation Neutron Source Division
Los Alamos National Laboratory

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## 1.0 Introduction

The Spallation Neutron Source (SNS) is an accelerator-based neutron research facility being designed for scientific and industrial research and development. Specifically, SNS will generate and use neutrons as a diagnostic tool, much like X-rays, for medical purposes as well as physical, chemical, biological, and material sciences. The SNS will produce neutrons by bombarding a heavy metal target with a high-energy beam of protons, generated and accelerated with a linear particle accelerator, or linac. To effectively accelerate the protons, the linac requires an evacuated environment. This vacuum serves two purposes. First, the gas pressure in the accelerating structure must be minimized ($<10^{-6}$ Torr) to provide an acceptable environment for the Radio Frequency (RF) electrical energy to propagate within the copper structure. If the gas pressure is too great, high electrical fields established by the RF will tend to arch or locally discharge electrons between copper surfaces, which could damage the structure. Second, a low gas density is required along the beam line to minimize collisions of the accelerated protons with gas molecules. These undesirable collisions create stripping or scattering of the protons, which results in activation of the surrounding structures and reduce the beam power delivered to the target.

One of the primary accelerating structures is the Drift Tube Linac (DTL), which accelerates the SNS proton beam from 2.5 MeV to 87 MeV. The basic design features of the DTL can be found in [1.1] and are summarized briefly in Section 1.4 of this report. A preliminary design for the Drift Tube Linac (DTL) vacuum system was completed in June of 2000, and documented in [1.2]. This report summarizes the final design of that DTL vacuum system.

### *1.1 Project Scope, Deliverables, and Design Criteria*

The complete project scope associated with the DTL Vacuum System includes the design, analyses, fabrication, assembly, installation, testing, and certification of the vacuum system components. The efforts associated with this project scope include performing final design engineering calculations and developing corresponding engineering drawings, preparation of procurement packages, liaison with vendors and participation in assembly, installation, and testing at Oak Ridge National Laboratory (ORNL).

This report covers the final design efforts, based on a preliminary design outlined in [1.2]. To develop a functional, reliable, and affordable vacuum system, the following final design deliverables were identified [1.3]:

1. Revision of preliminary design aspects as directed by LANL SNS-PO following the DTL Vacuum System PDR [1.4].
2. Completion of all engineering calculations.
3. Completion of P&IDs as well as assembly and detail drawings for the pumping stations, vacuum manifolds, support structures, etc.
4. Complete design of instrumentation, controllers, and software for the local control system and global control system integration plans.
5. Specifications and procedures for vacuum system material preparation, cleaning, handling, and shipping.
6. Completion of detailed mechanical drawings and procurement plans with bill of materials for procurement of off-the-shelf items and fabrication plans for specialized components.
7. Completion of assembly, installation, testing, and certification/quality assurance plans.

Table 1.1 lists the general design criteria that were applied to the SNS DTL Vacuum System design. Each criterion has a brief description and a weighting factor associated with it. The weighting factor is intended to give a measure of the criterion's importance in the overall DTL vacuum system design, and consequently, assist the engineering design team in selecting between various design alternatives. An example of the use of the design criteria and weighting factors in assessing two different design alternatives can be found in [1.3].

Table 1.1. SNS DTL vacuum system design criteria.

| Design Criteria | Weighting Factor♣ | Description |
|---|---|---|
| Functionality | 5 | • Base pressure must be met (pumps must overcome outgassing and leaks)<br>• Vacuum hardware must not interfere with support structure<br>• Vacuum system must be resilient to react to beam line expansions/adjustments |
| Safety | 5 | • Proper controls and safety features, following appropriate DOE guidelines, should be employed to protect personnel and the beam line (equipment and operation) |
| Procurement, Fabrication, Assembly | 3 | • Design with standard, off-the-shelf parts<br>• Avoid using exotic materials<br>• Assembly and maintenance issues should be incorporated in the design to ensure compatibility with other subsystems (i.e, support structure, water system, etc.) |
| Durability/ Reliability | 4 | • A reliability assessment should be performed to ensure the vacuum system performs to a satisfactory level (minimize down time).<br>• Vacuum pumps should be selected for **30** year lifetime and have a 5 year maintenance period.<br>• The pumping speed must be designed with a safety margin of 2 in the beam tube pressure (i.e, designed vacuum pressure will be half the value of the required operational pressure) to account for pump failure, leaks, or unforseen gas loads, and still allow for accelerator operation. |
| Cost | 4 | • Optimize functionality to minimize procurement, fabrication and assembly costs to fit within the allocated budget (based upon the conceptual design) |
| Maintainability | 3 | • Vacuum pumps and hardware should be accessible for maintenance/replacement with minimal impact on beam down-time |
| Consistency | 2 | • Every effort should be made to use the same type of vacuum components throughout the Linac. In addition, these components should be consistent with those used elsewhere in the SNS facility (i.e., RFQ, storage ring, target, etc) |

♣ 5 = very important, 1 = least important

### *1.2 Drift Tube Linac Vacuum Environment*

The SNS linear particle accelerator, or linac, is comprised of three main structures including the Drift Tube Linac (DTL), the Coupled Cavity Linac (CCL), and the Super Conducting Linac (SCL), as displayed in Figure 1.1. The first proton accelerating structure following the ion injector and RFQ, is the DTL. The 402.5 MHz Alverez DTL [1.5], is used to accelerate the H- beam from 2.5 MeV to 86.8 MeV. The SNS DTL is comprised of six tanks, the first of which is roughly 4 m in length, and the remainders are approximately 6 m in length. Tank 1, as shown in Fig. 1.2{a), is made up of 2 seamless copper-plated, carbon-steel cylinders that are bolted together with RF and vacuum seals at each joint, and tanks 2 through 6 are made up of 3 sections each, as shown in Fig 1.2(b). The RF structure provides a stable platform for an array of drift tubes, post

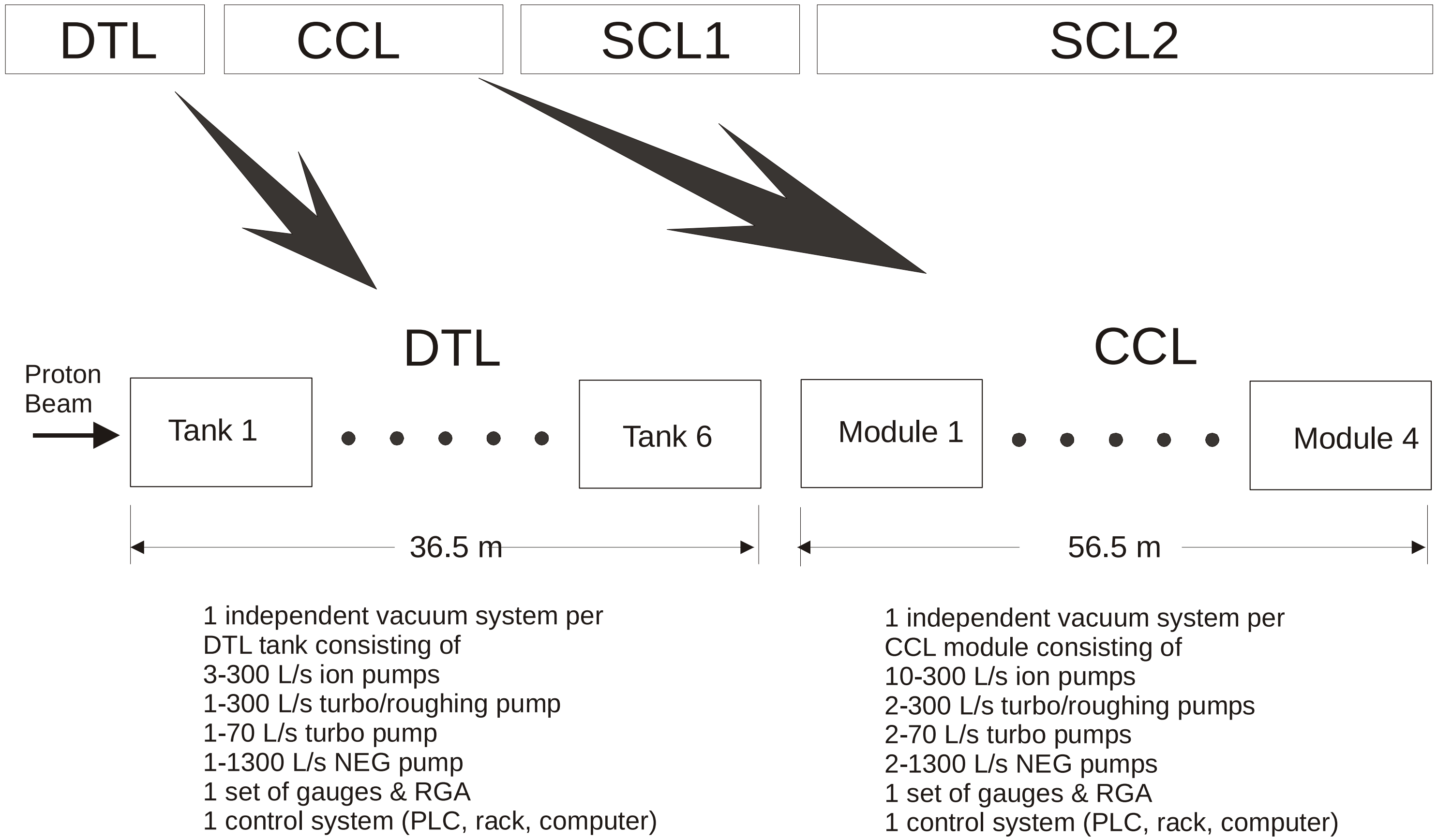
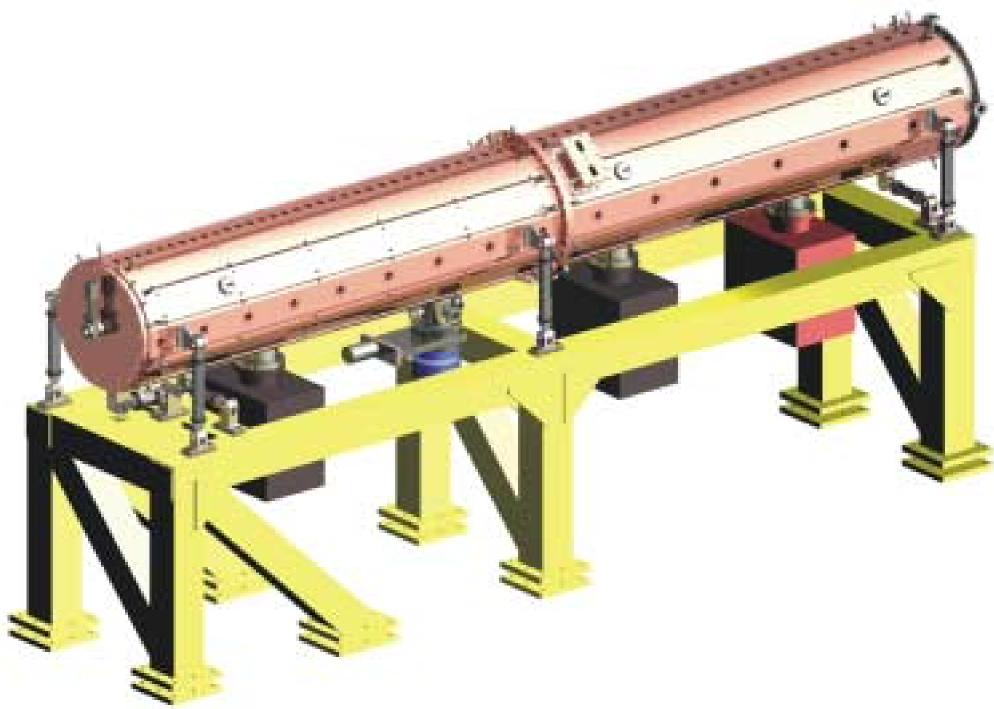
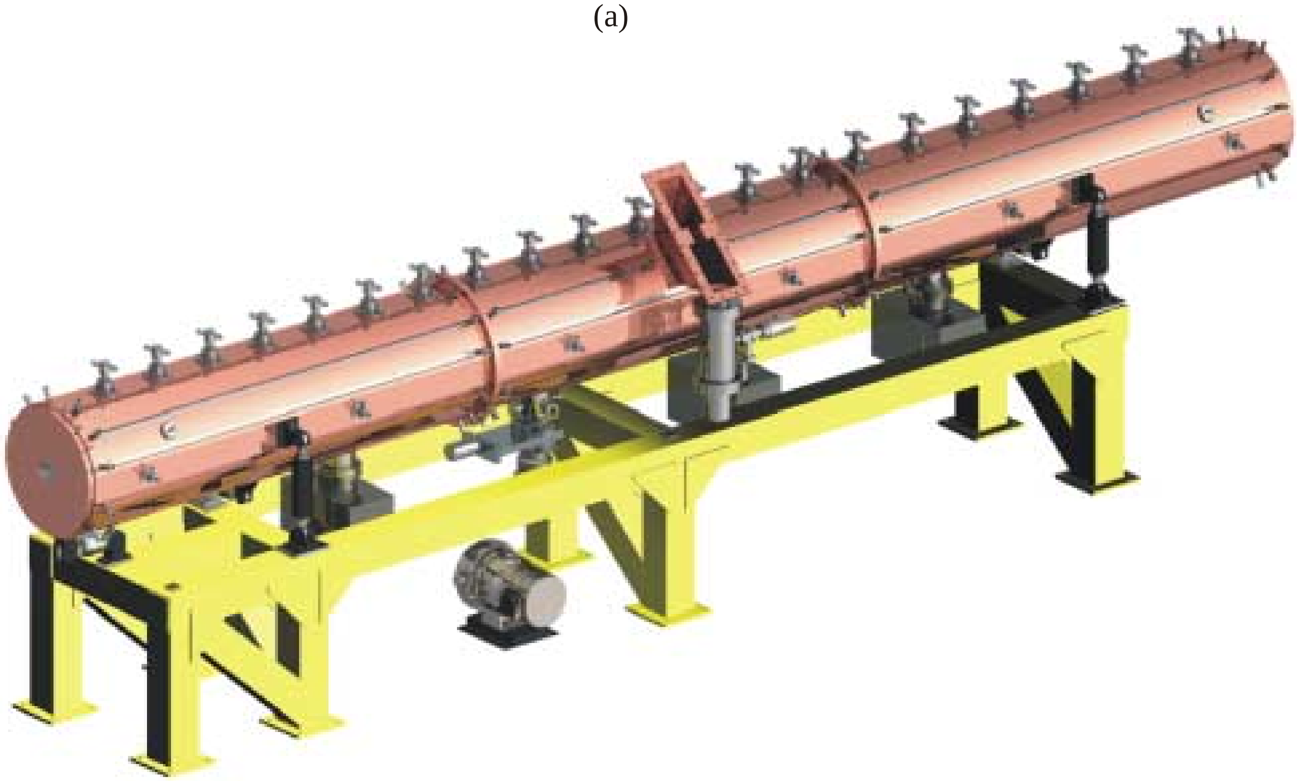



Figure 1.1. General layout of the SNS Linac and basic summaries of the DTL and CCL vacuum systems.



(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..

couplers, and slug tuners, all used to shape and tune the structure to maintain precise resonance and optimal acceleration of the proton beam. These components, and other design details, are shown in the cut-away view of tank #1 in Fig. 1.3. A more detailed description of these components and their functionality can be found in [1.1] and [1.5]. Table 1.2 summarizes the number of tank sections, cells, drift tubes, post couplers, slug tuners, and drive irises within each of the DTL tanks.

Table 1.2. Summary of DTL tank component distributions.

| DTL Tank # | Tank section # | # of cells | # tank wall cooling channels | # of drift tubes | # of endwall noses (half of drift tube) | # of post couplers | # of slug tuners | # of drive irises |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 & 2 | 60 | 12 | 59 | 2 | 20 | 8 | 1 |
| ” | 1 | | 12 | 34 | 1 | 11 | 4 | 0 |
| ” | 2 | | 12 | 25 | 1 | 9 | 4 | 1 |
| 2 | 1, 2, & 3 | 48 | 12 | 47 | 2 | 23 | 12 | 1 |
| ” | 1 | | 12 | 19 | 1 | 9 | 4 | 0 |
| ” | 2 | | 12 | 15 | 0 | 8 | 4 | 1 |
| ” | 3 | | 12 | 13 | 1 | 6 | 4 | 0 |
| 3 | 1, 2, & 3 | 34 | 12 | 33 | 2 | 16 | 12 | 1 |
| ” | 1 | | 12 | 12 | 1 | 6 | 4 | 0 |
| ” | 2 | | 12 | 11 | 0 | 5 | 4 | 1 |
| ” | 3 | | 12 | 10 | 1 | 5 | 4 | 0 |
| 4 | 1, 2, & 3 | 28 | 12 | 27 | 2 | 27 | 12 | 1 |
| ” | 1 | | 12 | 9 | 1 | 9 | 4 | 0 |
| ” | 2 | | 12 | 10 | 0 | 10 | 4 | 1 |
| ” | 3 | | 12 | 8 | 1 | 8 | 4 | 0 |
| 5 | 1, 2, & 3 | 24 | 12 | 23 | 2 | 23 | 12 | 1 |
| ” | 1 | | 12 | 8 | 1 | 8 | 4 | 0 |
| ” | 2 | | 12 | 8 | 0 | 8 | 4 | 1 |
| ” | 3 | | 12 | 7 | 1 | 7 | 4 | 0 |
| 6 | 1, 2, & 3 | 22 | 12 | 21 | 2 | 21 | 12 | 1 |
| ” | 1 | | 12 | 7 | 1 | 7 | 4 | 0 |
| ” | 2 | | 12 | 7 | 0 | 7 | 4 | 1 |
| ” | 3 | | 12 | 7 | 1 | 7 | 4 | 0 |

For a single DTL tank, the vacuum environment can be essentially divided into three main regions, as displayed in Figure 1.4. The first and largest vacuum region is the DTL tank volume, containing the vast array of RF tuning and shaping devices listed in

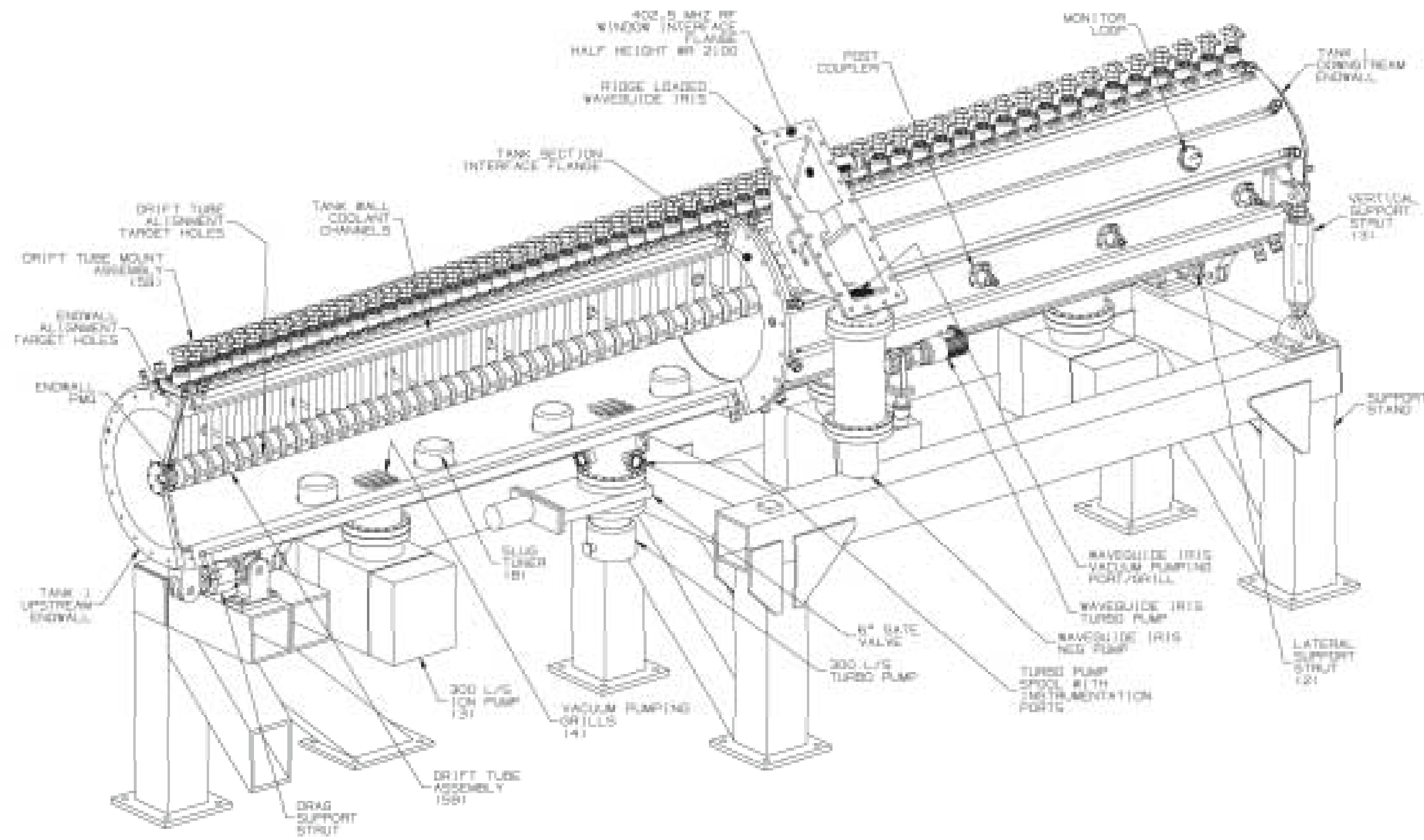



Figure 1.3. Cut-away details of DTL tank #1.

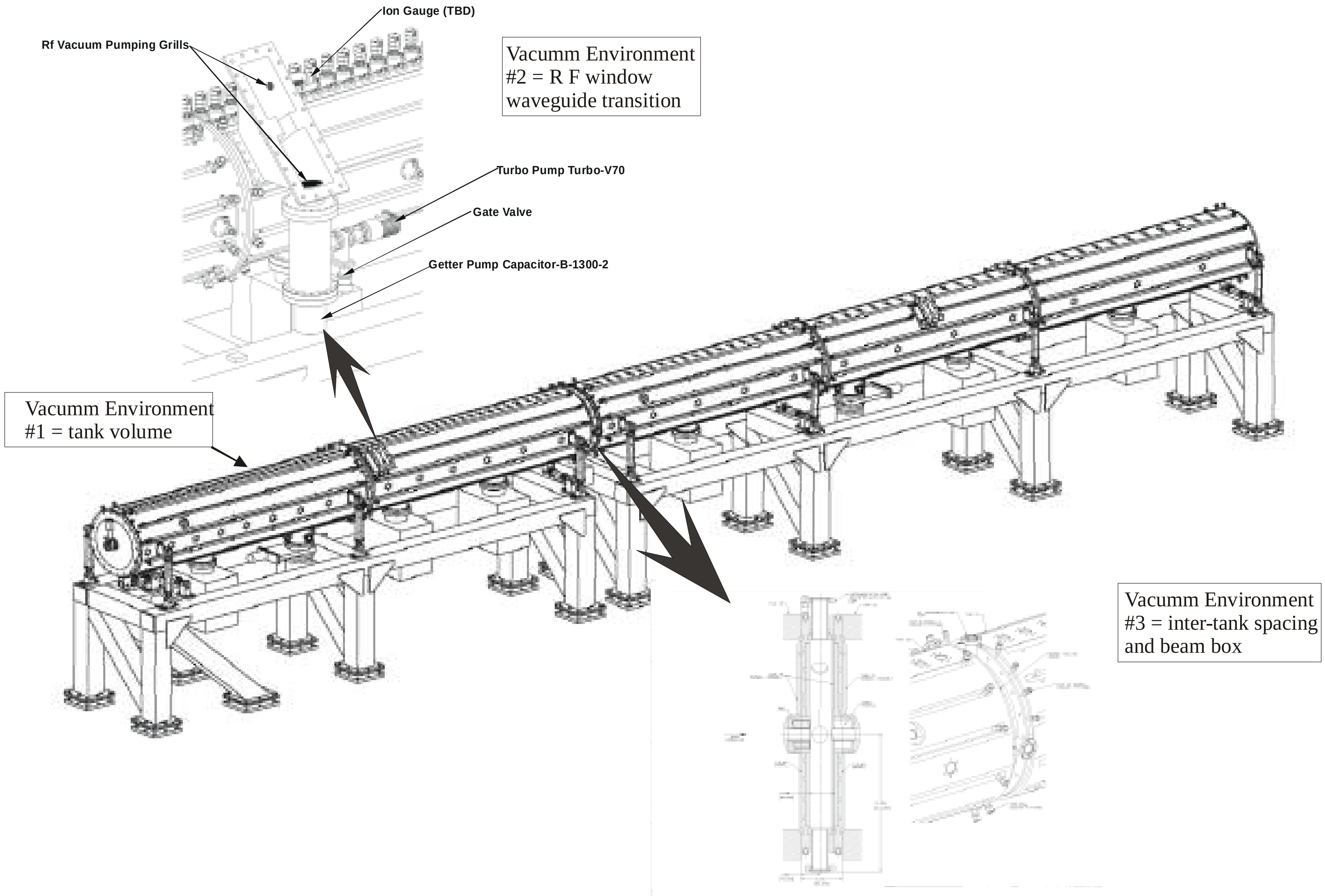



Figure 1.4. The three primary vacuum environments in the DTL vacuum system.

Table 1.2. The gas loads in the DTL tank volume include the outgassing from the copper surfaces (i.e., tank walls, drift tubes, etc.), leaks from the environment through seals, outgassing from the permanent quadrupole magnets and beam diagnostic devices located in various drift tubes. The second vacuum region concern is the volume between the RF window and iris, located on the tank wall near the mid-way length of the tank body. The RF window has the potential to be a large gas load, as it is porous and the trapped gas molecules get released when excited by applied RF energy. The iris, which is a narrow slit in the tank wall, has a large conductance and is not efficient for pumping through. Consequently, the waveguide transition housing between the RF window and iris, forms a vacuum region that is nearly independent of the tank volume. The third vacuum region corresponds to the volume between the DTL tanks. The gas loads in this region arise from outgassing of beam diagnostic equipment within the inter-tank beam box spaces.

Section 3 of this report contains detailed numerical and analytical vacuum analyses to estimate the required pumping speeds and obtainable base pressures to overcome the gas loads of each of these three vacuum regions.

### *1.3 DTL Vacuum System Design Summary*

The preliminary and final design of the DTL vacuum system has been completed. The basic vacuum system features are as follows:

- Each DTL tank will have its own complete, stand-alone vacuum system.
- All main vacuum pumps will be attached to the bottom of the DTL tanks through ports provided with RF shields.
- A turbo/roughing pump combination will condition each DTL tank and serve as transitional pumping to a suitable base pressure ($10^{-5}$ Torr) to allow for ion pump operation. Ion pumps will provide for the steady-state vacuum pumping.
- The turbo pump carts will be connected via instrumentation spool pieces and isolated from the DTL tanks by pneumatic isolation valves
- A small nonevaporatable getter pump and backing turbo pump will be provided near the RF window (iris) to supply the additional pumping requirements needed to compensate for potentially high outgassing rates from the window during conditioning. The turbo pump will be backed by an oil-free roughing pump.
- Pneumatic actuated vacuum isolation valves (with positioning output signal for safety interlock) will be provided between each DTL tank (and at the ends of tanks 1 and 6) for vacuum isolation, with the exception of the inter-tank spacing between tanks 1 & 2 and 2 & 3, where clearance limitations prevent the incorporation of valves. This

will ease vacuum leak checking, vacuum conditioning and system operation certification, and all-around maintenance. Pneumatic actuated vacuum isolation valves (with positioning output signal for safety interlock) will be required between the turbo pump and NEG pump on each RF window vacuum pump assembly. Pneumatic valves with position indicators will also be provided at each turbo/roughing station location.

- A low vacuum convectron gauge and a high vacuum cold cathode gauge will be provided on each tank for system operation (i.e. when to turn on ion pumps), vacuum monitoring, and safety interlocks. Cold cathode gauges will be provided on each RF window vacuum assembly to monitor system pressure and serve as a safety interlock. An RGA attached to each DTL tank will provide critical vacuum system data during the early conditioning periods and provide a means of trouble shooting during the lifetime of the accelerator. The RGA controller will be located outside of the linac tunnel to prevent radiation damage to the controller's electronics.
- Nitrogen purge lines with pressure regulators and relief valves will allow the DTL tanks to be safely back-filled with dry nitrogen gas during maintenance periods.
- A local control system will be provided for each DTL tank. This local control system will monitor all vacuum pumps, valves, and instrumentation. It will provide for vacuum conditioning of the DTL tanks prior to beam operation. The local control system will interface with the SNS global control system and provide for vacuum system operation and monitoring, data storage, and safety interlocks.

### *1.4 Vacuum Requirements*

The primary requirement for the DTL and CCL vacuum systems is to provide sufficient pumping to overcome the surface outgassing of vacuum facing components and maintain a beam tube pressure that is below the values required for a 2-mA $H^-$ beam operation. The vacuum requirements for the DTL and CCL, given in Table 1.3, were determined from calculations involving the stripping of the proton beam by gas molecules in the vacuum environment [1.6]. The underlying criterion for the vacuum levels is the acceptable activation of linac hardware. For the SNS linac, a maximum radiation dose rate was defined to be of 10 mrem/hr at 1 ft from the linac, 4 hours after shutdown following a 100 consecutive day run. Using this activation criterion and basic proton scattering/activation theories, an $H^-$ scattering model was developed to determine the acceptable vacuum pressure levels in the SNS linac. The model shows that the amount of $H^-$ scattering and the associated activation of linac hardware, is directly proportional to the linac beam energy and gas specie partial pressure within the vacuum environment. As the beam energy increases, the amount of beam scattering increases for constant vacuum pressure. Consequently, the allowable vacuum pressure along the DTL and CCL must decrease as the proton beam energy increases from 2.5 MeV to 185 MeV. In addition, since the $H^-$ scattering is highly dependent on the cross-section of the gas molecules present in the beam tube, the allowable vacuum pressure is gas species dependent. The maximum allowable beam tube pressure, $P_{allowable}$, is a weighted sum of the individual gas specie partial pressures, $P_{sub}$:

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

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

$W_{He}$ = 0.125 (helium)
$W_{H2}$ = 0.15 (hydrogen)
$W_{H2O}$ = 0.66 (water)
$W_{N2}$ = 1.0 (nitrogen)
$W_{CO}$ = 1.0 (carbon monoxide)
$W_{O2}$ = 1.0 (oxygen)
$W_{CO2}$ = 1.5 (carbon dioxide)

Note that these weighting factors reflect the ability of the corresponding gas molecules in scattering the high energy protons. The maximum allowable pressures in the DTL and CCL, as a function of beam energy, are given in Table 1.3. Note that these pressures correspond to an average pressure measured over a beam tube length of 5 meters.

Table 1.3. Vacuum pressure limits along the beamline in the DTL and CCL.

| Linac Section | DTL Tank or CCL Module | Exit Beam Energy | Max Allowable Pressure |
|---|---|---|---|
| | No. | MeV | Torr |
| DTL | 1 | 7.5 (starts at 2.5) | $1.84\times10^{-7}$ |
| DTL | 2 | 22.8 | $1.84\times10^{-7}$ |
| DTL | 3 | 39.8 | $1.84\times10^{-7}$ |
| DTL | 4 | 56.6 | $1.84\times10^{-7}$ |
| DTL | 5 | 72.5 | $1.84\times10^{-7}$ |
| DTL | 6 | 86.8 | $1.84\times10^{-7}$ |
| CCL | 1 | 107.2 | $1.84\times10^{-7}$ |
| CCL | 2 | 131.1 | $1.53\times10^{-7}$ |
| CCL | 3 | 157.2 | $1.21\times10^{-7}$ |
| CCL | 4 | 185.6 | $0.89\times10^{-7}$ |

Additional vacuum system design requirements, such as space envelopes, acceptable pumps and materials, interfaces, etc. can be found in [1.3] and [1.8].

### *1.5 Mechanical and Electrical Interfaces*

The key mechanical interfaces between the DTL Vacuum System hardware and the DTL RF structure are summarized in Table 1.4. Further mechanical and vacuum analyses that relate to these interfaces can be found in Sections 3 and 4 of this document.

Table 1.4. Mechanical Interfaces between the DTL Vacuum System and DTL RF structure.

| Interface Description | Mechanical Connection | Vacuum Impact |
|---|---|---|
| Main tank pump ports | Bolted Conflat flange | RF shielding is required for pump port |
| Instrumentation ports | Spool piece with bolted Conflat flanges | Spool piece must be provided with an RF shield port |
| RF window pump ports | Bolted Conflat flange | RF shielding is required for pump port |
| Vacuum isolation valves | Bolted, metal or polymer o-ring seals | • Isolation valves will be pneumatic with position indicators.<br>• Beamline valves provided between tanks where clearance is available.<br>• Turbo cart valves provided between pump port and pump cart. |
| DTL RF structural components | A variety of common mechanical connections will be used to connect drift tubes, post couplers, slug tuners, tank end walls, etc. | • All seals will be of the knife-edge, spring seal, or polymer o-ring type. All polymers subject to radiation hardening requirements as detailed in Section 4.<br>• All DTL structural components in vacuum environment will be cleaned to specifications given in the Appendix of this report. All engineering drawings will specify these cleaning specs and require review and approval of a vacuum engineer. |
| DTL beam diagnostic equipment | Varios mechanical and electrical feed-throughs | • All seals will be of the knife-edge, spring seal, or polymer o-ring type. All polymers subject to radiation hardening requirements as detailed in Section 4.<br>• All DTL structural components in vacuum environment will be cleaned to specifications given in the Appendix of this report. All engineering drawings will specify these cleaning specs and require review and approval of a vacuum engineer.<br>• Total outgassing rate for beam diagnostic equipment in a single location will be kept below levels specified in Section 3 of this report. |

All equipment (pumps, instrumentation, valves, etc) shall operate from the linac tunnel and klystron gallery utilities. The SNS conventional facility requirements for the Linac are specified in [1.7]. Table 1.5 lists the electrical requirements for typical pieces of vacuum equipment needed in the DTL vacuum system, while Table 1.6 summarizes the required utilities (based on the final design) for the DTL vacuum systems. In addition, the electrical requirements listed in Table 1.6 do not include any surpluses required by electrical codes. In case of an electrical power failure, uninterruptible electrical power service (UPS) will be required for the vacuum diagnostics and PLC for the DTL vacuum systems, as shown in Table 1.7. The UPS will permit the operators to determine vacuum conditions prior to an overall system restart once electrical service is restored.

The communication interfaces between the DTL Vacuum Control System and the SNS Global Control System are described in detail in Section 5 of this report.

All other facility-type interfaces are covered in Section 6 of this report.

Table 1.5. Summary of electrical requirements for various pieces of vacuum equipment on the DTL vacuum systems.

| Equipment | Voltage (volts) | Phase | Start-up current (Amps) | Steady-state current (Amps) |
|---|---|---|---|---|
| Scroll pump | 120 | 1 | 12 | 7 |
| Turbo pump (300 L/s) | 120 | 1 | 4 | 1 |
| Ion pump (300 L/s) | 120 | 1 | 2 | 0.5 |
| NEG pump (1300 L/s) controller | 120 | 1 | 9 | 9 |
| Turbo pump (70 L/s) | 120 | 1 | 1 | 0.25 |
| Backing pump for small turbo | 129 | 1 | 4 | 2 |
| RGA | 120 | 1 | 4 | 4 |
| PLC & IOC | 120 | 1 | 4 | 4 |
| Gauge Controller | 120 | 1 | 0.5 | 0.5 |

Table 1.6. Summary of SNS building utilities required for the DTL 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/P hase) |
|---|---|---|---|---|
| DTL | 125 psia | Yes | TBD/2.0/120/1 (turbo cart) | 6/3.0/120/1 (elec. rack) |

Table 1.7. Summary of UPS requirements for the DTL 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 |

### *1.6 Comments and Action Items from Preliminary Design Review*

The DTL/CCL vacuum system preliminary design review (PDR) committee's comments and the corresponding design team responses and/or actions are given in Table 1.8. Each item of concern that was raised by the PDR committee has been addressed and documented in this final design report.

Table 1.8. Preliminary design review committee comments and corresponding responses or actions taken during final design of the DTL/CCL vacuum systems.

| Comment # | 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. |
| 5 | Include water vapor pumping in analysis | The vacuum pressure design criterion is a weighted function of partial pressures of multiple species. Multiple gas species were included in the DTL tank and CCL module vacuum models through the use of superposition. The % distribution of gas species in the gas load was determined from LEDA hot model RGA data. |
| 6 | "design margin is to provide excess capacity utilized when an off normal event occurs…" | In the PDR, the design margin was also used to cover unknown scenarios not covered in the model such as dirty surfaces, virtual leaks, outgassing of diagnostics, etc. The design margin of 2 has been defined to cover pump failure and unforeseen gas loads. See response to 1$^{st}$ comment. |
| 7 | The determination of the conditioning and recovery times for the vacuum systems must be conducted to insure that the availability budgets for the respective linac systems and the conditioning schedules are not exceeded. | The RAMI plan that was initially developed by ORNL has been replaced by the incorporation of "good engineering practices" to ensure good availability. Consequently, the availability studies that were planned have been canceled.<br>The vacuum conditioning schedule should not impact the overall conditioning of the Linac as long as proper cleaning and handling procedures for all vacuum hardware have been followed and hence the vacuum conditioning time is minimized. |
| 8 | The use of dual pump controllers across tanks or modules should be considered if they can be accessed and | Dual pump controllers was investigated but not found to integrate properly with the vacuum control system architecture and modularization scheme or produce any significant cost savings.. |

| | | |
|---|---|---|
| | replaced with spare units without shutting down the accelerator. | |
| 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. Historical data from LANSCE indicates that a backing vacuum system was required at a later date to accommodate this occurrence while the DTL elastomer seals at AGS has had no difficulty over 30 years. The failure mode of the LANSCE seals needs to be further investigated and documented. | 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. |
| 11 | Personnel responsible for the vacuum must have sign off responsibility for all final release drawings for components that connect to the vacuum system. | LANL/SNS Division has implemented appropriate procedures. 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. |
| 14 | latest geometry's to be incorporated | 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. |
| 15 | outgassing rates > 100 hrs should be included for accident scenario | Outgassing rates have been defined to account for species concentrations and dependence on vacuum and RF conditioning times. Some limited outgassing data does exist (from LEDA hot model RGA data) and has been referenced in the DTL/CCL vacuum FDR reports. |
| 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. |
| 18 | Inclusion of turbo pump stations during off-normal operation should not be | This recommendation has been included in the vacuum system design. |

| | | |
|---|---|---|
| | addressed as a necessary feature. | |
| 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. |
| 20 | Recommend diode ion pumps | The desired pumping speed and other pump characteristics were listed in an appropriate ion pump specification sheet. These DTL/CCL ion pump specifications will be reviewed by the ORNL-ASD to determine consistent ion pump selection with other SNS vacuum systems. |
| 21 | Standardization: procedures for operations such as cleaning need to be standardized to ensure comparable levels of cleanliness. | LLNL already has a set of comprehensive, robust specifications for cleaning vacuum system hardware. These specifications will be supplied to all DTL/CCL hardware designers to ensure proper cleaning of all materials entering the vacuum environment. We will make these specifications available to the other SNS vacuum system design teams during the final design phase. |
| 22 | The effect of arcing, multi-pactoring, and electro-magnetic interference in the DTL tanks must be evaluated. Do peak RF fields exceed dielectric strengths? What is the waveguide cut-off for the pump ports? Do higher order modes propagate to the pumps and gauges? | Many of the questions concerning the electric field parameters can not be appropriately responded to by the vacuum design team. These questions will be passed along to the RF engineers and cavity design physicists and dealt with during the DTL RF structure PDR.<br>The issues concerning the RF shield design on the pump ports was addressed by the vacuum design team during final design. The pump RF shield design was also reviewed by the vacuum team. The absence of RF shields on gauges and the CCL vacuum manifold, has also been justified. |
| 23 | The $10^{-10}$ Torr L/s/cm$^2$ surface outgassing rate for the DTL tank walls due to RF conditioning should be verified | The DTL tank is lined with copper which should have a pre-RF conditioned outgassing rate similar to clean copper surfaces referenced in the literature and documented from the APT/LEDA CCDTL hot model test. During RF conditioning, the RF field interaction with the DTL tank walls will be much less than that experienced on the CCDTL hot model cavities, and hence the RF conditioned gas load documented for the LEDA hot model, may not be appropriate to use in the DTL vacuum model. It is reasonable to expect that the DTL gas load (on a per unit surface area basis) during RF conditioning will be lower than that seen on the CCL and LEDA hot model due to lower RF interaction with the DTL tank walls. Consequently, the gas loads on the DTL will not decrease as fast as they should for the CCL. All of this was considered in establishing species and conditioning time dependent gas loads which were incorporated in the vacuum models. |
| 24 | DTL RF seals design – "virtual leak" | The designs of all RF and vacuum seals in the DTL and CCL (currently designed by the RF structures engineers) were reviewed by vacuum engineers to ensure that the seal materials satisfy radiation exposure criteria and do not serve as virtual leaks. |
| 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. |
| 26 | The mechanical support for the vacuum pumps off the floor should be considered to alleviate any structural impact on the DTL tank. | Stress analyses of the DTL and CCL ion pumps determined that additional mechanical support (in addition to the attachment flange) was unnecessary. |
| 27 | The spool pieces between the DTL tanks and the pumps needs to be finalized. | The DTL and CCL vacuum instrumentation spool piece designs have been completed. |

| | | |
|---|---|---|
| 28 | The possibility of encasing the ferrite magnets in copper shrouds, providing cooling and reducing outgassing should be considered. | Cooling isnot required for permanent magnets.<br>We have defined maximum allowable outgassing rates of drift tube bores and compared this to the magnet outgassing load. The magnet gas loads were found to be acceptable. |
| 29 | Increase roughing time on tanks 2-6 | Our model shows that the 30 min. roughing time is adequate to achieve a pressure to initiate the turbo. Why increase the roughing time? Please clarify this question. |
| 30 | Can the two manifolds on one CCL module be joined by a bellows and utilize a single roughing port? | A single manifold, sectioned in 2 pieces and joined by a bellows, has been designed for a single CCL module vacuum system. The manifold design was based on vacuum pumping requirements, manufacturing limitations/costs, and assembly/installation requirements. |
| 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. |
| 32 | The bellows attachment configuration between the CCL RF structures and the manifolds needs to be finalized. | The bellows design has been finalized to ensure that it forms the proper interface between the CCL side coupling cells and vacuum manifolds. The flange attachments, clearances, and positioning of the bellows have been verified with the use of a top level CCL assembly drawing which combines the RF structure, the support structure, and the vacuum equipment. A uniform formed bellows design was selected for use on all CCL vacuum manifolds. The lateral and axial deflections of the bellows are more than sufficient (by a factor of 2) to handle the misalignments due to machining, assembling, and aligning errors. The forces induced on the CCL by mis-aligned bellows was found to be neglible. |
| 33 | The impact of the vacuum force on the CCL RF structures & alignment need to be evaluated. | This analysis has been performed. |
| 34 | The stepping down of the air pressure from 120 to 90 psi versus using separate manifolds for the different valve actuation pressures should be considered. | This recommendation was implemented. |
| 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. |
| 36 | Need to derive conditioning plan for DTL & CCL to determine simultaneous pump-down requirements. | A review of the assembly, installation, and commissioning schedules for the DTL and CCL was conducted. The current schedule indicates sufficient time to vacuum condition the DTL and CCL with the quantity of turbo pump carts available.. |
| 37 | Attempt to minimize number of logic points in the event of a vacuum failure. | Number of logic points will be minimized during the PLC programming phase. Loop run times will be documented along with communication and safety response times for the entire DTL/CCL vacuum I&C system. |
| 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. |
| 39 | Insure additional components present in the vacuum be verified by vacuum group | We met with the lead hardware design engineers and reviewed all critical hardware which would impact the vacuum environment (i.e., seal designs on DTL and CCL, beam diagnostic hardware, penetrations, etc.). Design guidelines, based on the vacuum requirements, were developed and supplied to these hardware engineers. In addition, the anticipated gas loads from equipment residing in the vacuum environment (diagnostics, seals, etc.) |

| | | |
|---|---|---|
| | | were added to the vacuum models. |
| 40 | Recommend using a control box for each RGA head for matching and calibration purposes. | This recommendation has been incorporated. We are working with the SNS ASD to develop an RGA procurement specification which will satisfy the needs of all SNS vacuum systems (one controller per head, 100+ft radiation hardened communication cable, etc.) |
| 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. |
| 43 | The use of particulate generating components, such as hot filament gauging in the Low Beta (DTL & CCL), are not acceptable due to their contaminating effect on the superconducting section. | The design team reviewed the use of cold cathode gauges rather than hot filament ion gauges on the DTL/CCL vacuum systems. This issue was also raised at the latest SNS vacuum systems meeting in ORNL. The plan is to use cold cathode gauges throughout the linac and storage ring vacuum systems. The lower accuracy of the cold cathode gauge, compared to an ion gauge, will require additional RF conditioning time since the RF vacuum trip point must be set at a more conservative value. |
| 44 | Further optimization of the RF window pumping systems needs to be performed. The size and definition of the proposed systems is excessive in its current configuration. | The RF window vacuum system has undergone final design and optimization. We don't agree that the size and definition of the proposed system is excessive. The uncertainty in the RF window conditioning gas load and conductance losses by the RF grills, and outgassing data from LEDA RF window tests indicate that the 1000 L/s NEG pump is required and must be backed with a turbo for conditioning. This RF window pumping system parallels a successful design for the LEDA accelerator. We plan to further back our design choices with RF window outgassing RGA data from the CCL hot model tests in the spring of 2001. |
| 45 | The selection of emergency power for the ion pump controllers' needs to be determined. | The back-up electrical requirements for the DLT/CCL vacuum systems have been reviewed. The decision by the ORNL-SNS operations team was to supply UPS only for the vacuum system PLCs and pressure gauge controllers for monitoring the vacuum environment prior to system restart. It is believed that during a power failure, the gas loads to the vacuum environment should be sufficiently small that the pressure will not rise significantly during a power failure in which the vacuum pumps are shut off for several days. |
| 46 | A fault tree analysis of the vacuum interlocks needs to be performed to identify failure modes and risk abatement. | A fault tree analysis of the vacuum system and interlocks was created in the final design phase. |

## 2.0 Vacuum System Design

### *2.1 Vacuum System Layout*

The vacuum system equipment layout for DTL tank #1 is displayed in the Piping and Instrumentation Diagram (P&ID) of Figure 2.1. The P&ID symbol legend for Figure 2.1 is presented in Figure 2.2. The P&IDs for tanks 2 through 6 are contained in Appendix C. As Figure 2.1 indicates, the vacuum system for the main tank body will consist of a turbo pump cart, three ion pumps, a gas pressurization cart, and a multitude of valves and instrumentation. In addition, Figure 2.1 displays the turbo-assisted Non Evaporatable Getter (NEG) pump assembly for the RF window. The details of these vacuum components are discussed in the following sections.

### *2.2 Valves and Plumbing*

As shown in Figure 2.1, pneumatic gate valves have been incorporated in the DTL vacuum design to isolate the turbo/roughing pumps from the vacuum environments. These pneumatic valves will receive compressed air from line sources located in the SNS Linac tunnel. The valves are connected to the vacuum control system PLC for remote control operation and valve positioning status. Pneumatic valves will also be placed along the beam-line before and after tanks 1 and 6, respectively, and in the inter-tank spacing between tanks 3 and 4, 4 and 5, and 5 and 6. Clearance limitations prevent placing valves between tanks 1 and 2 as well as tanks 2 and 3. These beam-line valves will serve as isolation valves to segregate DTL sections for maintenance and leak checking procedures and will fail in the closed position. Proper global beam-permit controls must be in place to ensure that any power failures that may cause the beam line isolation valves to close, also cause the proton beam to trip off. Manual valves will be used in the gas pressurization system to isolate the gas pressurization cart and vent the system to atmosphere if required. All valves will have metal seats and either metal or polymer o-ring seals. The polymer O-rings will adhere to the radiation hardening and leak rates specified in other sections of this report.

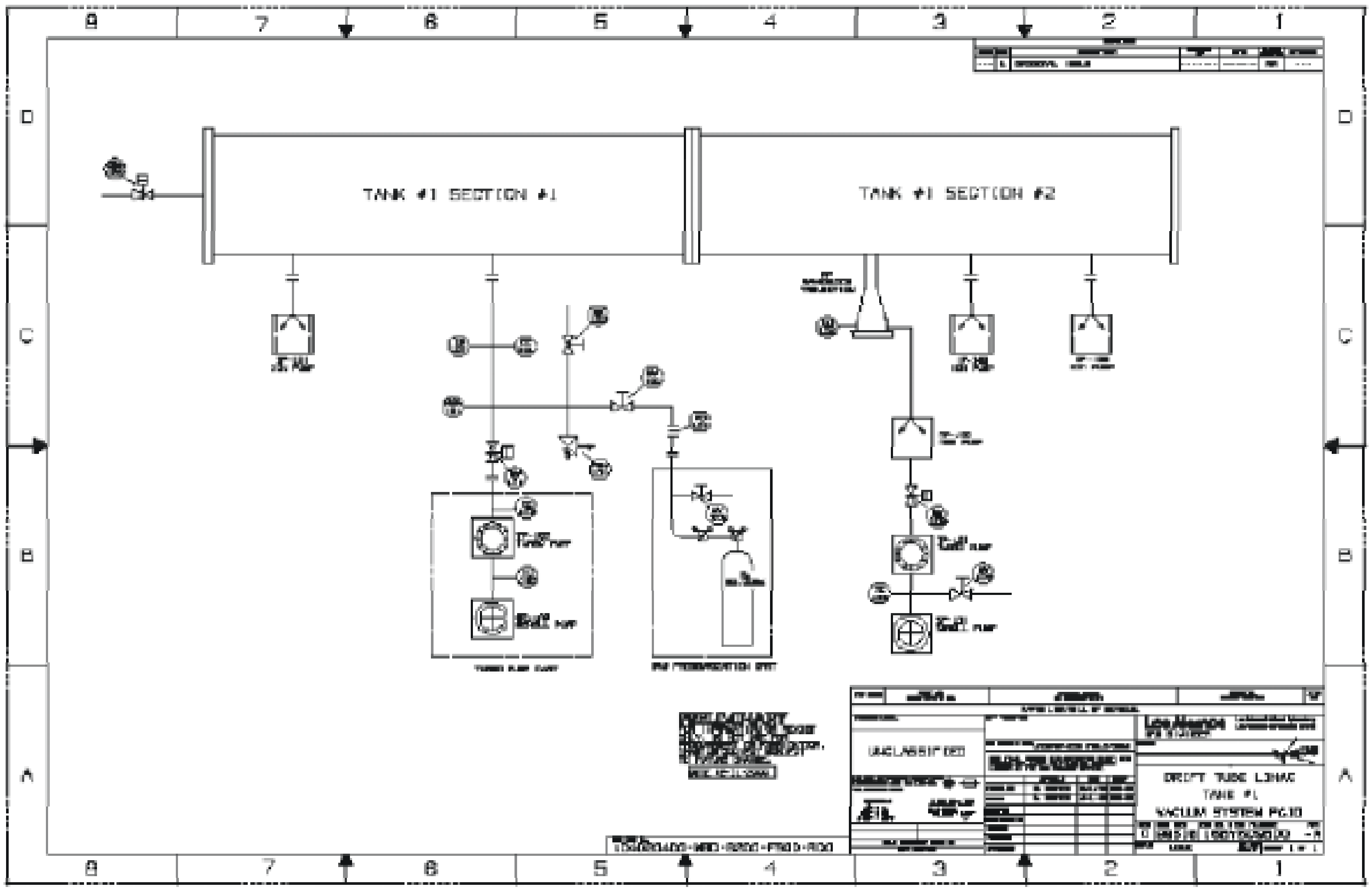



Figure 2.1. P&ID for DTL tank #1 vacuum system.

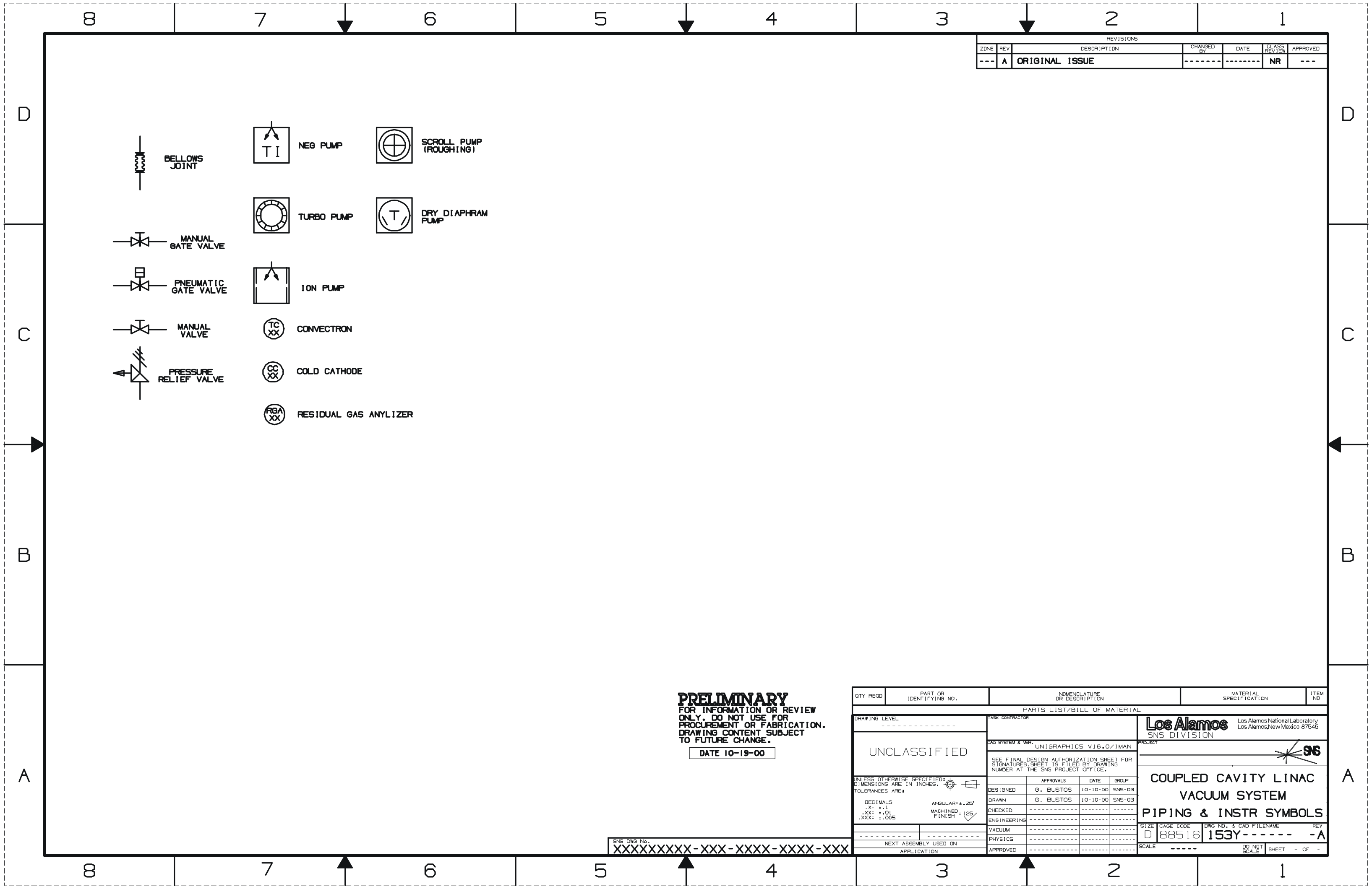



Figure 2.2. P&ID legend for the DTL and CCL vacuum systems.

The remaining vacuum plumbing on the DTL vacuum system consists of an instrumentation spool piece and a few basic vacuum connectors (i.e., elbows, T's, etc.). All plumbing will be joined with knife-edge sealed flanges.

### *2.3 Vacuum Seals*

Vacuum seals are used for all vacuum equipment connections as well as tank body junctions and component penetrations. The vacuum seal types, sizes, and quantities for DTL tank 1 are displayed in Table 2.1. Similar tables for tanks 2 through 6 are contained in Appendix H.

The DTL vacuum system seal designs have been reviewed as part of the DTL Preliminary Design Review and can be found in [2.1].

Table 2.1. Summary of vacuum seal types, sizes, and quantities for DTL tank 1.

| Seal Name or Location | Seal Type | Qty. | Material | Nominal Seal Diameter (cm) | Seal Cross-section Diameter (cm) |
|---|---|---|---|---|---|
| Endwalls | Vacuum | 3 | Viton | 45.720 | 0.476 |
| Endwalls | Rf | 3 | silver plated inconel | 43.942 | 0.635 |
| Drift tube tank interface | Rf / vacuum | 59 | silver plated inconel | 3.658 | 0.318 |
| Drift tube stem interface | Vacuum | 59 | silver plated inconel | 3.493 | 0.159 |
| Drift tube lock screw | Vacuum | 59 | silver plated inconel | 0.719 | 0.159 |
| Post couplers | Rf | 30 | silver plated inconel | 3.810 | 0.318 |
| Post couplers | Vacuum | 30 | Viton | 4.445 | 0.318 |
| Slug tuners | Vacuum | 12 | Viton | 14.605 | 0.318 |
| Slug tuners | Rf | 12 | silver plated inconel | 11.748 | 0.318 |
| vacuum spool tank interface | Vacuum | 4 | Viton | 15.875 | 0.318 |
| vacuum spool tank interface | Rf | 4 | silver plated inconel | 15.723 | 0.476 |
| 6" gate valve / turbo pump | Vacuum | 1 | copper- conflat type | 15.240 | 0.635 |
| vacuum spool pump interface | Vacuum | 4 | copper- conflat type | 15.240 | 0.635 |
| Iris waveguide tank interface | Vacuum | 1 | Viton | 15.572 (equiv. diam.) | 0.318 |
| Iris waveguide tank interface | Rf | 2 | silver plated inconel | 5.460 (equiv. diam.) | 0.318 |

| | | | | | |
|---|---|---|---|---|---|
| Waveguide window | Rf / vacuum | 1 | alum | 44.490<br>(equiv. diam.) | 0.399 |
| Vat series 08 gate valve | Vacuum | 2 | Viton | 8.890 | 0.318 |
| Endwall to gate valve | Vacuum | 1 | Viton | 7.620 | 0.318 |

Table 2.2 lists the outgassing and leak rates and loads as well as the total seal gas loads for DTL tank 1. Outgas rates were taken from [2.2] while leak rates were obtained from [2.3] and [2.4]. Similar tables for tanks 2 through 6 are included in Appendix H. The seal gas loads were incorporated in the vacuum numerical and analytical models discussed in Section 3.

Table 2.2. Summary of vacuum seal outgassing and leak rates for DTL tank 1.

| **Seal Name or Location** | **Outgas Rate (Torr L/s/cm$^2$)** | **Leak Rate (Torr L/s/mm)** | **Outgas Load (Torr L/s)** | **Leak Load (Torr L/s)** | **Total Outgas and Leak Load (Torr L/s)** |
|---|---|---|---|---|---|
| Endwalls | 1.14E-08 | 1.04E-10 | 3.67E-06 | 4.481E-07 | 4.123E-06 |
| Endwalls | 5.00E-10 | 3.70E-10 | 2.07E-07 | 1.532E-06 | 1.739E-06 |
| Drift tube tank interface | 5.00E-10 | 3.70E-10 | 1.69E-07 | 2.508E-06 | 2.677E-06 |
| Drift tube stem interface | 5.00E-10 | 3.70E-10 | 8.07E-08 | 2.395E-06 | 2.476E-06 |
| Drift tube lock screw | 5.00E-10 | 3.70E-10 | 1.66E-08 | 4.930E-07 | 5.096E-07 |
| Post couplers | 5.00E-10 | 3.70E-10 | 8.95E-08 | 1.329E-06 | 1.418E-06 |
| Post couplers | 1.14E-08 | 1.04E-10 | 7.58E-07 | 4.357E-07 | 1.194E-06 |
| Slug tuners | 1.14E-08 | 1.04E-10 | 9.96E-07 | 5.726E-07 | 1.569E-06 |
| Slug tuners | 5.00E-10 | 3.70E-10 | 1.10E-07 | 1.639E-06 | 1.749E-06 |
| vacuum spool tank interface | 1.14E-08 | 1.04E-10 | 3.61E-07 | 2.075E-07 | 5.685E-07 |
| vacuum spool tank interface | 5.00E-10 | 3.70E-10 | 7.39E-08 | 7.310E-07 | 8.049E-07 |
| 6" gate valve / turbo pump | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 3.831E-08 |
| vacuum spool pump interface | 1.26E-09 | 0.00E+00 | 1.53E-07 | 0.000E+00 | 1.532E-07 |
| Iris waveguide tank interface | 1.14E-08 | 1.04E-10 | 2.78E-07 | 5.085E-08 | 3.288E-07 |
| Iris waveguide tank interface | 5.00E-10 | 3.70E-10 | 8.55E-09 | 6.344E-08 | 7.199E-08 |
| Waveguide window | 6.00E-10 | 2.00E-08 | 5.25E-08 | 2.794E-05 | 2.799E-05 |
| Vat series 08 gate valve | 1.14E-08 | 1.04E-10 | 1.01E-07 | 5.809E-08 | 1.592E-07 |
| Endwall to gate valve | 1.14E-08 | 1.04E-10 | 4.33E-08 | 2.490E-08 | 6.822E-08 |
| | | | | Total | 4.764E-05 |

Metal seals will require specific surface finishes on the sealing surfaces. These surface finish requirements, supplied by the seal vendor, will be specified on all engineering drawings of hardware on which these seals are used.

There are several types of polymer materials that can be used for vacuum o-ring seals. Table 2.3 lists the radiation resistance and gas permeability rates of several common o-ring materials. The maximum acceptable cumulative radiation dose limit of $4.3\times10^{6}$ Rads (see Section 4 on materials) and a maximum Nitrogen permeability rate (see Section 3 on modeling) of $2\times10^{-8}$ (Std cc cm)/(cm$^2$ sec bar) limits the acceptable o-ring materials listed in Table 2.3 to Buna, Neoprene, and Viton.

Table 2.3. Radiation and gas permeability rates for various o-ring materials

| **O-ring Material** | **Radiation Dose Limit♣ [Rads]** | **Nitrogen Permeability Rate♣♣ $\times10^{-8}$ [(Std cc cm)/(cm$^2$ sec bar)]** | **Acceptable Vacuum Seal for DTL/CCL?** |
|---|---|---|---|
| Ethylene-Propylene Rubber (EPR) | $8\times10^{7}$ | 7.7 to 29.7 | No |
| Styrene-Butadiene Rubber (SBR) | $4\times10^{7}$ | 4.7 | No |
| Acrylonitrile Rubber (Buna-N) | $2\times10^{7}$ | 0.177 to 1.89 | Yes |
| Polychloroprene Rubber (Neoprene) | $2\times10^{7}$ | 0.1 to 2 | Yes |
| Fluorocarbon (Viton) | $1\times10^{7}$ | 0.233 | Yes |
| Silicone Rubber (SIR) | $9\times10^{6}$ | 75 to 210 | No |
| Butyl Rubber | $2\times10^{6}$ | 1.25 | No |

♣ See Section 4 for more details on materials. Maximum cumulative dose that materials will be exposed to over 30 years ≈ $4.3\times10^{6}$ Rads.

♣♣ Permeability rates obtained from Reference [2.3]. Maximum suggested permeability rate ≈ $2\times10^{-8}$ [(Std cc cm)/(cm$^2$ sec bar)].

### *2.4 RF Grills*

In order to shield the various vacuum pumps used in the DTL and CCL from RF energy, RF grills were designed. It was determined that slotted RF grills offered the better vacuum conductance over a grill made with holes. One type of grill is located at the mouth of the NEG pump in the RF window vacuum pumping system. Another grill design was used on the DTL tank pumping ports for the ion and turbo pumps. No grills were used between the CCL vacuum manifold and the CCL accelerating structure for several reasons. First, the pumping ports between the CCL and manifold are small and little RF energy will get through. Second, the CCL vacuum manifold connects to the accelerator structure through the side coupling cavities and these cavities, in the pi/2 mode, theoretically, do not contain any RF energy.

The calculations that were done on the RF grills utilized the same basic attenuation formula. The RF attenuation equation for the grill is [2.10]:

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

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

Where $\lambda_c$ is the cut-off wavelength of the grill and $\lambda$ is the wavelength of the RF in the accelerating cavity. The dominant mode in a rectangular wave guide is TM10 and the cut-off formula for this mode is

$$\lambda_c := 2 \cdot a$$

where "a" is the width of the wave guide in centimeters. Most of the attenuation takes place in the round nipples that are attached to the grill and supports the pumps. In a round waveguide, the dominated mode is TE11 and the formula to calculate the attenuation is [2.10]

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

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

were Ds is the diameter of the waveguide and Ls is it's length.

The above formulas were used to design the grill geometries as shown in Appendix I. The resulting attenuation of the optimized grills and pipes (nipples) significantly reduces the RF power to well under a watt (see Appendix I for complete calculations). The power that reaches the NEG pump in the RF window is about 4 milliwatts, and the power that reaches the Turbo pump and Ion pumps is about 50 milliwatts. SLAC [2.11] had problems with RF energy reaching one of their Ion pumps and it stopped pumping. They estimated that between 100 to 300 watts of energy was reaching that pump.

The combination of a slotted grill RF shield and a pipe or nipple of sufficient length greatly reduces the RF power that reaches the various vacuum pumps in the DTL to negligible levels. No problems due to RF power effecting the vacuum pumps are foreseen.

### *2.5 Vacuum Pumps*

To achieve the pumping requirements of the DTL and maintain a simplistic design approach, a distributed vacuum pumping system was chosen in which the main vacuum pumps were mounted directly to the tank body. Mounting pumps in this fashion resulted in minimal conductance losses between the pumps and vacuum environment, however, it did require the use of RF shields across the pump ports.

As shown previously in Figure 2.1, a combination of roughing, turbo, ion, and Non Evaporatable Getter (NEG) pumps were chosen for the DTL vacuum system. Each DTL tank body is equipped with one 300 L/s turbo/scroll pump cart port and three 300 L/s ion pumps. A portable turbo/scroll pump cart was selected for pumping the DTL tank from atmospheric pressure, down to a pressure (>10-5 Torr) that the main ion pumps can be turned on. The portable turbo/scroll pump cart is a temporary pumping system to be used during the early vacuum and RF conditioning of the DTL tank. The high pumping speed and flow through design makes the turbo pump ideal for conditioning the SNS linac. Upon completion of the conditioning stages, the turbo/scroll pump cart will be removed and be made available for other vacuum system operations. A pneumatic isolation valve will be placed on the DTL tank spool piece to allow for attaching and removing the turbo pump cart without impacting the vacuum environment. A dry scroll pump was chosen over a piston pump for roughing and turbo pump backing operations. A detailed design report that addresses this comparison study is contained in Appendix F. There has been some concern about contamination of forelines caused by particulates from scroll pumps. Particulates are generated by scroll pumps during normal operation due to the PTFE seals on the vane tips moving against their sealing surfaces. Varian Product Information bulletin #194S discusses proper isolation and venting of scroll pumps to prevent scroll pump generated particulates from reaching the turbo pump.

Ion pumps were selected to maintain the base pressure during the lifetime of the linac, mainly because of their high pumping speed, lack of moving parts, low cost, and high reliability for long-term operation. The pump size was chosen to be the largest that could be supported by and interfaced with the selected ports, while still remaining as an "off-the-shelf" item to ease procurement. The number of ion pumps was determined by inspection from a plot of beam tube pressure versus ion pump quantity for a single DTL tank, as presented in Section 3 of this report. In the unusual event of failure of an ion pump, the outgassing from the pump is insignificant for pressures above $10^{-10}$ Torr. Because of the low risk of ion pump failure, combined with the low outgassing rate of the pump components and extra pump capacity, ion pump isolation valves were not incorporated in the design.

As mentioned previously, the narrow opening, or iris, that exists between the DTL tank and its associated RF window, prevents the main tank vacuum pumps from effectively evacuating the waveguide transition piece between the iris and the RF window. In addition, the RF window is predicted to have a large outgassing rate of $5\times10^{-8}$ Torr Liter/s/cm$^2$, much of which is hydrogen and water vapor, during the early stages of RF conditioning [2.4]. The high RF window gas load, in combination with a minimal spatial allotment for vacuum hardware and supports around the RF window, required the use of a special vacuum pump. The design criteria of high pumping speed (especially for hydrogen), lightweight, minimal vibrations, and a small spatial envelope, led to the selection of a Non Evaporable Getter (NEG) pump. This pump is extremely compact and lightweight in comparison to ion pumps of equivalent pumping capacity. In addition, the NEG pump has an extremely high pumping speed for hydrogen. The details of one such NEG pump (SAES CapaciTorr-B 1300-2) are shown in Figure 2.3(a). A NEG pump has been in successful operation on the Low Energy Demonstration Accelerator's (LEDA) RFQ RF window at Los Alamos National Laboratory [2.5], see Fig. 2.3(b), and was also selected for the LEDA's Coupled Cavity Drift Tube Linac RF window vacuum pumping system [2.6]. For the SNS DTL, the NEG pump will be mounted directly to the RF transition waveguide assembly to maximize the conductance. An RF grill will be placed across the pump port to attenuate RF fields and prevent RF excitation of the pump housing. The longevity of the NEG pump for this vacuum


(a)

(b)

Figure 2.3. (a) Photo and schematic of an SAES CapaciTorr®-B 1300 NEG pump and (b) NEG pump installed on LEDA R F window.

application, the need for high conductance between the pump and waveguide, and the motivation to reduce hardware cost and control system complexity, have resulted in an omission of an isolation valve between the NEG pump and waveguide.

One drawback of the NEG pump is that it cannot pump inert gases. To overcome this limitation, a small turbo pump (70 L/s) was added to the RF window pumping system. This turbo pump also provides for initial and periodic vacuum conditioning of the NEG pump. Space and clearance limitations required that the turbo pump be mounted on the housing of the NEG pump. A pneumatic isolation valve was placed between the NEG and turbo pumps to allow for shutting down of the turbo during steady state operation of the Linac. A dry scroll was chosen to back the RF window turbo pump. To isolate the vacuum pumps from the RF energy in the waveguide transition piece, RF shields were positioned across the vacuum hardware ports. The arrangement of the complete RF window vacuum system is noted in Figure 2.4.

The CapaciTorr-B 1300 uses ST185, a sintered NEG material in the form of a blade. Two cartridges within the NEG pump housing, hold multiple NEG material blades. A concern has been raised that a small number of the NEG particles on the blade surface may not bond well during the sintering process and may fall off, creating dust particles. Operational experience on the LEDA RF window vacuum system showed no signs of loose particulates when the system was disassembled for reconfiguration in May 1999. As a precautionary measure, the CapaciTorr-B 1300 was mounted on the bottom of the DTL waveguide transition segment to prevent any loose particulates from falling into the waveguide.

The CapaciTorr-B 1300 is initially shipped from the factory with a passivating layer, made up of physisorbed gases that form external monolayers covering the surface of the NEG material. The gases are $H_2$, $H_2O$, $CO$, $CO_2$ and $CH_4$. Before the NEG pump can be utilized, the passivating layer must be removed by heating the getter material to a temperature of 450°C. During this activation stage, the passive layers are desorbed from the surface of the NEG's getter material and drawn out of the vacuum environment by the small turbo pump. During activation or regeneration, the heat from the NEG will drive off other gases from the surrounding walls, which the turbo pump will also remove from the vacuum environment.

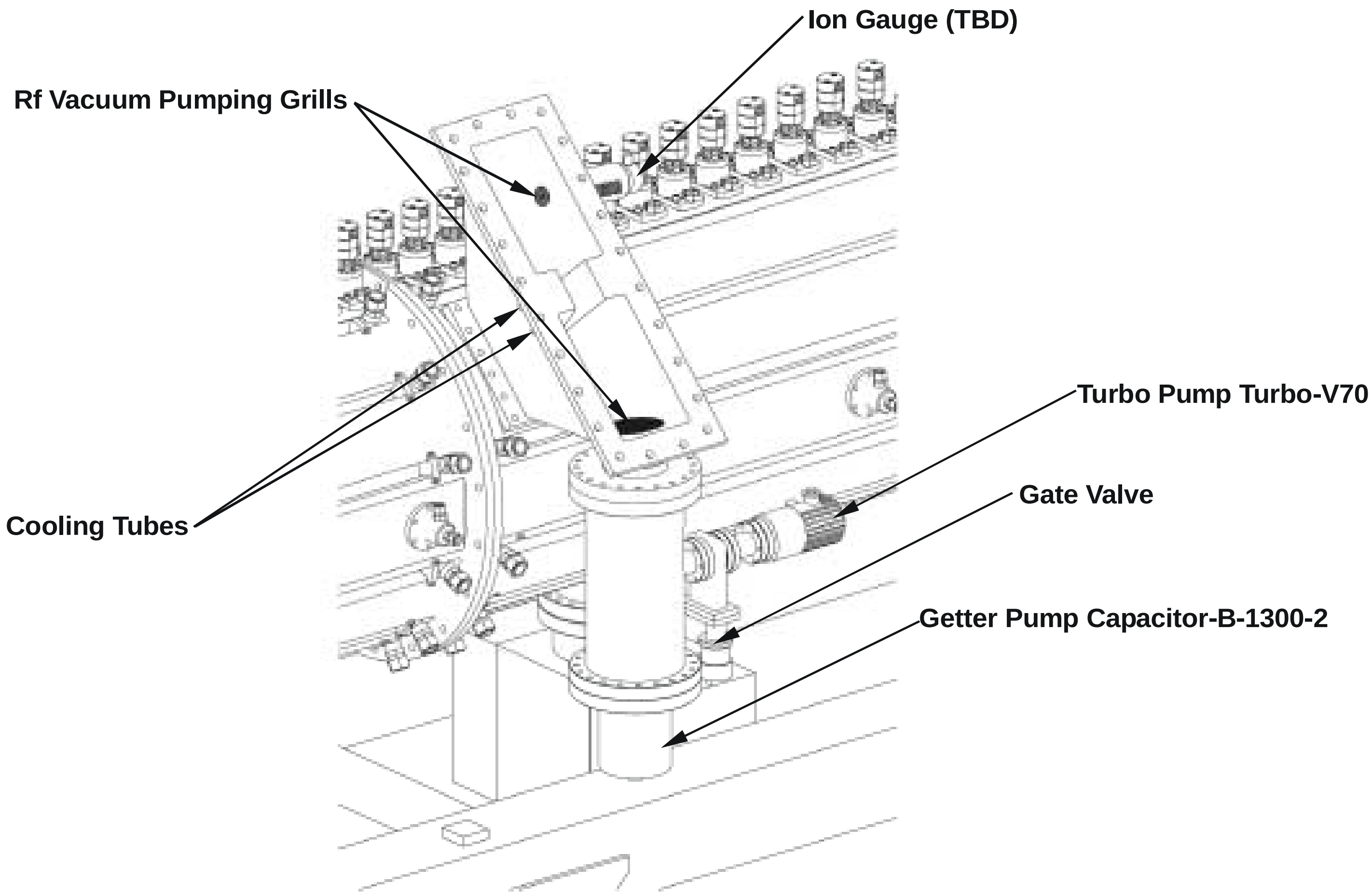



Figure 2.4. Details of the SNS DTL R F window vacuum pumping assembly..

Under normal vacuum operation without a vent to atmosphere, the NEG will pump active gases and some of the gas molecules will gradually form another passivating layer, requiring that the NEG be eventually regenerated. Regeneration also occurs at a temperature of 450°C. Note that NEGs can only pump hydrogen reversibly and all other active gas molecules are diffused further into the bulk getter material during regeneration.

There is some concern that the gases given off during activation or regeneration could contaminate the RF window or waveguide transition segment. As stated before, the gases desorbed during activation are $H_2$, $H_2O$, CO, $CO_2$ and $CH_4$. During subsequent regenerations without an air vent, NEGs can only give off hydrogen. Other gases that are desorbed from the walls of the pump due to the elevated temperature should be minimal with proper high vacuum fabrication and handling techniques. The gas molecules desorbed from the wall of the pump body may stick and form monolayers on the RF window or waveguide transition segment. These monolayers will be easily and quickly driven off by the RF and should not impact RF operations.

Mechanical, operational, and electrical specifications for all of the vacuum pumps are contained in Appendix E.

### *2.6 Instrumentation*

The DTL vacuum system design requires a means to monitor the vacuum pressure for system operation and provide vacuum safety interlocks to the LLRF and SNS Global Control Systems. Although vacuum pressure can be derived from ion pump current, there is a need to measure vacuum pressure before the ion pumps are started. An ion pump requires a moderately high vacuum (approximately $1 \times 10^{-5}$ Torr) to be established by the turbo pump cart before it can be started. Starting an ion pump at higher pressures causes the pump to overheat or generate internal electrical discharges and reduces the pump's operating life. In addition, SNS global control operations require continual monitoring of vacuum pressures, especially in the event of an electrical power failure. It is much more cost effective to provide UPS power to a set of vacuum gauge controllers than to ion pump controllers to monitor system pressure in the event of an electrical power failure. Consequently, to provide the most robust control system, an independent set of gauges is required to monitor the status of the DTL vacuum environment.

Two convectron gauges will be used per DTL tank. A convectron is used to measure pressure from atmosphere down to the milliTorr range. A convectron gauge is more accurate than a thermocouple gauge or Pirani gauge since it has a temperature compensated heat sensor and precisely controls the power delivered to the heating element.

One convectron will be used to monitor the foreline pressure for each turbo pump. This gauge will provide an interlock to the PLC to protect the turbos from high foreline pressures. The second convectron will monitor the pressure in the DTL tank during pumpdown from atmosphere.

Two cold cathode gauges per DTL tank will be used to monitor operating vacuum pressures ($10^{-3}$ to $10^{-9}$ Torr). One cold cathode gauge will be mounted on the instrumentation spool piece and will monitor tank pressure. This gauge will provide vacuum system monitoring and provide interlocks for turning on the ion pumps and the RF power. One cold cathode gauge will be mounted to the RF window waveguide transition and will monitor system pressure in the vicinity of the RF window. This gauge will provide a safety interlock signal for the LLRF controls.

The SCL requires a particulate-free environment to minimize electron discharges and quenching of the super-conducting cavities. Consequently, ion gauges were ruled out for vacuum measurements in the DTL and CCL because of their potential to generate particulates. In addition, the environment in the storage ring required the use of cold cathode gauges rather than ion gauges. In order to limit the number of gauge types in the SNS vacuum systems and satisfy the minimal particulate generation requirements of the SCL, cold cathode gauges were selected for high vacuum pressure measurements in the DTL. The standard accuracy of the cold cathode gauge (≈ 50%) is significantly less than an ion gauge (5-10%). Consequently, the RF trip vacuum levels will need to be set at a more conservative value ($10^{-6}$ Torr) with the cold cathode gauge.

A quadrupole type Residual Gas Analyzer (RGA) with an electron multiplier and an atomic mass unit range of at least 0 to 100 will be required to measure the partial pressure of gas species in the DTL vacuum system. The RGA is an effective tool to monitor for vacuum system leaks, check for surface contamination such as oils and residues left over from the manufacturing and assembly processes, and observe the various gas species within the vacuum environment. The high levels of radiation in the linac tunnel requires that only the RGA's quadrupole head can be mounted to the DTL tank. The RGA controller will need to be remotely mounted in the vacuum control system's electronics rack, located in the klystron gallery. This will require an approximate 100 ft. power and communications cable to be run from the RGA controller to the quadrupole head.

### *2.7 Controls*

Each DTL tank is being designed to have its own vacuum control system. This design choice was made to allow each DTL tank to be vacuum leak checked, conditioned, operationally certified, and operated and maintained on an individual basis. This control system segregation is also consistent with the DTL water cooling and resonance control systems [2.7] and the DTL assembly and installation plans.

The control system for the DTL vacuum will consist of a local control system that can operate in a stand-alone mode or be connected via a network to the SNS global control system running under EPICS. The stand-alone mode will be used for initial testing and commissioning. This mode will also be useful after commissioning in the event EPICS is not running.

The local control system will be implemented using an agreed-upon SNS project standard Allen Bradley ControlLogix Programmable Logic Controller (PLC) that monitors and controls all of the individual vacuum pump and instrumentation controllers. The PLC will be programmed with Allen Bradley's RSLogix5000 ladder code programming toolkit. A local touch screen operator interface terminal will be provided for local display of the instrumentation and system operation. A password-protected screen will allow operators to access the control system parameters to make changes if needed, as well as provide manual control of the vacuum pumps and instrumentation. The PLC will also be connected via Ethernet to an IOC and the SNS Global Controls system.

An equipment rack will be provided that complies with the SNS rack standards. The rack will contain the vacuum pump and instrumentation controllers, the ControlLogix system, the PanelView operator interface, power supplies, terminal blocks, and a cooling fan.

Additional details of the control system can be found in Section 5 of this report.

### *2.8 Gas Pressurization and Relief*

The DTL vacuum system must be equipped with a clean gas handling system to allow the DTL vacuum environment to be pressurized back up to atmospheric pressure during maintenance procedures in which the vacuum seal must be broken. The gas handling system must also provide as a pressure relief mechanism to prevent over-pressurization of the DTL tank.

Figure 2.5 displays the gas pressurization and relief system that has been designed for the DTL vacuum system. A dry Nitrogen gas bottle (99.999% $N_2$) serves as the pressurized gas source, used to fill the DTL tank volume. Dry nitrogen will be used to purge the DTL vacuum system during vacuum shut-down or DTL maintenance procedures so that the interior surfaces of the vacuum remain as clean and moisture free as possible. Two gas pressure regulators (coarse and fine), connected to the outlet of the $N_2$ gas bottle, were incorporated to step down the gas bottle pressure from several thousand psig, to less than a single psig. A manual isolation valve separates this part of the gas pressurization system from the DTL vacuum environment. On the vacuum side of the isolation valve, an orifice plate gas throttling mechanism has been incorporated to limit the gas flow rate out of the gas bottle. Next to the orifice plate is a pressure relief valve, which has been designed to crack at 1 to 2 psig and thus limit the amount of pressurization of the DTL tank. Internal pressure limits for the DTL and CCL were calculated in order to determine safe operating pressures for the nitrogen purge subsystem. Finite element modeling of the DTL components subject to internal pressure loads was completed [2.12]. The limiting component for the system with respect to internal pressure was identified and the specific pressure at which yielding initiates was calculated. The calculated internal pressure limit for the DTL is 51.0 psig. The limiting DTL component is the OFE copper endwall. The nitrogen purge system design operating pressure is less than 2 psig and the over pressure relief valve setting will be 1 to 2 psig. Considering the calculated internal pressure limits, the purge system design provides ample protection against internal over-pressurization.

To correctly size the orifice plate and pressure relief valve, an orifice plate restrictive gas flow study by Shrouf [2.8] was referenced. As a basis for this analysis, a determination was made to not allow the accelerator tanks to be pressurized above 2 psig when backfilling with dry nitrogen. A pressure relief valve that met this requirement was the one inch CTI-Cryogenics PRV supplied by Scientific Sales [2.9]. A performance graph of this valve is shown in Figure 2.6. Notice that this graph displays an "original" design and an "improved design". The improved design was selected for the DTL vacuum system. Using the improved valve's performance curve of Figure 2.6, it is seen that this pressure relief valve will allow about 13 SCFM flow rate at a cracking pressure of 2 psig pressure in the tanks.

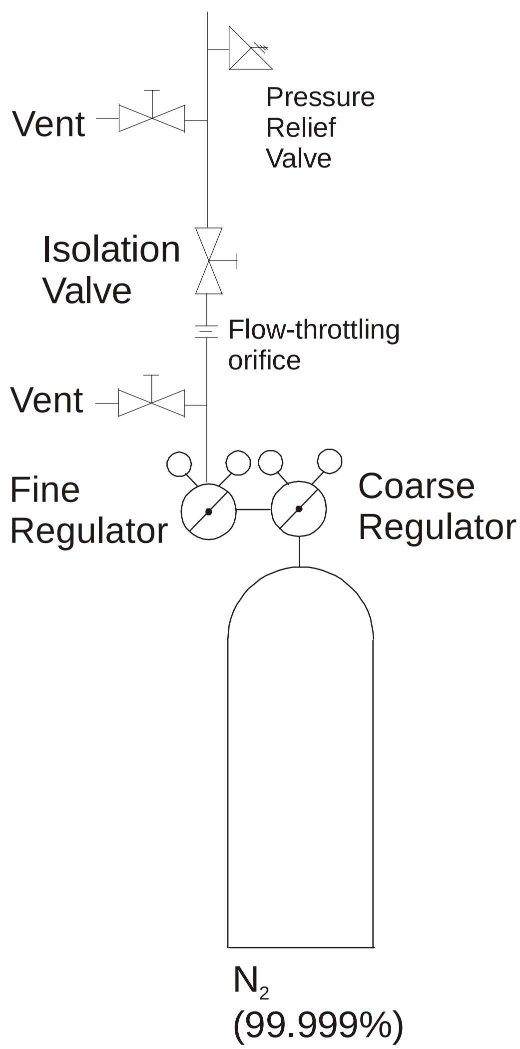



Figure 2.5. DTL gas pressurization system.

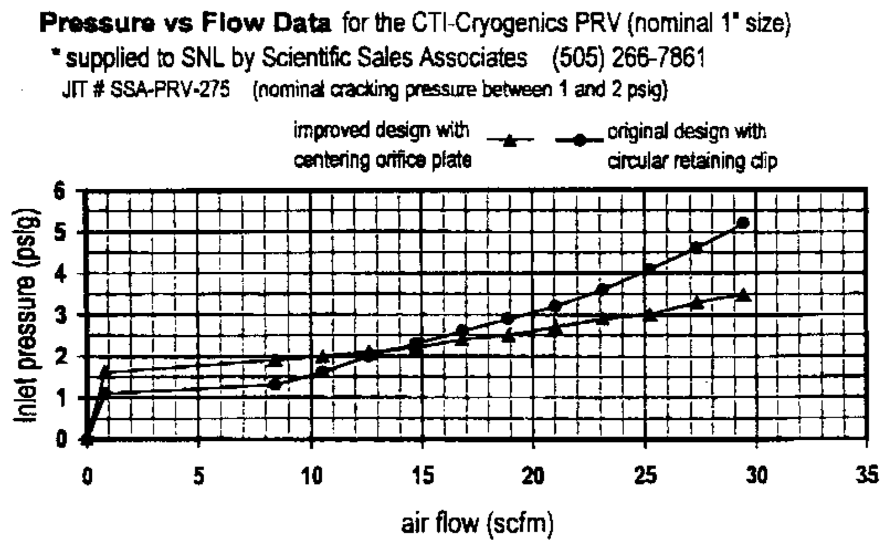



Figure 2.6. Performance curve of the CTI-Cryogenics PRV.

A standard nitrogen bottle holds about 220 standard cubic feet of gas under a pressure of 2,000 to 2,200 psig. To determine the orifice size necessary to hold the flow rate to about 13 SCFM, Table 1 of [2.8] was referenced. In that Table, a 0.020 inch inner diameter orifice, and 1997 psig gas bottle will allow about 13.5 SCFM flow rate of air. At this flow rate, it will take about 6 minutes to backfill two DTL tanks, which have a volume of about 62 cubic feet. It should be possible to backfill these tanks two to three times before replacing the nitrogen bottle. This depends of course, on how long one is willing to wait to fill up the tanks.

The data taken in the SNL paper is relevant to a specific orifice design. One can not drill out a blank cylinder and expect it will perform as expected. The restrictive orifice that was used in the calculation, and that used for the actual DTL vacuum system, should be in agreement with Table 1. For a more detailed discussion of these calculations, see Appendix I.

Finally, manual vent valves have been included as a means to vent any part of the gas pressurization system to atmosphere, should it be required. The gas handling system will attach to a conflat flange port on the DTL vacuum equipment spool piece. It is anticipated that the portion of the gas handling system upstream of the gas throttling device (refer to Fig. 2.5), will be mounted on a portable cart, and will thus be available to service all SNS vacuum systems.

## 3.0 Vacuum System Analyses

## 3.1 DTL RF Structure Vacuum Model

### *3.1.1 Design Goals and System Description*

The requirement for the Drift Tube Linac vacuum system is to provide sufficient pumping to overcome the surface outgassing of vacuum facing components, leak rates of seals, and maintain a sufficient drift tube bore pressure. When the $H^-$ beam is present, the drift tube bore pressure must be below 1.84 x $10^{-7}$ Torr [1.3] when pressures are averaged over 5 meters of beam tube. These limits are for beam energy less than 100 MeV, which is the case for all 6 DTL tanks. This pressure is the maximum recommended to reduce scattering of the $H^-$ beam, and associated activation of the DTL hardware by limiting the radiation dose to 10 mrem/hr one foot from the tank for personnel protection. In the numerical model, a design goal for a pressure that is half of the above limits was desired in order to have an operating margin of two. Thus the pumps were sized to achieve an operating base pressure of at least 9.2 x $10^{-8}$ Torr for a reasonable gas mixture. It was found that using a gas mixture in the numerical model, as will be discussed below, produces pressure that is lower than that obtained for "air" as the gas medium (with a composite mass of 28.98 amus). Consequently to minimize the complexity of the analysis, a design goal for an operation base pressure of 9.2 x $10^{-8}$ Torr was sought using air as the gaseous medium. Finally, an additional goal of maintaining a base pressure of 1.84 x $10^{-7}$ Torr in the event that one pump failed, was defined.

Turbo and scroll pumps, mounted on a portable cart, have been chosen for roughing down the vacuum environment and providing initial vacuum conditioning of the DTL. These pumps are used to lower the pressure below $10^{-5}$ Torr, after which ion pumps, used for steady-state vacuum pumping of the DTL, can be turned on. Ion pumps were chosen for steady-state operation because of their reliability and lack of the need for a backing pump.

The surface outgassing rate of the annealed OFE copper is assumed to reach 1 x $10^{-10}$ Torr-L/s/cm$^2$ after 100 hours of vacuum and RF conditioning. This rate is based on measurements from the APT/LEDA CCDTL Low Beta Hot Model [2.6]. It is also consistent with measurement results from SLAC/B-Factory (see Appendix A). To achieve this outgassing rate, rf power is turned on to provide surface heating and molecular excitation to drive out trapped and adsorbed gases. During vacuum conditioning, the turbo pumps and ion pumps can be used to maintain $10^{-6}$ Torr until conditioning is complete and the outgassing rate drops to the post-conditioning value of $1 \times 10^{-10}$ Torr-L/s/cm$^2$. Table 3.1 summarizes many of the vacuum system design requirements.

TABLE. 3.1. System requirements specified by SNS and Design Values for all 6 DTL Tanks.

| Parameter | | Requirements / Value |
|---|---|---|
| Surface Outgassing Rates | | $1.0 \times 10^{-10}$ Torr-L/sec/cm$^2$<br>(at 100 hrs: post-cond.)<br>$2.5 \times 10^{-9}$ Torr-L/sec/cm$^2$<br>(at 100 hrs: pre-cond.) |
| Drift tube bore pressure<br>• Post - rf conditioned<br>• Normal mode of operation: all ion pumps functioning | Design<br>Required | $9.2 \times 10^{-8}$ Torr (avg.) for mixed gases<br>< $1.84 \times 10^{-7}$ Torr for mixed gases |
| Drift tube bore pressure<br>• Post - rf conditioned<br>• Failure mode of operation: all but 1 ion pump functioning | Design<br>Required | $1.84 \times 10^{-7}$ Torr (avg.) for mixed gases<br>< $1.84 \times 10^{-7}$ Torr for mixed gases |

A description of components to be evacuated along with the optimized pumping system is provided in Table 3.2. This table refers to DTL Tank 2 because this tank produced the highest beam tube pressure. Pressures shown are the maximum values within the drift tube bores. Figure 3.1 shows a 3-D drawing of the tank and optimized pumping configuration. Figure 3.2 shows the interior detail that is also included in the numerical model

TABLE 3.2. DTL optimized vacuum system description.

| |
|---|
| 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<br>Tanks 2 to 6: 48 to 22 sockets, drift tubes, and drift tube stems, and 24 to 11 post-couplers<br>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 = $4.0 \times 10^{-5}$ Torr-L/sec |
| Total seal permeability & outgassing rate = $2.1 \times 10^{-5}$ Torr-L/sec (53% of post-conditioned total) |
| Magnet outgassing rate inside of each drift tube =<br>$1.25 \times 10^{-7}$ 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) = $8.0 \times 10^{-8}$ Torr |
| Peak pressure after conditioning and pumping air with 2 ion pumps (failure mode) = $1.1 \times 10^{-8}$ Torr |

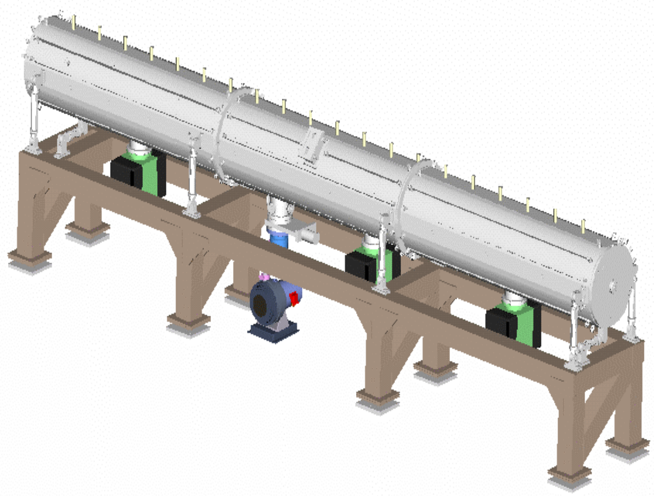


FIGURE 3.1. Drift tube linac with optimized pumping configuration.

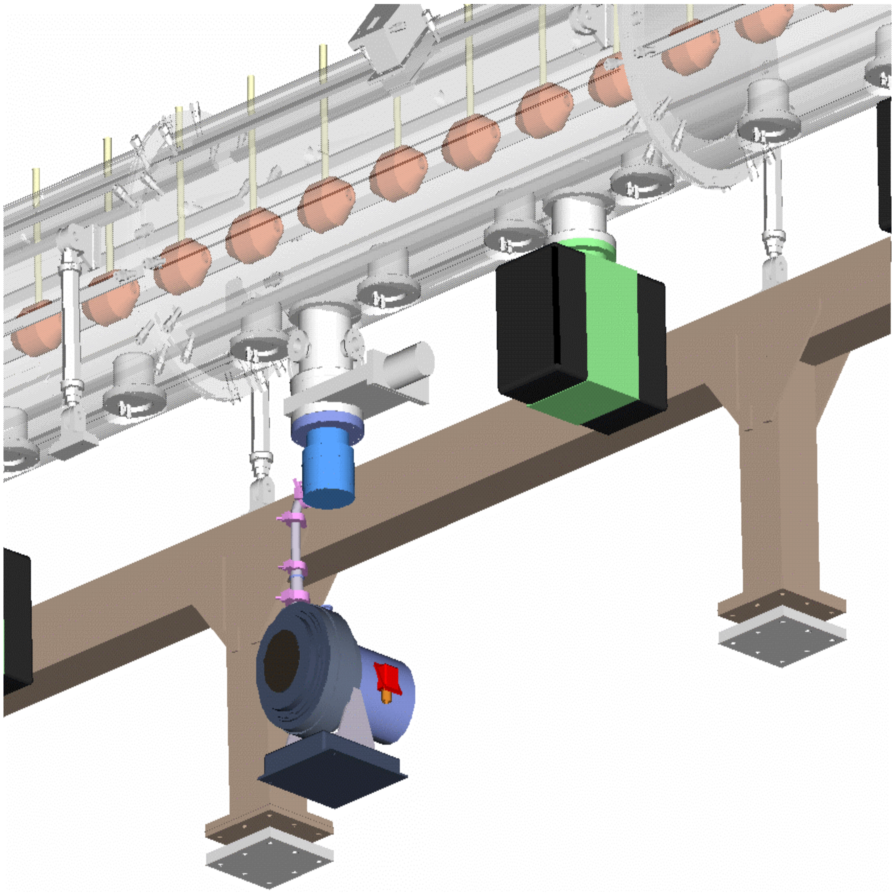


FIGURE 3.2. Interior detail of tank showing the drift tubes, stems, sockets, and slug tuners that are included in the numerical model.

### *3.1.2 Numerical Model Description*

The numerical model of the vacuum system models the gas load balance between the DTL tank, a representative drift tube section, and the vacuum pumps. The sketch in Fig. 3.3 shows the layout of the volumes to be evacuated and the division into 7 sub-volumes and interconnecting conductances. Four sub-volumes represent each tank quadrant and three represent two drift tubes and the gap in between them. These drift tubes are attached to the 4th tank quadrant. The geometry of the representative drift tubes uses the longest drift tube in the tank. It also illustrates the placement of quadrupole magnets, seals and O-rings.

Pressure history is studied by solving the coupled gas load equations between all the sub-volumes. A summary of the features in the code is presented in Table 3.3. Details of these features are discussed in the following subsections.

TABLE. 3.3. Features of the numerical model.

| Features of Numerical Model |
|---|
| Solves entire transient pumpdown curve |
| Separate time-dependent outgassing rates for conditioned copper and stainless steel surfaces |
| Pressure-dependent pumping speeds for all three pump types |
| Automatic distribution of pumps for parametric studies |
| Inclusion of seal permeability and outgassing rates independent of time |
| Inclusion of magnet outgassing rate into each drift tube independent of time |
| Flag for air, $H_2$, $H_2O$, $N_2$, or $CO_2$ analysis to choose proper pump speeds and conductances |
| Pressure solved for 7 sub-volumes including sample (worst case) drift tube section |
| Written with Mathematica [3.1] and runs in 20 seconds on a 266 MHz Power Mac G3 |

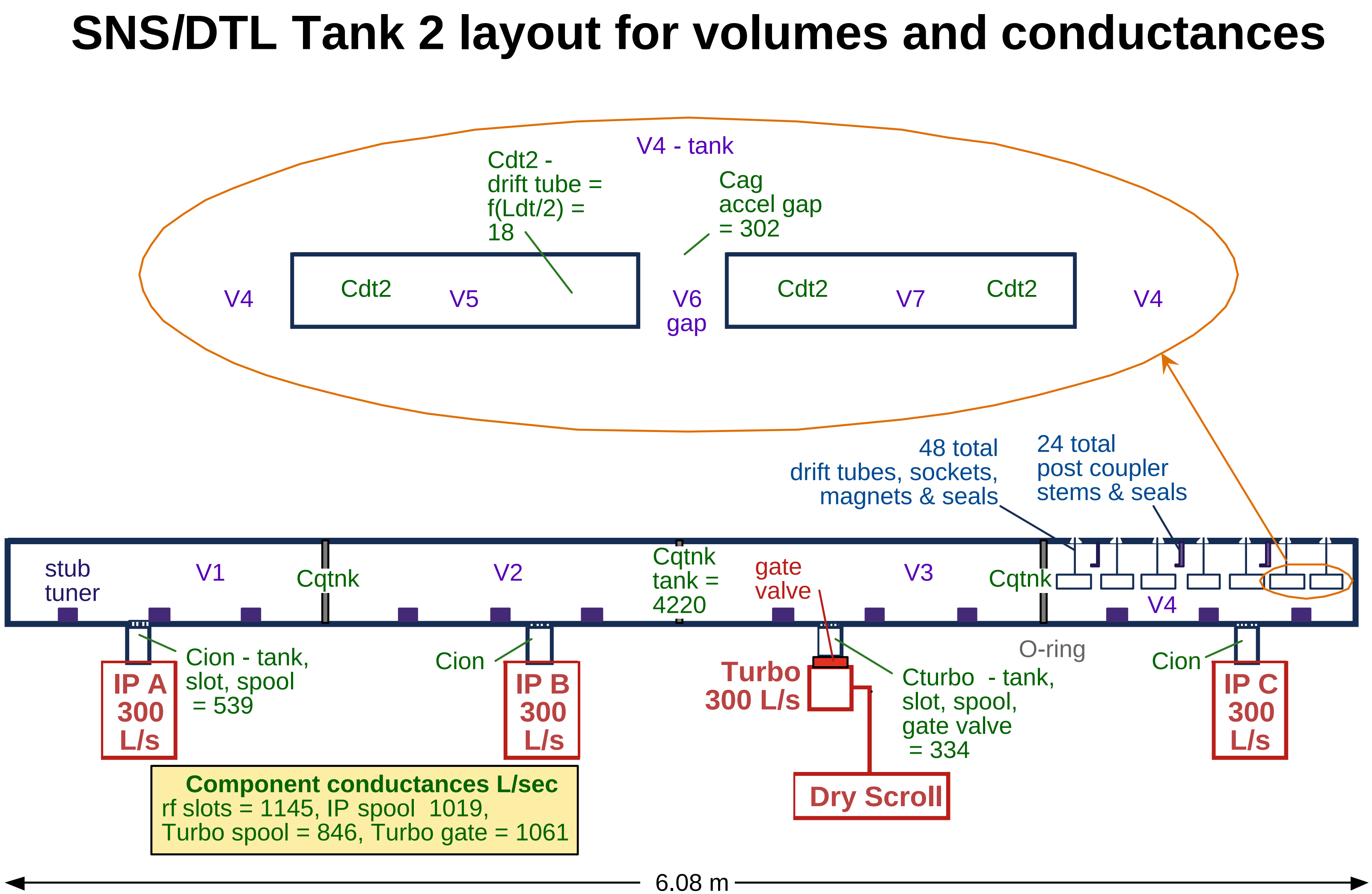



FIGURE 3.3. Layout of sub-volumes and conductances (L/sec) in the model of the SNS/DTL Tank 2.

The gas load equations, shown below, are solved simultaneously for all sub-volumes for each time during pumpdown.

$V_i \, dp_i/dt = \Sigma \, Q_{i\,in} - \Sigma \, Q_{i\,out}$
where *i* is the index for the *ith* volume,
*V* is the volume (L);
$dp_i/dt$ is the rate of change in pressure (Torr/sec);
$\Sigma \, Q_{i\,in}$ is the sum of outgassing or leakage into $V_i$ (Torr-L/sec);
(surface outgassing is a function of time but permeability is constant)
and $\Sigma \, Q_{i\,out}$ is sum of the gas throughput from $V_i$ into $V_j$,
where $Q_{i\,out} = C_{i \rightarrow j} \, (p_i - p_j)$
and $C_{i \rightarrow j}$ is the conductance (L/sec);
and/or $\Sigma \, Q_{i\,out}$ is sum of the gas throughput out of $V_I$,
where $Q_{i\,out} = S \, p_i$ ,
where S, the effective pump speed (L/sec), is
$S = S_p(p_i) \, C_p \, / \, (S_p(p_i) + C_p,$
where $C_p$ is the conductance between $V_i$ and the pump
and $S_p(p_i)$ is the pressure dependent pump speed.

#### *3.1.2.1 Gas Loads*

All vacuum-facing surfaces, except for the pump spool pieces and gate valves, are composed of OFE copper. The tanks are copper-plated carbon steel. The drift tubes, post couplers, and slug tuners are fabricated from OFE copper. The pump spool pieces and gate valves are electropolished stainless steel. The transient outgassing rate for these components is a combination of three distinct conditioning periods and is shown in Fig. 3.4. The early outgassing rate (first hour) is taken from Roth [3.2]. The history from 2 to 80 hours is taken from measurements made from the APT/LEDA Hot Model, a coupled-cavity drift tube linac structure [2.6]. While this structure was not the same as the present DTL, it is anticipated that the gas loads of each RF structure will be similar. As a conservative design measure, a limiting outgassing rate was chosen in the current study. Prior to rf conditioning the final outgassing rate for the copper is assumed to be 2.5 x $10^{-9}$ Torr-L/sec/cm$^2$. After conditioning the final rate for the copper is 1 x $10^{-10}$ Torr-L/sec/cm$^2$. The rate for the stainless steel is assumed to be 1 x $10^{-10}$ Torr-L/sec/cm$^2$ for both the pre- and post- conditioning phases. For modeling convenience, the final outgassing rate is assumed to occur at 100 hours. Note however, in Fig. 3.4, the LEDA Hot Model data shows that lower outgassing rates can be achieved beyond 100 hours of conditioning.

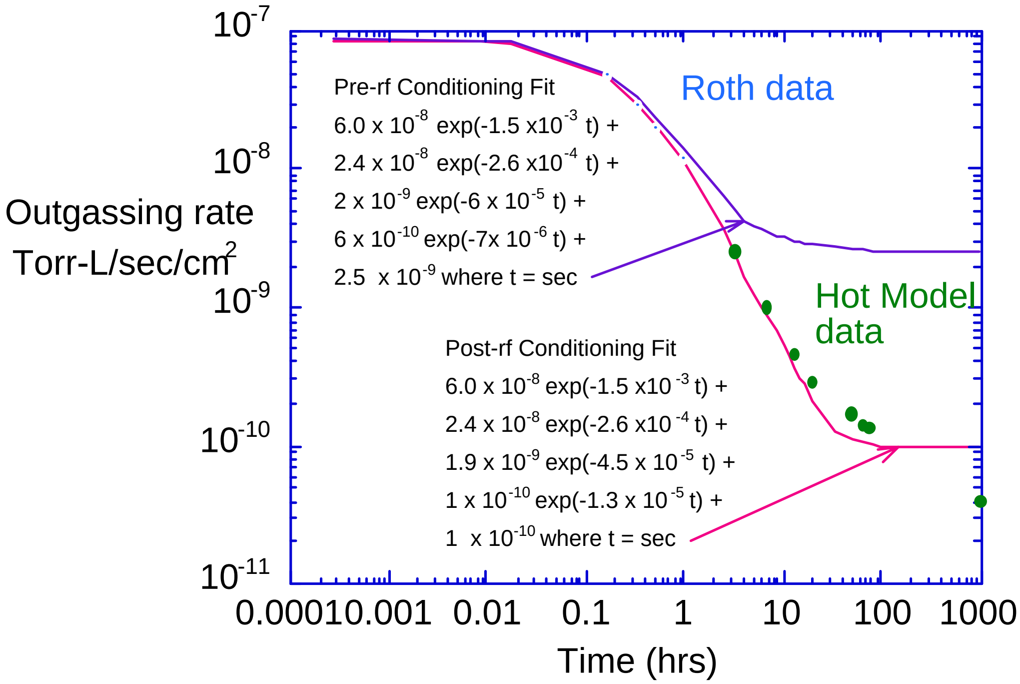



FIGURE 3.4. Pre- and Post-Conditioning Fits for Outgassing Rates for Copper. The stainless steel rate is assumed to be the same as the post-conditioning fit for copper.

The design of all seals and penetrations, and their calculated gas loads are listed in the Tables of Section 2.3 and Appendix H for all six tanks. As summarized in Table 3.5, in a typical tank, the gas loads from seals represents 54% of the total. Based on the measurement results from a prototype [3.3], the gas loads of the quadrupole magnet in each drift tube were also estimated. In a typical tank, it represents 15% of the total. (see also Table 3.5.)

### *3.1.2.2 Pump Models*

For each pump, the dependence of pump speed on local pressure $S_p(p_i)$ was scanned from the manufacturer's catalog and fit to a numerical formula. An example of this for the Captorr 300 conventional ion pump for dry air is shown in Fig. 3.5. To solve for other gases, a multiplier is used as shown in Table 3.4. These factors are taken from the vendor catalogs.

TABLE. 3.4. Pump scaling factors for various gases.

| Gas (mass in amu) | Varian Turbo 300 | PHI conv. Ion Pump |
|---|---|---|
| Air 28.98 | 1.00 | 1.00 |
| $H_2$ 2.016 | 0.75 | 2.20 |
| $H_20$ 18.016 | 1.00 | 1.00 |
| $N_2$ 28.02 | 1.00 | 0.85 |
| $CO_{2\ 44.01}$ | 1.00 | 1.00 |

For the roughing pump, the gas load balance is solved with an initial pressure at atmospheric. All gases are treated the same through the roughing pump. The roughing time is chosen to be 44 minutes so that the final drift tube bore pressure is 0.05 Torr. A Varian PTS 300 scroll pump with a working pump speed of 250 L/min was used in the numerical model. Next the final pressures for the 7 sub-volumes were saved to provide the initial conditions for the turbo pumping phase.

The turbo pump was on for 14 hours – the time needed to achieve 5 x $10^{-7}$ Torr in order to safely turn on the ion pumps. This final pressure was about 80% of what could be achieved if the turbo pump was on for 100 hours. This long pump-down time resulted because the outgassing rate is relatively high during the initial pump-down phase (<100 hrs).

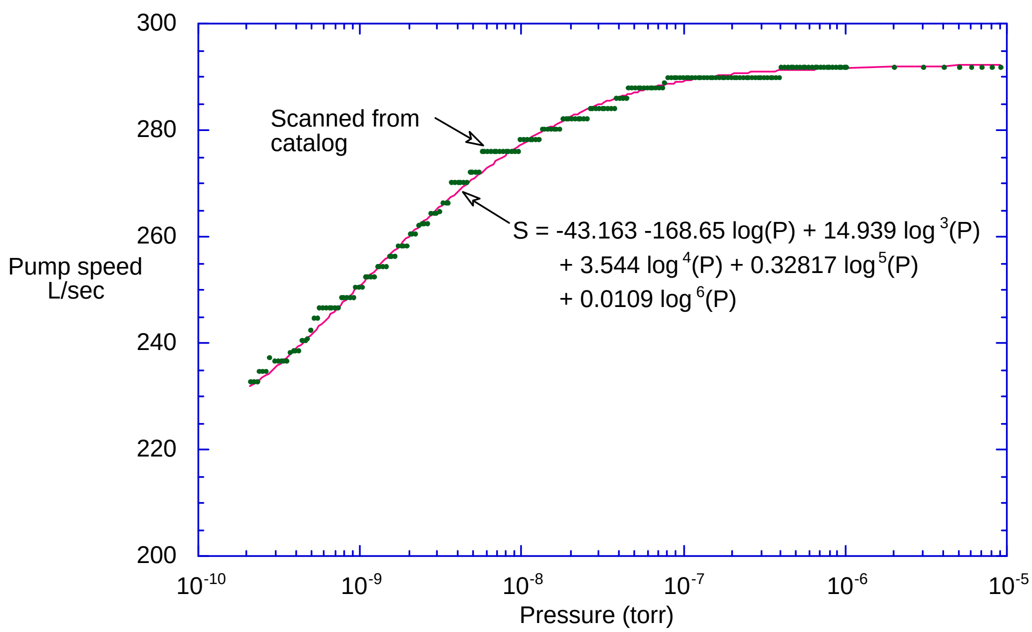



FIGURE 3.5. Dependence of pump speed on pressure for a PHI 300 Captorr conventional ion pump. The data was scanned from the vendor catalog and a numerical expression was fit to the data and used in the model.

### *3.1.2.3 Conductance Formulas*

The majority of the conductances in the DTL vacuum model, correspond to that of molecular flow in a short tube. The molecular conductance of air in a short tube is given by Roth [3.2] as:

$$C_{air} = 12.1(\frac{D^3}{L})K$$

where D is the inside diameter of the tube in cm, L is the tube length in cm, and K is Clausing factor given as:

$$K = \frac{15(L/D)+12(L/D)^2}{20+38(L/D)+12(L/D)^2}$$

For the RF grill slots between the pump and tank, a conductance value was taken from the calculations by Ilg (see Appendix I). When the various gasses were studied, all conductances were multiplied by the square root of the ratio of the molecular weight of air (28.98) to that of the particular gas species, as shown in Table 3.4.

The detailed areas, volumes conductances, and final outgassing rates are summarized in Table 3.5.

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).

| Sub-volume Location in Layout = Component | Area ($cm^2$) | Volume (lit) | Conductance (lit/sec) |
|---|---|---|---|
| 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 = $2.1 \times 10^{-5}$ Torr-L/sec (54% of total) | | | |
| Total magnet outgassing rate = $6.0 \times 10^{-6}$ Torr-L/sec over a total length of 218 cm (15% of total) | | | |
| Total final gas load = $4.03 \times 10^{-5}$ 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 | | |

### *3.1.3 Results*

#### *3.1.3.1 Summary*

Running the model with a range of pump sizes determined the optimal configuration. Consideration was made for satisfying the design requirements while minimizing the number of pumps to minimize the costs. An attempt was successfully made to use the same pump types and sizes for the DTL and CCL vacuum systems. As seen in Fig. 3.1, the pump configuration chosen for each DTL tank was 1- PTS 300 dry scroll pump, 1 – Varian Turbo 300, and 3-PHI 300 Captorr conventional ion pumps. The pressure history for pumping the conditioned surfaces is shown in Fig. 3.6. Note that the 100 hours needed to achieve a final pressure is driven by the outgassing and seal leak rates, which is forced by the model to reach a final value at 100 hours.

#### *3.1.3.2 Turbo Pump Optimization*

The turbo pump has been optimized based on its functions to achieve a pressure of $5 \times 10^{-7}$ Torr so that the ion pumps can be safely turned on during normal operation. After 14 hours of pumping, one turbo 300 achieves this pressure. As shown previously, the series conductance of the turbo pump spool, gate valve, and rf slot, and manifold quarter-length is 334 L/sec. The model does not consider the use of an extension piece to connect the turbo pump cart to the turbo gate valve. Generally the extension should be designed to be of minimal length and maximum diameter so that its conductance is much larger than the 334 L/sec discussed above. The effect of the extension conductance will be to increase the pump-down time for that tank and thus for the whole DTL/CCL system. This total time will depend on the number of turbo carts available to pump the system in parallel.

#### *3.1.3.3 Ion Pump Optimization*

The main function of the ion pumps is to achieve a base pressure significantly below $10^{-6}$ Torr during conditioning (turbo pump on) and reach $9.2 \times 10^{-8}$ Torr after conditioning. With the standard outgassing rate of $10^{-10}$ Torr-L/sec/cm$^2$ for air, 3 ion pumps were found to provide a peak drift tube bore pressure of $8.0 \times 10^{-8}$ Torr that is well within the design goal. It should also be noted that outside the drift tube bores, the pressure in subvolume 1 was $7.5 \times 10^{-8}$ Torr. Thus a pressure gauge at the tank spool piece would show a value within 6% of the drift tube pressure.

Figure 3.7 shows drift tube pressure versus the number of Captorr 300 ion pumps. Note that with only two ion pumps (if one of the 3 failed), the pressure requirements are still met.

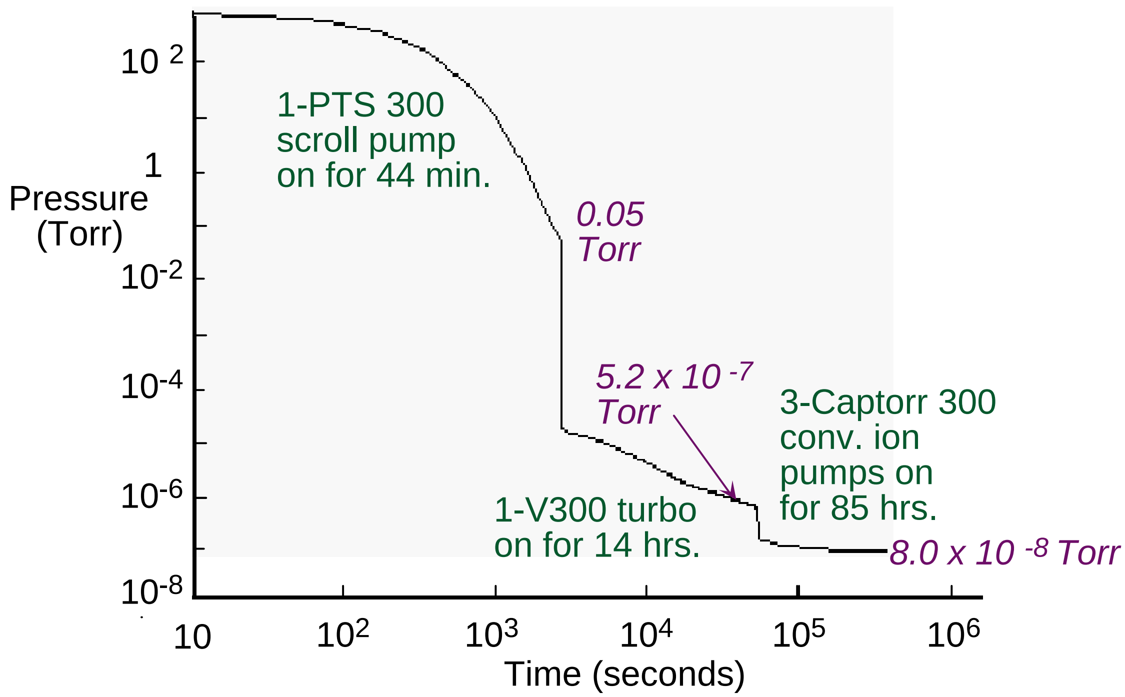



Figure 3.6. History of maximum pressure in the drift tube from atmosphere to the base pressure.

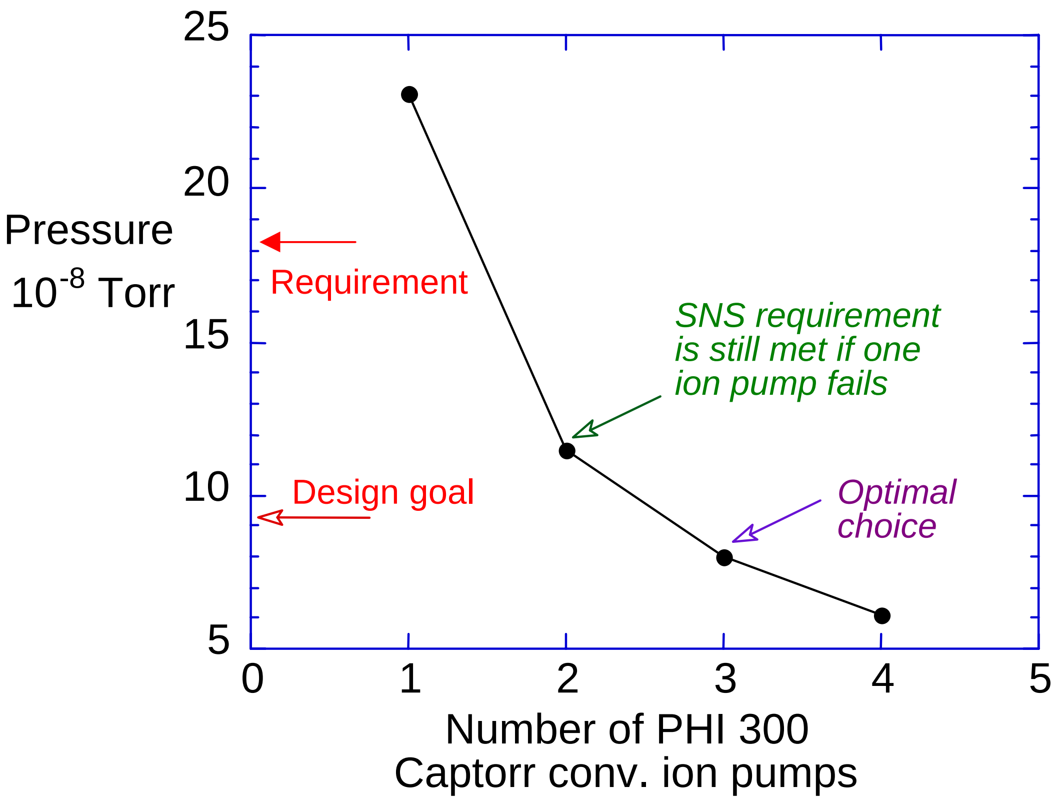



Figure 3.7. Maximum drift tube pressure versus number of ion pumps for a steady-state surface outgassing of $10^{-10}$ Torr-L/sec/cm$^2$.

### *3.1.3.4 Model Results with Multiple Gas Species*

The previous vacuum analyses were conducted with a gas species of "air", which was assumed to have a composite molecular weight of 28.98 amu. However according to the scattering study of Shafer [1.6], the scattering of the proton beam is highly dependent on the gas species present in the vacuum environment. Consequently, the vacuum analysis needed to consider the effects of multiple gas species on the pumping speed and obtainable base pressures.

In performing the multiple gas species vacuum study, one cannot assume that the gas load is formed from a typical composite of atmospheric air. The gas composition depends on what is absorbed and then desorbed from the metal surfaces and what is most likely to leak or permeate in through seals. The most relevant and recent vacuum gas composition data published for a copper accelerator structure was that obtained from the APT/LEDA CCDTL hot model, following vacuum and RF conditioning [2.6]. Table 3.6 summarizes the gas composition measured in that study and applied to the DTL vacuum model.

Also shown in Table 3.6 are the proton scattering weighting factors that were describe in Section 1.4 to be used in determining the total effective pressures. A measure of the contribution of each gas species to the scattering of the proton beam is obtained by multiplying the scattering weighting factor by the gas composition percentage, as shown in the last column of Table 3.6 for the gas species distribution obtained for the APT/LEDA CCDTL hot model. As the last column of Table 3.6 indicates, based on the gas composition and weighting factors, the nitrogen gas will have the greatest contribution in determining the total maximum pressure, while hydrogen, water, and carbon dioxide will have a lesser impact for this particular study. Consequently, the previous study in which the vacuum gas was considered to be 100% air, will give more conservative results in determining pumping speeds and base pressures, than study with multiple gas species. Never the less, the amount of conservatism should still be determined by performing the multiple gas species study.

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 |

In the multiple gas species analysis, the vacuum model was repeatedly run for each individual gas species of interest, including $H_2$, $H_2O$, $CO_2$, and $N_2$, with the corresponding conductance values and pumping characteristics included for each particular gas species. In each of the model runs, the total gas load described in Section 3.1.2.1 was applied to obtain the average drift tube pressure $P_{avg}$, assuming that the entire gas load was made up of the single gas species. To correct for the fact that only a portion of the total gas load is made up of a particular gas species, the average drift tube pressure obtained for each gas species, was multiplied by the composition percentage, C/100, to obtain the partial pressure of each gas species, or

$$P_{gas} = P_{avg} \times C/100,$$

where $P_{avg}$ and $P_{gas}$ are listed in Table 3.7 for each gas species. Finally, the weighted partial pressure for each gas species, $P_{gas,w}$, was calculated:

$$P_{gas,w} = P_{avg} \times C/100 \times W = P_{gas} \times W,$$

which are listed in the last column in Table 3.7.

The total effective gas pressure from the multiple gas species was then obtain from

$$P_{total} = P_{H2,w} + P_{H20,w} + P_{N2,w} + P_{CO2,w}, = 6.76 \times 10^{-8} \text{ Torr},$$

which is well below the maximum allowable pressure of $1.84 \times 10^{-7}$ Torr and the design goal of $9.2\times 10^{-8}$ Torr. Also note that the weighted multiple gas species average pressure value of $6.76 \times 10^{-8}$ Torr is 16% below that of $8.02 \times 10^{-8}$ Torr calculated using air.

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

| Gas (amu) | Drift Tube Pressure P ($10^{-8}$ Torr) with 100% Gas $P_{avg}$ | Partial Pressures ($10^{-8}$ Torr) $P_{gas} = P_{avg} \times C/100$ | Weighted Partial Pressures ($10^{-8}$ Torr) $P_{gas,w} = P_{avg} \times C/100 \times W = P_{gas} \times W$ |
|---|---|---|---|
| $H_2$ (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** |

### 3.1.4 Conclusions

It was demonstrated that the vacuum pump configuration of using three 300 L/s ion pumps and a 300 L/s turbo pump backed by 250 L/m scroll pump is an optimized design for vacuum conditioning and operating the SNS DTL system. The design not only satisfies the requirements but also provides comfortable operation margins. The key conclusions are summarized in Table 3.8.

It should be noted that the final drift tube bore pressure depends heavily on the outgassing rate assumed in the numerical model. In general this pressure is linearly dependent on the surface-outgassing rate. Thus, cleanliness during manufacturing and assembly is essential to achieving the predicted base pressure.

TABLE. 3.8. Key conclusions from DTL RF structure vacuum modeling.

| **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 – Multiple Gas Species | Satisfactory results for mixed gases with $H_2$, $H_2O$, $N_2$ and $CO_2$. |
| Gas Load % Distribution | Surface outgassing = 31%<br>Seal leaks = 54%<br>Magnet outgassing = 15% |
| Main Tank Vacuum Pump Selection | Three 300 L/s ion pumps, one 300 L/s turbo pump, one 250 L/m scroll pump. |
| 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. |

## 3.2 RF Window Vacuum Model

### *3.2.1 Numerical Model Description*

To correctly size the NEG pump, the RF window and waveguide outgassing loads, desired operating base pressure, pump port dimensions, and the RF shielding port geometry must be known. The effective pump speed, $S_{eff}$, required to overcome the gas load is given by [2.6]

$$S_{eff} = (Q_w \times A_w + Q_{wg} \times A_{wg})/P_{base}, \quad (3.2.1)$$

where $Q_w$ = RF window outgassing rate (Torr L/s/cm$^2$)
$A_w$ = RF window vacuum surface area (711 cm$^2$)
$Q_{wg}$ = waveguide outgassing rate ($10^{-10}$ Torr L/s/cm$^2$)
$A_{wg}$ = waveguide surface area (4701 cm$^2$)
$P_{base}$ = base pressure in waveguide transition section ($10^{-7}$ Torr).

A typical gas load for the stainless steel waveguide surface, $Q_{wg}$, is $10^{-10}$ Torr L/s/cm$^2$ [3.2]. The gas load for the RF window varies during RF conditioning. Cummings [3.4] found that for RF windows similar to those designed for the SNS Linac, a steady-state outgassing rate of approximately $5\times10^{-9}$ Torr L/s/cm$^2$ was achievable for RF feed-through powers of 600 to 1000 W after several days of vacuum and RF conditioning. Cummings indicated that outgassing rates of at least an order of magnitude greater ($5 \times 10^{-8}$ Torr L/s/cm$^2$) were observed during early RF conditioning [2.4].

If it is assumed that all of the vacuum pumping is done through the RF shield (neglect the pumping through the iris by the main CCL vacuum pumping system), then the required NEG pumping speed, $S_{NEG}$, is higher than the effective pump speed and is given by [3.2]

$$S_{NEG} = S_{eff} \times [C_{port}/(C_{port} - S_{eff})], \qquad (3.2.2)$$

where $C_{port}$ is the conductance of the RF shield, $C_{rfs}$, the pump attachment nipple, $C_{nip1}$, and the NEG housing nipple, $C_{nip2}$, or

$$C_{port} = (C_{rfs}^{-1} + C_{nip1}^{-1} + C_{nip2}^{-1})^{-1} \qquad (3.2.3)$$

From a vacuum pumping perspective, it is advantageous to maximize the diameter of the pump port and maximize the conductance of the RF shielding. The current waveguide transition section will allow a nipple with an inside diameter of 3.844 in. The RF shield design, shown in Figure 3.8, consists of 38 rectangular slots with a width of 0.125 in. (0.318 cm), a depth of 0.25 in. (0.635 cm), and various lengths. These shield slots plus the nipple provide an attenuation factor of 78 dB to the RF energy, which results in a RF leakage power to the NEG pump of less than 1 W (see Appendix I). The conductance for a rectangular aperture, $C_{slot}$ (Liters/s), with an air medium is given by [3.2]

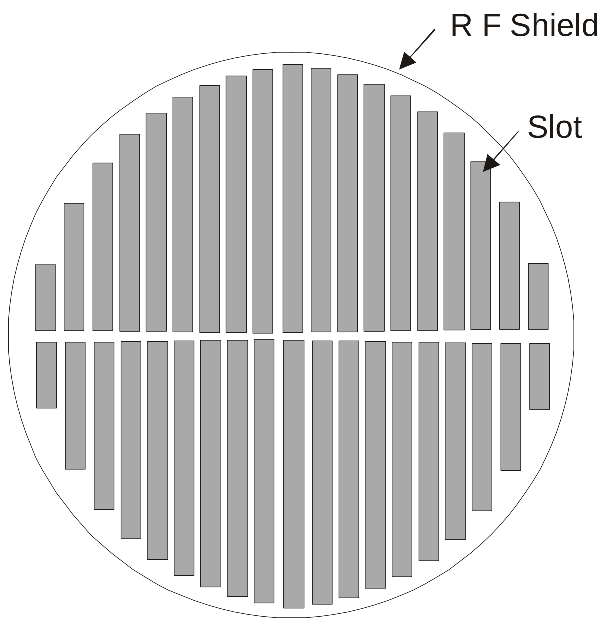
$$C_{slot} = 30.9\, a^2\, b^2\, K/(a+b)/L, \qquad (3.2.3)$$

where a is the slot length (cm), b is the slot width (cm) (a>b), L is the slot depth (cm) or shield thickness, and K is a geometrical correction factor which is approximately 1.3 for the chosen slot geometry (see Appendix I). The conductance of the RF shield, is then the summation of the individual slot conductances

$$C_{rfs} = \sum_{i=1}^{38} C_{slot,i} \qquad (3.2.4)$$

### *3.2.2 Results*

Using an RF window outgassing rate of $5\times10^{-8}$ Torr L/s/cm$^2$, a waveguide outgassing rate of $10^{-10}$ Torr L/s/cm$^2$, and a base pressure of $10^{-7}$ Torr, Equation (3.2.1) predicts an effective pumping of 360 L/s is required to overcome the gas loads. For the slot geometries given in Figure 3.8, the RF shield conductance is 707 L/s. From Appendix I, the total conductance between the NEG pump cartridges and vacuum environment inside the waveguide is 242 L/s. Since this conductance is less than the effective pumping speed, the RF window vacuum is conductance limited and sufficient pumping can not be provided to reach the desired base pressure of $1E^{-7}$ Torr. The maximum available pumping will cause the RF window vacuum pressure to increase from $1E^{-7}$to $1.5E^{-7}$ Torr during the period of window conditioning. Space constraints on the DTL RF window waveguide transition will not allow additional vacuum pumps to be installed or to increase the size of the vacuum port. To reach the desired operational pressure of $10^{-7}$ Torr during conditioning, the RF window will need to be precondition with RF energy to reduce the maximum outgassing rate to $3.5E^{-8}$ (torr*liters)/(sec*cm sq.) prior to installing it in the DTL. Note that the steady-state RF window outgassing rate of $5\times10^{-9}$ Torr $L/s/cm^2$ will only require about 53 L/s of pump speed.




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

Figure 3.8. RF grill design for the DTL RF window.

### *3.2.3 Conclusions*

The RF window vacuum system will be configured around a high capacity NEG pump. Engineering calculations show that during early conditioning of the RF window, the RF window waveguide transition section is conductance limited and the base pressure of $10^{-7}$ Torr can not be met with the anticipated RF window gas load of $5 \times 10^{-8}$ Torr L/s/cm$^2$. The best solution is to precondition the RF windows to an out gas rate less than $3.5E^{-8}$ (torr*liters)/(sec*cm sq.) before installing it in the DTL waveguide. Cummings [2.4] indicated that RF preconditioning would easily accomplish this. The other option is to insert the RF window without preconditioning and to slowly condition it in place with small amounts of RF power to keep the outgassing rate and operational pressure down. In any case, the 1300 L/s NEG pump by SAES is being recommended for the RF window pumping, as this pump is a convenient off-the-shelf component and has seen successful operation on the APT/LEDA RFQ RF window vacuum pumping systems. This pump will also satisfy the pumping requirements of the CCL RF window vacuum pumping system.

In the final RF window vacuum system design, a slotted RF shield will be placed across the NEG pump port to minimize the leakage of RF power from the waveguide. The NEG pump will be supported by a 70 L/s turbo pump, which in turn will be backed by a dry roughing pump from the main CCL vacuum pumping system. The turbo pump will be used to pump inert gases and for conditioning the NEG pump. Finally, a cold cathode gauge will be employed to monitor the vacuum pressure in the vicinity of the RF window. This vacuum hardware configuration is similar to that be used on the LEDA RFQ RF window vacuum system, which has experienced successful operation

### 3.3 Drift Tube Vacuum Model

The drift tubes are used to shield the beam from a negative accelerating field during the reverse field in the tanks. Some of these tubes also house various beam diagnostics that have a higher outgas rates than then just the drift tube body. If the gas pressure in the linac increases too much due to these localized outgas sources, stripping of the beam will occur.

#### *3.3.1 Numerical Model Description*

To model the maximum outgas load which will not exceed the vacuum pressure limit, the longest drift tube in the DTL was selected as a worst case. The total outgas load from the interior of the drift tube was assumed to be located in the center of the drift tube and the gas flowed in both directions to the open ends of the bore (see calculations and drawing in Appendix I). The maximum outgas load was calculated using:

$$Q = C(P1-P2),$$

where C is the conductance of the bore tube, P1 is the pressure at the center of the bore, and P2 is the pressure at the opening of the bore tube.

#### *3.3.2 Results*

Using a maximum permissible vacuum pressure allowable anywhere along the DTL beam line of $1.87E^{-7}$ torr, the maximum allowable outgas rate from any diagnostic in a drift tube was determined to be $2.4E^{-6}$ torr*liters/sec.

### *3.3.3 Conclusions*

The maximum allowable outgas rate of any diagnostic in a DTL drift tube has been determined to be $2.4E^{-6}$ torr*liters/sec, which appears to be easily achievable considering the diagnostics that are presently envisioned.

## 3.4 Inter-tank Vacuum Model

The inter-tank space between DTL tanks is used to house various motorized diagnostic devices to analyze the beam. The types of diagnostics are generally more complex than non-motorized and consequently have more gas loads. The diagnostic device with the highest gas load was determined to be the Torroid. A question that was asked is "is a separate vacuum pump needed in the intertank region to maintain the vacuum in this area, and if so, what size pump is required?" Note that the space between tanks is short, therefore, limiting the diameter of the pump port that can be accommodated in this space.

### *3.4.1 Numerical Model Description*

The calculated outgas loads for the diagnostics are based on preliminary diagnostic device designs. The inter-tank space is referred to, in the calculations, as a DTL beam box. The outgas loads of the various motorized beam diagnostics and toroid were considered. The calculations were done to determine if a separate vacuum pump was needed in this area, or whether, because of the limiting diameter of the pump spool, the pump would be conductance limited to the extent it wasn't a practical option. If this was the case, could the volume be "pumped" through the half drift tubes by the main tank vacuum pumping system?

### *3.4.2 Results*

The calculations (see Appendix I) show that the space between the tanks resulted in a limiting conductance of 19 L/s for an appendage vacuum pump. Consequently, pumping through the half drift tubes into the DTL tank were considered using the outgas rate of the toroid, which appeared feasible. The final part of the calculation revealed that the total outgas rate from any diagnostic must be below $4.6E^{-6}$ liters/sec so as not to exceed the maximum allowable beamline pressure.

### *3.4.3 Conclusions*

The DTL inter-space diagnostic area will not require a separate vacuum pump to maintain the required vacuum pressure. The pressure can be maintained by "pumping" through the half drift tubes into the DTL accelerating tank. In addition, the maximum outgas rate of any diagnostic that is place in the inter-tank space can not exceed $4.6E^{-6}$ liters/sec.

## 4.0 Mechanical Design and Analyses

### *4.1 Introduction*

This section of the report discusses many facets associated with the mechanical design of the DTL vacuum system. These topics include a discussion on the types of vacuum materials that may be used in the radiation environment, the design of the turbomolecular pump cart, stress analyses of the pump spool pieces under a variety of loading conditions, and mounting of the ion pumps.

### *4.2 Materials*

The radiation emanating from a particle accelerator can degrade mechanical properties of materials in close proximity to the beam line. The extent of this degradation will depend on the dose rate and cumulative radiation dose, as well as other factors such as operating temperature, mechanical stress, and exposure to air [4.1]. Scientists and Engineers at CERN have compiled a fairly extensive data base which relates radiation damage to cumulative dose rate for a variety of materials [4.2]. Table 4.1 lists the radiation damage (cumulative radiation dose) limits for various materials used around high-energy particle accelerators [4.2].

Table 4.1. Radiation damage limits for materials used around high-energy particle accelerators [4.2].

| Material | Cumulative Dose Limit (Rad) |
|---|---|
| Polyvinyl Chloride (PVC) | $1\times10^{8}$ |
| Polyurethane Rubber (PUR) | $7\times10^{7}$ |
| Ethylene-Propylene Rubber (EPR) | $8\times10^{7}$ |
| Styrene-Butadiene Rubber (SBR) | $4\times10^{7}$ |
| Polychloroprene Rubber (Neoprene) | $2\times10^{7}$ |
| Chlorosulfonated Polyethylene (Hypalon) | $2\times10^{7}$ |
| Acrylonitrile Rubber (Buna-N) | $2\times10^{7}$ |
| Acrylic Rubber | $8\times10^{6}$ |
| Silicone Rubber (SIR) | $9\times10^{6}$ |
| Fluoro Rubber | $9\times10^{6}$ |
| Butyl Rubber | $2\times10^{6}$ |
| Tefflon (PTFE) | $1\times10^{5}$ |
| Fluorocarbon (Viton) | $1\times10^{7}$ |
| Nylon | $1\times10^{7}$ |
| Plexiglass | $1\times10^{7}$ |
| Phenolic Resin | $1\times10^{6}$ |
| Metals | $1\times10^{10}$ |

Assuming a particle beam loss of 1 Watt/meter along the entire SNS linac, the prompt radiation dose rate, in close proximity to the accelerator, will be approximately 10 Rad/hour at the low energy (80 MeV) end of the CCL and roughly 20 rad/hour at the high energy (185 MeV) end [4.3]. If the SNS accelerator were to run for 300 days/year [4.4], the maximum cumulative dose for a year would be approximately $1.44 \times 10^5$ Rads. This assumes that the radiation dose rate when the beam is shut off, is significantly less than 10 Rad/hour.

To determine which materials will be acceptable for the DTL and CCL vacuum systems (from a radiation performance perspective), the material cumulative dose limits need to be compared to the annual dose present during accelerator operation. Assuming a thirty year desired lifetime for all materials in the Linac vacuum system, the total cumulative dose would be $4.3 \times 10^6$ Rads. Thus the minimum acceptable dose rate limit for vacuum system materials near the linac beam line must be greater than $4.3 \times 10^6$ Rads. Referring to Table 4.1, both Buna-N and Neoprene rubbers, and metals such as copper and stainless steel, would be acceptable from a radiation damage resistance perspective. These materials have been used on the LANSCE 800 MeV particle accelerator at Los Alamos National Laboratory with good success. Flexible Buna-N water lines on the LANSCE DTL have been observed to harden over time by a combination of radiation and atmospheric damage, however they have maintained working lifetimes of well over ten years [4.5]. In addition, Buna-N/Neoprene hoses have been used as flexible jumper water lines for the majority of the focusing and steering magnets on the LANSCE accelerator for the last twenty years [4.5]. Note that the annual cumulative dose rate estimated above was based on the high-energy end of the SNS linac and is thus very conservative for the majority of the room temperature linac structure.

### *4.3 Turbo Pump Cart*

As discussed previously in Section 2.5, a portable turbo/scroll pump cart was selected for pumping the DTL tank from atmospheric pressure, down to a low enough pressure ($>10^-5$ Torr) that the main ion pumps can be turned on. The portable turbo/scroll pump cart is a temporary pumping system to be used during the early vacuum and RF conditioning of the DTL tank. The high pumping speed and flow through design makes the turbo pump ideal for conditioning the SNS linac. Upon completion of the conditioning stages, the turbo/scroll pump cart will be removed and be made available for other vacuum system operations. A pneumatic isolation valve will be placed on the DTL tank spool piece to allow for attaching and removing the turbo pump cart without impacting the vacuum environment.

The central feature of the DTL turbo pump cart is an oil-free 300 L/s turbomolecular pump, backed by an oil-free 250 L/min scroll pump. The turbo pump will be equipped with an inlet screen and a fan-driven air cooling system. The turbo pump will have an 8” Conflat flange for attaching to the DTL spool piece gate valve. The turbo pump will be attached to a translation platform that allows the pump to be elevated and rotated. In all, the turbo pump will have 3 translational (2 by movement of the cart) and 1 rotational degrees of freedom. The scroll pump will be mounted to the bottom of the cart with vibration isolators. The scroll pump will be connected to the turbo pump by a flexible, hydroformed bellows with KSO flanges. Each turbo pump cart will be equipped with a convectron gauge to monitor the foreline pressure between the turbo and scroll pumps, and an integrated controller that will monitor/control all system operations. This integrated controller will also be required to interface with the local DTL vacuum system PLC for remote operation. The vacuum pumps and controller will be mounted on a portable cart, as shown in Figure 4.1. The cart displayed in Figure 4.1, is a modified version of a standard cart provided by Varian. The additional translation devices were added to the standard cart configuration to allow the turbo pump to clear the DTL support structure and have enough translation to mate up with the spool piece gate valve. In addition, the cart was configured to be compatible with the CCL vacuum system and support structure.

A complete specification document that describes the necessary operational, mechanical, dimensional, and electrical features of the DTL/CCL turbo pump cart is contained in Appendix E. The required DTL/CCL turbo cart features should be compared against those required for other SNS vacuum systems (i.e., SCL, storage ring, etc.) so that its design can be adjusted to minimize the number of different cart designs needed for the SNS vacuum systems.

### *4.4 DTL Spool Piece*

This section describes the mechanical design of the DTL spool pieces. Stress analysis results are presented for the spool pieces under different loading conditions. Analysis results include normal loading conditions and seismic loading conditions for both the turbo pump spool piece and the ion pump spool piece. Pump mounting is also discussed.

#### *4.4.1 Design*

Each DTL vacuum tank supports three 300 L/s ion pumps (pump weight: 149 pounds or 69 kg) and one turbo pump gate valve. During the DTL pump down, a turbo pump cart will be connected to the valve and operated until the ion pumps can be safely run. The ion pumps and

Figure 4.1.  DTL turbo vacuum cart (see Appendix E for more details).

the turbo pump gate valve are connected to the DTL tank via stainless steel spool pieces. The spool pieces hang below the DTL tank.

The spool pieces are fabricated using six-inch diameter (outside diameter) stainless steel tubes. The tubes have a 1/8" wall thickness. This wall thickness was chosen because it is readily available, easy to weld, and avoids buckling for the DTL vacuum conditions. Eight-inch diameter flanges are welded to the tube ends. One flange connects to the pump while the other flange is bolted to a port cutout on the DTL tank.

The vacuum pumps and gate valve hang from the DTL spool pieces. The objective of the mechanical design is to minimize the conductance path while maintaining structural integrity; hence, the use of bellows and a separate structure to mechanically isolate the pumps from the DTL tank, was not incorporated in the design. Therefore, the stainless steel ports must support the entire weight of the vacuum pumps or gate valve under both static and dynamic conditions.

The spool piece that supports the turbo pump gate valve also contains four instrument ports. These ports will accommodate a Residual Gas Analyzer (RGA), a Convectron gauge, a cold cathode gauge, and a gas handling line.

#### *4.4.2 Strength Issues*

Each spool piece must be capable of safely withstanding gravity loading, pressure loading, and seismic loading. In this section, finite element results are presented that validate the structural integrity of the spool piece design.

##### *4.4.2.1 Normal Load Conditions*

The spool piece wall thickness and mounting scheme have been chosen to maintain stresses significantly below the yield strength of stainless steel (approximately 35,000 psi) during operation. The spool piece design will avoid permanent deformation during operation and assure vacuum integrity. Moreover, the stresses are sufficiently low to eliminate operational fatigue concerns over a thirty-year life span. Figure 4.2 illustrates the expected stress distribution in the ion pump spool piece under both a gravity load and an atmospheric pressure load. Figure 4.3 illustrates the expected stress distribution in the turbo pump spool piece under both a gravity load and an atmospheric pressure load. The maximum Von Mises stress on the ion pump spool piece is less than 400 psi. The maximum Von Mises stress on the turbo pump spool piece is less than 3000 psi. In both cases, a safety factor greater than ten is obtained.

Figure 4.2. Von Mises stress on the ion pump spool piece.

Figure 4.3. Von Mises stress on the turbo pump spool piece.

#### *4.4.2.2 Seismic Load Conditions*

During a seismic event, additional mechanical loading will exist on the pump spool pieces and RF structures. The seismic loads applied to the structure in the analyses depend on the requirements for the facility. The SNS facility specifies a horizontal seismic load of 0.08g. The natural frequency of the DTL support structure and the spool piece are not known. Therefore, amplification factors must be applied to the 0.08g load because the structures may resonate causing higher loads. LINAC structures are considered PC-2 structures. PC-2 structures have an assumed damping ratio of five percent. According to the SNS facility seismic specifications, a five-percent damping ratio results in a maximum amplification of approximately 2.25. Since the two structures – namely, the DTL structure and the spool piece – are connected in series, the amplification factors must be multiplied. This results in a seismic load at the spool piece of 0.08g x 2.25 x 2.25 = 0.4g. This is the maximum seismic load in the horizontal direction. The vertical seismic load is unknown; hence, 0.4g will also be used for this directional component.

Figure 4.4 illustrates the expected stress distribution in the ion pump spool piece under a gravity load, an external pressure load, and a seismic load. The seismic load consists of a 0.4g horizontal load and a 0.4g vertical load (1.4g load including gravity). The maximum Von Mises stress under these load conditions is under 600 psi. For this worst case loading condition a safety factor greater than ten is obtained. Hence, the ion pump spool piece easily withstands these loads.

Figure 4.4. Ion pump spool piece stress results under seismic loading.

Figure 4.5 illustrates the expected stress distribution in the turbo pump spool piece under the same loads as the ion pump spool piece. The maximum Von Mises stress under these load conditions is still under 3000 psi. For this worst case loading condition a safety factor greater than ten is obtained. Hence, the turbo pump spool design is acceptable.

Figure 4.5.  Turbo pump spool piece stress results under seismic loading.

### *4.5  Ion Pump Mounting*

The ion pumps need to be hung from the ion pump spool pieces.  These 300 L/s pumps weigh approximately 150 pounds each, and will thus require a mechanical lifting device to place and hold the pumps while the mounting bolts are attached.  Several vendors have been contacted about mounting and supporting ion pumps of this size, and each has indicated that the pumps can simply be hung from their flanges without additional support.  In addition, the DTL tank and spool pieces are rigid enough that the weight of the vacuum pumps will not cause significant stresses or deformations.  The design

## 5.0 Instrumentation and Controls

### *5.1 Introduction and Design Requirements*

The design of the instrumentation and control system for the SNS DTL vacuum system was based on a previous design for the APT/LEDA RFQ vacuum system [5.1], while still complying with all SNS standards.

Each DTL tank vacuum control system will be required to operate as a stand-alone system. In addition, each DTL tank vacuum control system will also be required to interface with the global control system, EPICS.

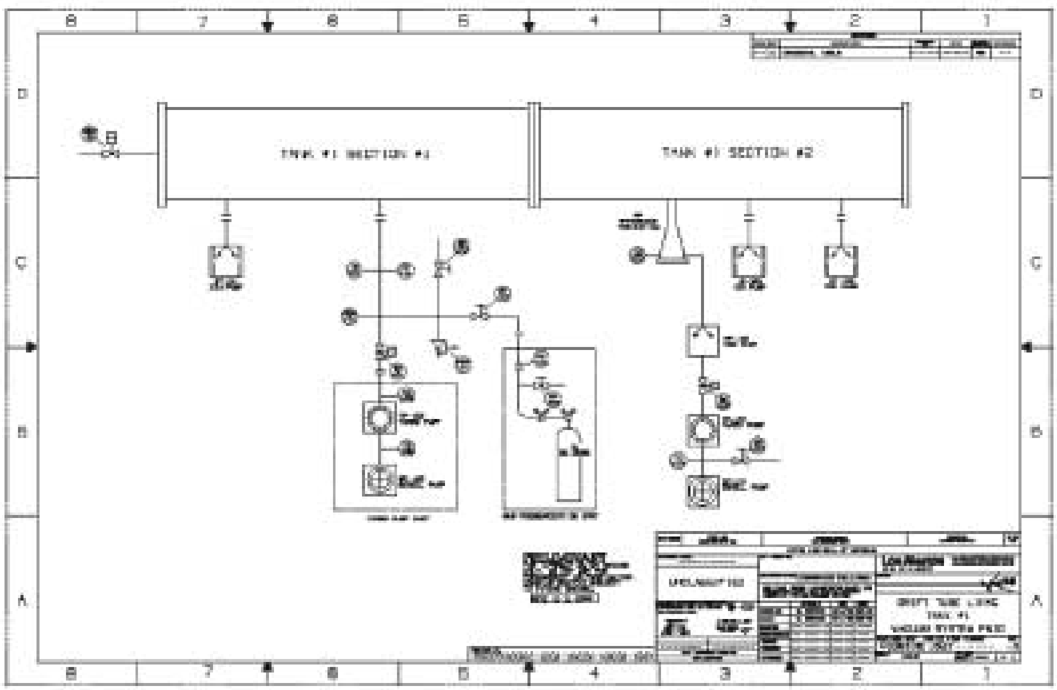



Figure 5.1. P&ID for the DTL vacuum system

The design of the DTL vacuum system uses ion pumps connected directly to the drift tube linac tanks. A turbomolecular pump cart will be used to pump down the system from atmosphere to a pressure where the ion pumps can be started without overheating the pump or causing internal electrical discharges. The turbomolecular pump cart will have a dry scroll pump backing the turbo, a convection gauge mounted on the foreline and a cold cathode gauge mounted at the inlet of the turbo.

A P&ID for tank 1 is shown in Figure 5.1. The control system will monitor the status of the vacuum system and use interlocks to ensure proper operation of the pumps and valves in the vacuum system. In the event of a vacuum system malfunction, interlocks will be available to the RF system to shutdown RF power to the cavities.

During a power failure, the vacuum system will shut down. When power is restored, the control system will reboot, but will not restart the vacuum system. The state of the vacuum system will have to be determined by an operator who will then use the control system in a manual mode to restart the vacuum pumps. If a reasonable vacuum condition still existed after a power failure, the ion pumps could be restarted immediately and high vacuum could be re-established very quickly.

### *5.2 Instrumentation and Control System Architecture*

The control system for the DTL vacuum will consist of a local control system that will be implemented using a Programmable Logic Controller (PLC). A PC running Windows NT 4.0 will be required during the development phase to run the configuration and ladder logic software for the PLC. The PC will also be needed after development and installation if the configuration changes or the ladder logic needs to be updated.

The primary operating mode is for the PLC to communicate via Ethernet to an EPICS IOC (Input/Output Controller). The IOC is a VME crate with a PowerPC processor running VXWorks. The IOCs form part of the backbone of the global control system, EPICS. The PLC can also operate in a stand-alone mode. The stand-alone mode will be used for initial testing and commissioning in the RATS building. This mode will also be useful after commissioning in the event EPICS is not running. A block diagram of the vacuum control system is shown in Figure 5.2.

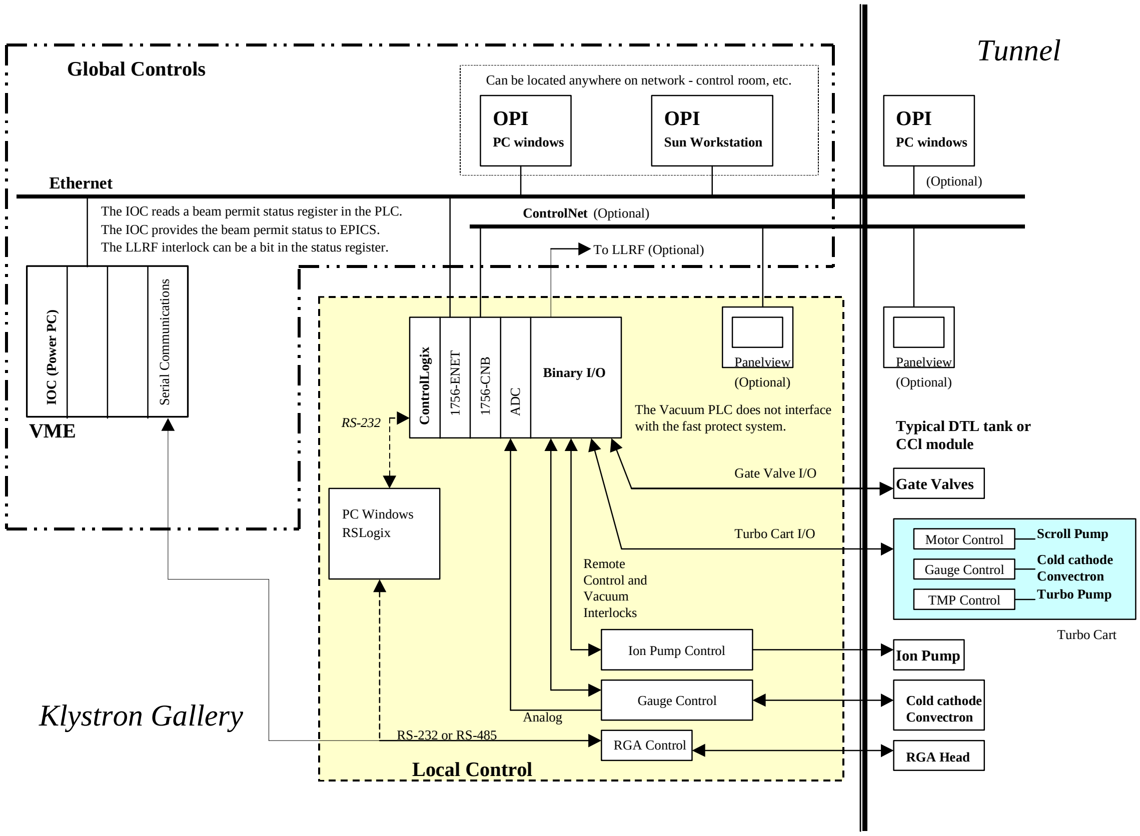



Figure 5.2. Block diagram for the DTL vacuum system controls

The SNS collaboration will use Allen-Bradley ControlLogix as the standard for PLCs. RSLogix from Allen-Bradley is a programming environment that runs under Windows NT and is used to configure and program the ControlLogix PLC. The DTL vacuum control system shown in Figure 5.2. adheres to all current SNS standards.

Allen-Bradley PanelView operator terminals will be used to provide a graphical user interface to the local control PLC in the stand-alone mode for the DTL vacuum system. Functions such as starting and stopping a pump or opening and closing a valve will be represented by graphical pushbuttons on the PanelView touchscreen.

Allen-Bradley PanelBuilder32 software will be used to configure the PanelView operator terminals. Software tools are provided to create objects and symbols that can be cut and pasted to generate a graphical user interface. In Figure 5.2, ControlNet is shown as communications link to the PanelView operator terminals. Currently, PanelView does not support Ethernet communications. Allen-Bradley is expected to release Ethernet compatible PanelView operator terminals in the near future, eliminating the need for ControlNet.

The control system can be quickly prototyped and debugged under RSLogix. During installation, the operator will use the graphical user interface on the PanelView operator terminal to operate the DTL vacuum system in the stand-alone mode. After installation, the DTL vacuum system will be integrated with EPICS. EPICS will command the PLC and provide a graphical user interface. The PLC will still do the actual control of the pumps and valves and will not differentiate if a command came from the PanelView operator terminal or EPICS. Eventually, a laptop computer can be used anywhere there is an Ethernet port to access EPICS, reducing the need for PanelView operator terminals

The vacuum pump and ion gauge controllers will have programmable set points and alarms that will be passed directly to the PLC. The setpoints and alarms will be used by the PLC for interlocks. Interlock logic within the PLC will prevent the operator from selecting an improper valve or pump operation.

Many ion and turbo pump controllers have optional RS-232 interfaces. However, this would require a separate RS-232 interface from the control system to each pump. Each different type of pump controller would require a specific driver to be developed. Also, PLCs are not designed control equipment with serial communications. The IOC could effectively handle the serial communications, but then the interlock logic would have to reside in the IOC, essentially eliminating all the benefits of the PLC.

In comparison, if a simple contact closure/setpoint type interface is used, a single PLC could handle several dozen pumps rather than a large serial communications network with a dedicated port for each individual ion pump controller. The current design is based on contact closure/setpoint type interfaces. More importantly, the interlock logic resides in the PLC. A preliminary electrical wiring schematic for one DTL tank is shown in Appendix C.

Since the turbo pump cart will only be used during the initial pumpdown or in the case of a leak that the turbo can overcome, the pump cart controls will only be connected temporarily. The turbo pump cart will have its pump controllers and instrumentation resident on the cart. An interface cable from the PLC will connect to the pump cart. Each pumpdown port will have its own pump cart interface cable. The control system will determine which locations have pump carts attached by the cable connection. All pump cart functions will be controlled by the PLC. The pumpdown port will have an electro-pneumatic gate valve that will be controlled by the PLC. This will insure that the operation of the pump cart and the pumpdown port gate valve are properly interlocked.

Each DTL tank has a RF window that will use a NEG pump, a small turbo and a small scroll pump. The NEG pump is completely passive and does not require active control like a turbo. However, a NEG must be activated and periodically regenerated under vacuum at high temperature (450° C) for 45 minutes. This requires a heater element incorporated in the NEG pump housing, a heater power supply/controller and an auxiliary pumping system mounted on the NEG pump housing.

The PLC will use a digital to analog converter (DAC) to provide a setpoint to the NEG heater controller. The PLC will read back the temperature of the heater and control the activation/regeneration time.

A small turbo and scroll pump will provide sufficient pumping speed for the activation/regeneration. Vacuum pressure, NEG temperature and power supply current will be used as interlocks to safely activate or regenerate the NEG.

Although vacuum pressure can be derived from ion pump current, there is a need to measure vacuum pressure before the ion pumps are started. An ion pump operates more efficiently if it can be started at a moderately high vacuum (approximately $1x10^{-5}$ Torr). Starting an ion pump at higher pressures causes the pump to overheat or generate internal electrical discharges and reduces the pump's operating life. To provide the most robust control system, an independent ion gauge is required to determine if the turbo cart has pumped out the DTL to a sufficient vacuum condition.

The SNS collaboration will use the cold cathode type ion gauge to measure vacuum pressures. Cold cathode ion gauges are simple and inexpensive, but not as accurate as some of the newer types of hot filament ion gauges. The SNS collaboration has decided that the higher cost, high accuracy hot filament ion gauges are not necessary in the linac or ring vacuum systems.

The cold cathode ion gauge will be an inverted magnetron. The inverted magnetron will be used rather than a penning type cold cathode gauge because it has a more linear response and can measure pressure over a wider range of vacuum.

The RF window vacuum interlock (an alarm sent from the vacuum system to the LLRF controls when the vacuum exceeds $10^{-6}$ Torr) should be less than 16 milliseconds. In event of a vacuum failure, the 16 millisecond delay would allow only one RF pulse, at most to enter the Linac before the RF is shut down.

All ion gauges must integrate the raw signal over some period of time, otherwise the output signal would fluctuate too much to be useful. Some controllers integrate over a short period of time, around 10 milliseconds, others integrate over 100 milliseconds. A response time of less than 10 milliseconds is stated as part of the gauge controller specification.

Note that most gauge controllers have a trimpot on the controller that must be manually adjusted for the trip point. In LEDA, a software programmable trip point was required to speed up the conditioning of the RF window. Higher pressures could be set from the control room for initial conditioning at low power.

For LEDA, the analog signal from the gauge controller (10 ms delay) was sent to a fast analog to digital converter in the IOC. It was very easy to program a software programmable trip point in the IOC. The IOC would then set a bit on a digital output card and this was wired directly to the LLRF. The total delay was never accurately benchmarked and probably exceeded 16 milliseconds.

The 16 millisecond requirement can be met by hard wiring the vacuum alarm trip point directly from the cold cathode to the LLRF controls. Other options are still be explored. The ion pump controller developed by JLAB is one option being considered. The controller does not use very much integration time and has a 2 ms response. Instead of a cold cathode gauge on the RF window, a small ion pump could be used as a gauge. (A cold cathode and small ion pump operate on essentially the same principal.)

A convection type gauge rather than a thermocouple or Pirani gauge will be used to measure the pressure during pumpdown from atmosphere to the milliTorr range in each DTL tank. A thermocouple or Pirani gauge measures heat loss only by conduction from the gas molecules. This limits their measurement range from 1 milliTorr to about 2 Torr. At higher pressures, heat loss by convection becomes a greater factor. A convection type gauge is more accurate at atmospheric pressures than a thermocouple gauge or Pirani gauge because it measures heat loss by convection by using a temperature compensated heat sensor and precisely controls the power delivered to the heating element. Convection type gauges include a conductive heat loss measurement at the lower pressures.

One convection type gauge will be used to monitor the foreline pressure of the turbo pump on the pump cart. It will provide an interlock to the PLC to protect the turbo from high foreline pressures. A cold cathode gauge will be mounted near the inlet of the turbo on the pump cart. This will provide a high vacuum interlock to protect the turbo. The cold cathode gauge will also give a positive indication that the turbo is functioning properly before its gate valve can be opened to the DTL tank if the tank is under vacuum.

A quadrupole type residual gas analyzer without an electron multiplier will be used to measure the partial pressure of gases in each DTL tank. Modern quadrupole RGAs have digital signal processors and synthesized RF drives which results in higher sensitivities with the standard faraday cup detector. Electron multipliers only provide additional sensitivity when used in ultra high vacuum, but are probably not needed at the typical operating vacuum pressures in the DTL.

Modern quadrupole RGAs have compiled stand alone applications that run on a PC under Windows. The RGAs utilize serial communications link to a PC. However, for entire accelerator, it is not practical to have dozens of PCs in the control room, each controlling only a few RGAs. Also, the RGA application has no provision to synchronize its data with EPICS.

With this volume of RGAs, SNS will require access to the source code. The following functions will be ported to EPICS:

1) Start function: starts communications, assigns an instrument ID (similar to file ID), turns on the emissions, waits a few seconds and checks for errors. An error structure is returned.

2) Sequential scan function: acquire a spectrum from 0 to 100 amu. (0 to 100 amu is an example, can be programmed for any range of masses.). A structure is passed to the RGA that has the starting and ending masses and parameters such as points per amu and dwell time. A binary array is returned with amu versus ion intensity. An error structure is also returned.

3) Random scan function: default mode for the RGA. A structure is passed to the RGA with all the necessary parameters. A random scan usually only looks at specified masses rather than the whole spectrum. A data structure and an error structure are returned. Leak checking could be done with this function by only looking at mass 4 at a very fast rate.

4) Close function: turn off emissions and terminate communications.

By porting these to EPICS the RGA data will be timestamped and archived by EPICS. The data can be easily accessed by any operator screen and correlated with any data or event in the EPICS database.

Other functions such as tuning or calibrating will be handled by taking a laptop computer running the RGA application and connecting directly to the RGA. These functions are not required very often with modern RGAs. Also, since SNS will use RGAs with only faraday cup detectors, many of the functions in the RGA software will not be required since they are used for setting up and calibrating the electron multiplier.

### 5.3 Control Methodology and Logic

The primary requirement of the DTL vacuum control system software is to interface to the global control system, EPICS. This requirement will be met by adhering to SNS standards and providing good documentation.

While the LEDA/RFQ vacuum system utilized a different PLC, the ladder logic in the PLCs that describes the sequence of switch closures, interlocks and process control setpoints that have to be executed in order to energize a valve or start a vacuum pump will be very similar. The LEDA/RFQ vacuum system successfully demonstrated that the ladder logic for the local control system can be developed at a remote site and then integrated with EPICS at the facility.

A ladder logic fragment from a vacuum system that was built at LLNL is shown in Appendix J. The ladder logic is solved in a specific sequential order and coils from one function are used as interlocks in the next function. The ladder logic structure is in essence, a flow chart. For example, to open the foreline valve (SV6) to the turbo, scroll pump P7 must have been started in the previous function and must be currently running. If the scroll pump were to experience a thermal overload and shut down the foreline valve be forced to close too.

There are five functions the ladder logic example. They are:

1. Start the roughing pump - interlock will shut down pump if there is a thermal overload
2. Open the foreline valve to the turbo - scroll must be running
3. Start the turbo - foreline valve must be open, pressure must be adequate and there are no faults in the turbo pump controller
4. Open main gate valve - vessel can be roughed down through the turbo if the turbo is in start mode and pressure in the vessel is not too low. Also, the main gate valve can be opened if the vessel is in a high-vacuum condition when the turbo is running at full speed.
5. Start the ion pump if the vessel is at high vacuum and there are no faults in the ion pump controller

These five functions are examples from an operational vacuum system. Some of these functions will need only slight modifications to be re-used in the operation of the DTL vacuum system.

## 5.4 Safety Interlocks and Equipment Protection

An analysis of possible vacuum system failures, the probability of that failure, its common symptoms and the PLC interlock response to protect the equipment and/or personnel is shown in Table 5.1.

Table 5.1. Analysis for PLC Interlock Response for DTL Vacuum System Failures

| System | Failure or Condition | Probability | Symptom | PLC Interlock Response |
|---|---|---|---|---|
| Ion Pump | Insulator high leakage current or shorted by sputtered titanium | Low - insulator is shielded | High pump current | Ion pump controller will shut down pump and indicate a fault. PLC sends ion pump fault message to global control. Single ion pump failure does not cause immediate shutdown in beam. Ion gauges monitor pressure. If pressure rises too high, PLC interlock will send pressure fault message to global control. |
| | Anode to cathode short | Low -large amounts of conductive/magnetic particles would be needed to cause short | High pump current or short circuit | Same as above |
| | High voltage feed through failure | Low/med - usually results from physical damage | No pump current | Same as above |
| | High voltage cable failure open circuit | Low/med - usually results from physical damage | No pump current | Same as above |
| | High voltage cable failure short circuit | Low/med - usually results from physical damage | High pump current | Same as above |
| | Pressure too high | Med - Turbo carts have not pumped out DTL/CCL to a sufficient vacuum | Pressure too high to start ion pumps | Ion gauges monitor pressure. If pressure is too high, PLC interlock will prevent ion pumps from being turned on. Beam permit interlock from PLC will not be set. |
| | Pressure initially good, then rises above setpoint | Low/Med - very high gas load created by RF or beam or mechanical failure (a leak is created), ion pumps cannot overcome | Pressure too high | Ion gauges monitor pressure. If pressure climbs too high, PLC interlock will shutdown ion pumps. PLC interlock will send pressure fault message to global control. |
| | Ion pump end-of-life | Low - over 60,000 hours of operation - cathode sputtered through | Low base pressure<br>Pump instability | Ion gauges monitor pressure. If pressure climbs too high or pressure burst, PLC interlock will shutdown ion pumps. PLC interlock will send pressure fault message to global control. |
| | | | | |
| Vacuum Vessel - Manifolds, bellows, tanks, modules | Vacuum system leak | Low/med - Proper handling and installation will prevent leaks in joints and seals. Components will be leak checked before installation. | Cannot rough-down or takes a long time to rough-down<br>Low base pressure | If extremely large leak during rough-down, scroll pump will overheat. Motor control circuit will shutdown the scroll pump and send fault signal to PLC.<br>If large leak during rough-down, turbo will not spin up to normal RPMs. Turbo controller will shutdown and send fault signal to PLC.<br>If turbo cannot base system below $1x10^{-5}$ Torr, a programmable timeout in PLC will send warning message to global control.<br>If ion pumps do not reach expected base pressure, PLC will send high pump current/low vacuum warning message to global control |

| System | Failure or Condition | Probability | Symptom | PLC Interlock Response |
|---|---|---|---|---|
| Turbo cart | Scroll pump head failure | Low/med - failures are usually due to lack of periodic maintenance (every 10,000 hours) | Low base pressure<br>Low pump speed | Vacuum gauge monitoring foreline pressure<br>PLC interlock will shutdown scroll pump<br>PLC interlock will shutdown turbo<br>PLC interlock will close turbo gate valve to protect DTL/CCL vacuum<br>PLC sends turbo cart fault message to global control |
| | Scroll pump motor failure or short to ground | Low/med - motor bearing or winding failure uncommon<br>Wiring error or failure | High motor current or windings open or short | Motor control circuit (or circuit breaker) will shutdown the scroll pump and send fault signal to PLC<br>PLC interlock will shutdown turbo<br>PLC interlock will close turbo gate valve to protect DTL/CCL vacuum<br>PLC sends turbo cart fault message to global control |
| | Scroll pump gas load too high | Low/med - vacuum system leak or contamination | High motor current | Scroll pump will overheat, motor control circuit will shutdown the scroll pump and send fault signal to PLC<br>PLC interlock will shutdown turbo<br>PLC interlock will close turbo gate valve to protect scroll pump<br>PLC sends turbo cart fault message to global control |
| | Turbo pump bearing failure | Low - modern ceramic bearings are very reliable | High motor temp<br>High motor current | Turbo controller will provide safe shutdown and send fault signal to PLC<br>PLC interlock will close turbo gate valve to protect DTL/CCL vacuum<br>PLC sends turbo cart fault message to global control |
| | Turbo rotor crash | Low - Unless turbo ingests foreign object or is subject to multiple atmospheric vents while operating at full speed | Sudden drop in RPMs | Turbo controller will shutdown pump and send fault signal to PLC<br>PLC interlock will close turbo gate valve to protect DTL/CCL vacuum<br>PLC sends turbo cart fault message to global control |
| | Turbo gas load too high | Low/med - vacuum system leak or contamination | High motor current | Turbo controller will provide safe shutdown and send fault signal to PLC<br>PLC interlock will close turbo gate valve to protect turbo<br>PLC sends turbo cart fault message to global control |
| | | | | |

| System | Failure or Condition | Probability | Symptom | PLC Interlock Response |
| --- | --- | --- | --- | --- |
| RF Window | High pressure or contamination causing RF breakdown | High - mainly during conditioning | RF arcs<br>Pressure bursts | Vacuum gauge monitoring RF window pressure will send analog value directly to LLRF as feedback<br>Extremely large pressure burst will cause PLC interlock to shutdown ion pumps. PLC interlock will send pressure fault message to global control |
| | NEG Pump failure | Low - no moving parts or high voltage<br>NEG could become completely saturated with extended use or high gas load due to vacuum system leak or contamination | Low base pressure in RF window | Vacuum gauge monitoring RF window pressure.<br>PLC interlock will send RF window pressure fault message to global control. |
| | NEG Pump regen - Heater failure | Low - heater element failure uncommon | NEG fails to reach correct regen temp | Thermocouple monitors regen temperature.<br>PLC interlock will send regen fault message to global control |
| | NEG Pump regen - Scroll pump head failure | Low/med - failures are usually due to lack of periodic maintenance (every 10,000 hours) | Low base pressure<br>Low pump speed | Vacuum gauge monitoring foreline pressure<br>PLC interlock will shutdown scroll pump<br>PLC interlock will shutdown turbo<br>PLC interlock will close turbo gate valve to protect RF window vacuum<br>PLC interlock will shutdown NEG regen<br>PLC sends fault message to global control |
| | NEG Pump regen - Scroll pump motor failure | Low - motor bearing or winding failure uncommon | High motor current or windings open or short | Motor control circuit (or circuit breaker) will shutdown the scroll pump and send fault signal to PLC<br>PLC interlock will shutdown turbo<br>PLC interlock will close turbo gate valve to protect RF window vacuum<br>PLC interlock will shutdown NEG regen<br>PLC sends fault message to global control |
| | NEG Pump regen - Turbo bearing failure | Low - modern ceramic bearings are very reliable | High motor temp<br>High motor current | Turbo controller will provide safe shutdown and send NEG regen turbo fault signal to PLC<br>PLC interlock will close turbo gate valve to protect RF window vacuum<br>PLC interlock will shutdown NEG regen<br>PLC sends fault message to global control |
| | NEG Pump regen - Turbo rotor crash | Low - Unless turbo ingests foreign object or is subject to multiple atmospheric vents while operating at full speed | Sudden drop in RPMs | Turbo controller will shutdown pump and send NEG regen turbo fault signal to PLC<br>PLC interlock will close turbo gate valve to protect RF window vacuum<br>PLC interlock will shutdown NEG regen<br>PLC sends fault message to global control |
| | NEG Pump regen - Turbo gas load too high | Med. - NEG regen temp too high or vacuum system leak or contamination | High motor current | Turbo controller will provide safe shutdown and send NEG regen turbo fault signal to PLC<br>PLC interlock will close turbo gate valve to protect turbo<br>PLC interlock will shutdown NEG regen<br>PLC sends fault message to global control |

| System | Failure or Condition | Probability | Symptom | PLC Interlock Response |
|---|---|---|---|---|
| Sector Isolation Valves | Opening Sector Isolation Valve between tanks or modules | Normal operation | Cannot open Sector Isolation Valves due to large difference in pressure between tanks or modules | Vacuum gauges monitoring the pressure in an upstream tank or module indicates low vacuum. PLC interlock to downstream module or tank will not allow downstream PLC interlock to open valve. |
| | Isolation valve between tanks or modules is open, then a large pressure difference develops | Low/med - higher pressure or a burst of gas could develop in a tank or module under during operations such as beam conditioning | Sector Isolation Valve closes | Vacuum gauges detect a rise in pressure to an unacceptable level in a module or tank. PLC will close its upstream Sector Isolation Valve and send low vacuum interlock to PLC controlling downstream tank or module. Downstream PLC will close its valve and both PLCs send valve closed message to global control. Upstream PLC also sends low vacuum message to global control. |
| | | | | |
| I&C | Low vacuum gauge failure | Low - gauge is probably not connected or damaged | No reading | Gauge controller will not close the gauge's process control setpoint. PLC interlock will not let rough-down proceed. Can switch to redundant gauge and resume rough-down |
| | High vacuum gauge failure | Low/med - gauge not connected or contaminated Cannot start gauge at high vacuum | No reading | Gauge controller will not close the gauge's process control setpoint. Gauge controller may indicate a fault. With redundant gauges and ion pump currents monitoring pressure, PLC can be programmed to ignore a single faulty gauge. |
| | Valve failure | Low - Turbo gate valve and sector isolation valves will not be cycled very often | Solenoid energized, but position indicator does not show valve open | If PLC does not read valve position open within 5 seconds of energizing solenoid, the solenoid is de-energized and the valve reverts back to its normally closed position. |
| | PLC failure | Very low - PLCs are designed for very high reliability in harsh industrial environments | Various | PLC can be powered by UPS in case of power outage<br>PLC has extensive built-in self diagnostics<br>Watchdog timer can alert global controls if PLC is not operating<br>If an I/O module is defective, it can be hot-swapped |
| | | | | |

### 5.5 Signal/Device Naming Conventions

The SNS standard for device and signal naming [5.4] was used to create a device and signal list that defines all the I/O channels and internal commands for the PLC. This device and signal list will be used in creating the EPICS database. The device and signal list for DTL tank 1 is shown in Appendix D. The device and signal list for all six DTL tanks is available as an Excel spreadsheet.

## 6.0 SNS Facility

The design of the DTL vacuum system requires multiple mechanical and electrical interfaces with the SNS facility. Figure 6.1 shows a plan view of the portion of the SNS facility corresponding to the drift tube linac. The DTL portion of the facility is divided into two main structures; the linac tunnel, containing the DTL RF structures, vacuum pumps, and instrumentation, and the klystron gallery, containing the klystron and RF power systems, water skids, motor control centers, electronics racks, etc. Figure 6.2 shows a cross-section of the DTL facility structures. Running between the linac tunnel and klystron gallery are a number of concrete chases, which carry in part, vacuum pump and instrumentation power lines and diagnostic cabling. Each of these facility structures, and their various interfaces with the DTL vacuum system, is described in more detail in the following sections.

### *6.1 Klystron Gallery*

The klystron gallery is 30 ft wide by 26 ft high and contains much of the hardware and electronics for the various linac support systems (RF controls and power systems, water cooling and resonance control, vacuum, etc.). In particular, the klystron gallery houses six electronics racks for the DTL vacuum system. Each electronics rack contains the vacuum pump and instrumentation power supplies/controllers as well as a PLC and touch screen interface to form a complete and stand-alone control system for a single DTL tank vacuum system. As shown in Figure 6.1, the vacuum system electronics racks are distributed throughout the klystron gallery. The power and signal lines will run to and from the electronics racks and chases from overhead cable trays. Concrete shielding blocks located at the openings of the chases, as well as a multitude of overhead cable trays and junction boxes, will dictate the exact routing of the power and cable lines. The cable tray routing and junction box locations still need to be defined with SNS conventional facilities.

### *6.2 Linac Tunnel*

The linac tunnel is 14 ft wide by 12 ft high and contains the six DTL RF structures and the associated vacuum pumps and instrumentation. As shown in Figure 6.3, the proton beam line is 50 inches above the floor and 68 inches from the South wall. The DTL support structure has a ground clearance of 23 inches and has a 4-foot spacing to the South wall. The vacuum system cabling to/from the electronics racks will enter the Linac tunnel at the base of the South wall through the chases. The chases are centered on each of the DTL tanks. The exact routing of the

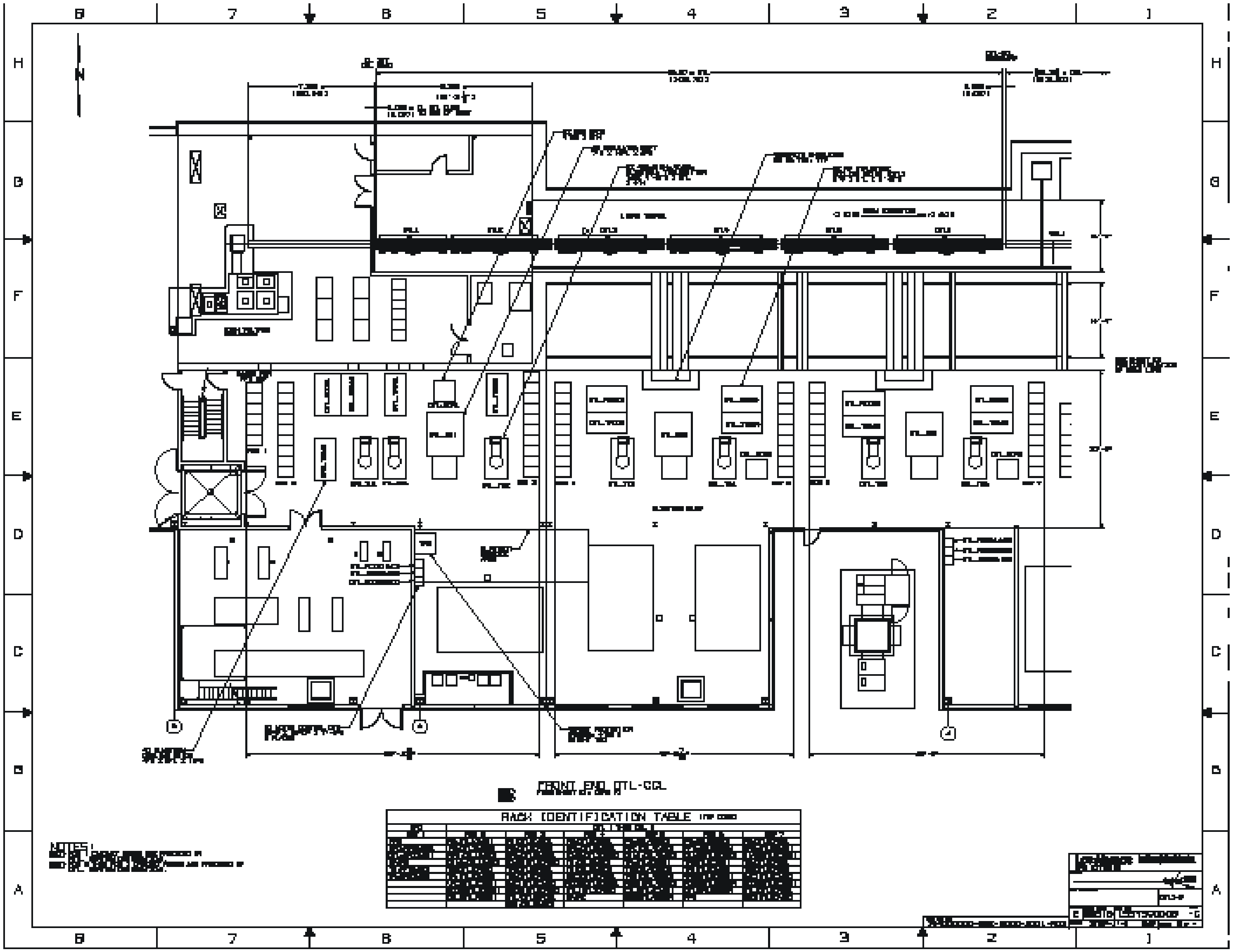



Figure 6.1.  SNS Facility plan view in the vicinity of the DTL.

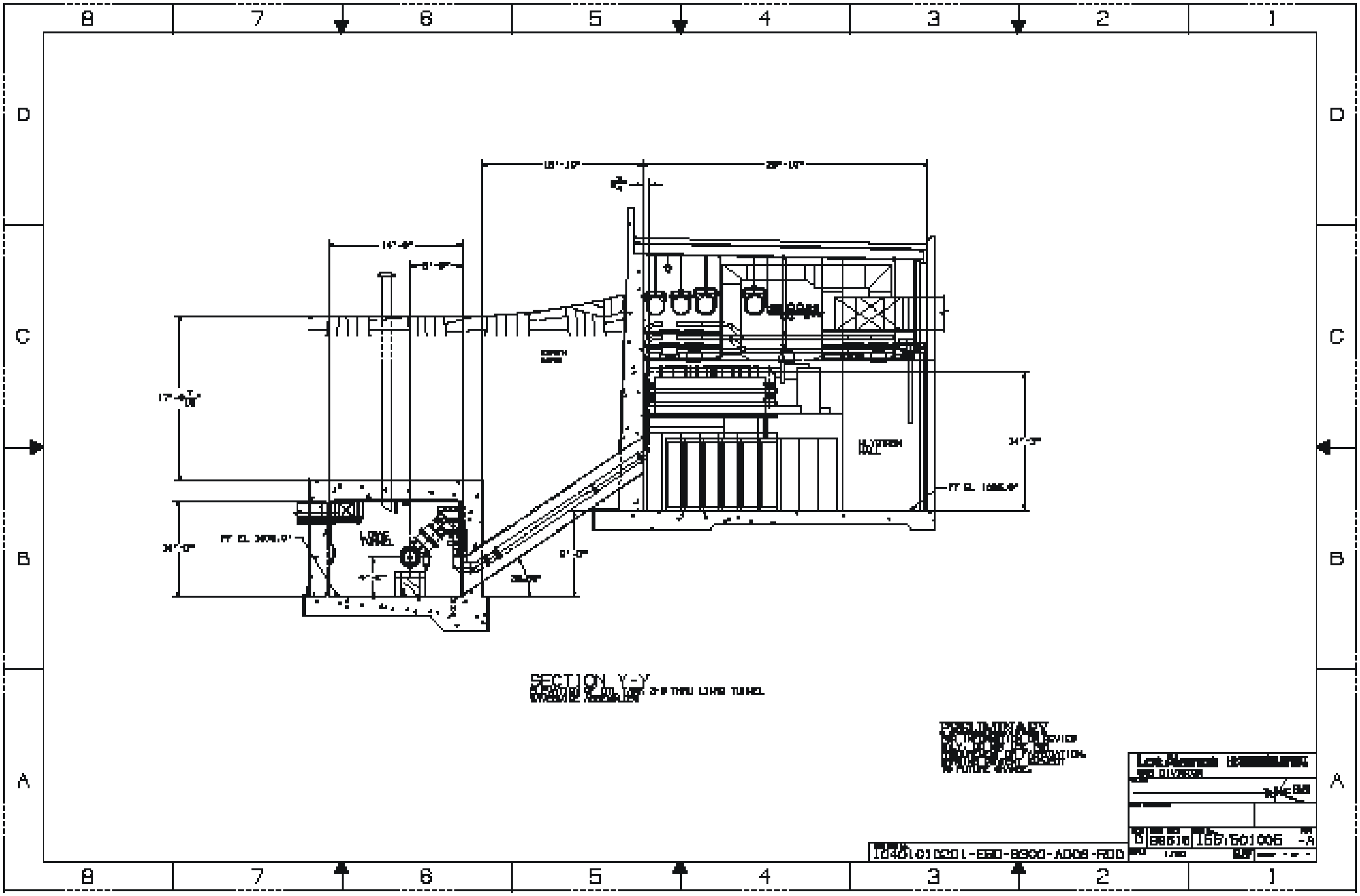



Figure 6.2.  SNS Facility cross-section in the vicinity of the DTL.

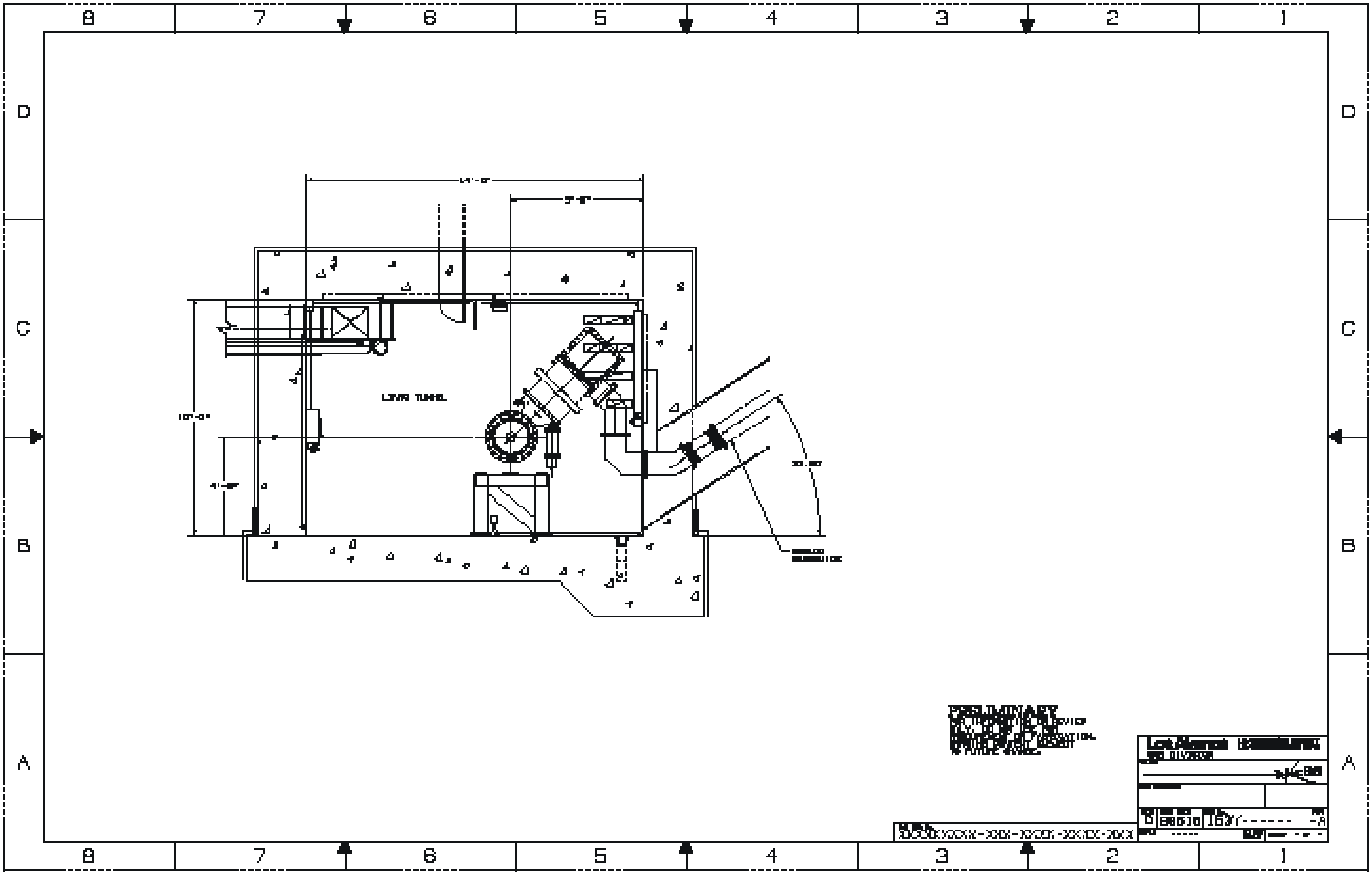


Figure 6.3. Cross-section of the Linac tunnel in the vicinity of the DTL.

cabling between the chase and the DTL structure is currently under development. It is expected that the vacuum cabling will be routed up to elevated cable trays, where it will run overhead to the associated tank chase entrances, pass through the chases to the Klystron Gallery, and be routed by additional cable trays to the corresponding vacuum controls rack.

RF shielding is required in the Linac tunnel at each chase entrance. The Linac shielding will be similar to the shielding on the Klystron gallery side of the chase. The stacked block shielding will provide a hole large enough for the vacuum cabling lines to pass through and still remain small enough to perform adequate neutron shielding. The shielding requirement on the Linac side of the chase is under design by ORNL.

### *6.3 Chases*

The chases will be located at an angle of 33.5° from the horizontal, running from the Klystron gallery downward to the Linac tunnel. The angled chase will have a length of approximately 20 feet. The chases will serve as passageways for the RF waveguides, water cooling lines, and power/communication cabling. The designs of the chases are currently under development at ORNL.

All vacuum system power and communications cables will be routed between the linac tunnel and klystron gallery via the chases. To simplify the wire routings in the chases and minimize the amount of time required for pulling and routing cables, junction boxes will be utilized on both ends of the chases. The junction boxes will be connected with specified numbers and types of cables, which will be wired and routed prior to installation of the DTL vacuum system. The use of junction boxes will eliminate the need to individually route standard cables and will significantly shorten the required installation time of the vacuum control systems. The installation teams will simply need to wire a vacuum control system electronics rack up to the corresponding junction box in the klystron gallery, as well as wire up the vacuum equipment to the matching junction box in the linac tunnel. Not all vacuum communication cables can be routed through the junction boxes, and will have to be run individually through conduits in the chases. Table 6.1 identifies the types, sizes, and routing plans for the vacuum system cabling on the DTL.

The chases are currently under design and remain the responsibility of ORNL.

Table 6.1 DTL vacuum system power cable requirements in chase conduits.

| Tank | Power Cable Component | Qty/line diameter | Type | Junction Box Connection? |
|---|---|---|---|---|
| Each DTL Tank (6 tanks total) | • Ion pump power cable | • 3 @ ½” ea | High voltage, low leakage current coax | • No |
| | • Turbo pump power cables (RF window) | • 1 @ ½” ea | 6 conductor, 16 awg, twisted pair | • Yes |
| | • Scroll pump power cables (RF window) | • 1 @ ¾” ea | 3 conductor, 12 awg | • Yes |
| | • NEG pump power cables | • 1 @ 1” ea | 3 conductor, 10 awg | • Yes |
| | • Cold cathode gauge power leads | • 2 @ ½” ea | High voltage triax | • No |
| | • RGA power lead | • 1 @ 1.5” ea | 7 conductor, 2 coax cable bundle | • No |

## 7.0 Safety

### *7.1 Hazard Analyses and Protective Measures*

There are numerous safety issues and concerns associated with the design of the DTL vacuum system including mechanical, chemical, electrical, and thermal. This section attempts to itemize the hazards associated with the vacuum system design, and list protective measures that have been incorporated to mitigate them. Additional vacuum design and operational safety information can be found in [7.1].

Some specific potential hazards regarding the DTL vacuum components/operation and their protection measures are discussed below:

1. The NEG pump is constructed with a sintered getter alloy that has pyrophoric properties. While the NEG pump is being activated at temperatures above 100°C, an accidental exposure to atmospheric air may result in combustion. This can be characterized as a very fast oxidation, but is not explosive. Even at temperatures under 100°C, damage to the pumps can occur in various degrees if exposed to atmosphere. By using proper vacuum interlocks and nitrogen gas purging systems, this combustion risk is reduced to an unlikely occurrence.

   Another hazard is the pumping of hydrogen with the pyrophoric NEG material. A NEG pump can sorb several standard liters of hydrogen which can react violently with atmospheric oxygen if the getter material is suddenly exposed to atmosphere. Consequently, it is essential that a NEG pump that has sorbed a substantial amount of hydrogen, undergo a complete regeneration cycle and passivation prior to removal from the vacuum system or exposed to the atmosphere. During regeneration of a NEG, the hydrogen is released from the getter material and removed from the vacuum system by the turbo and scroll backing pumps. The regeneration of a NEG pump takes place in a vacuum that is less that $1x10^{-4}$ Torr. The flow rate at the exhaust of the 70 l/s turbo operating at $1x10^{-4}$ Torr is only $7x10^{-3}$ Torr-Liters/sec. The foreline pressure is generally held below 20 milliTorr by the scroll pump. Under these conditions the hydrogen is given off at such a slow rate and there are not enough oxygen molecules in the vacuum system to form a combustible mixture. It is also unlikely that a combustible mixture could form in the vacuum exhaust. The scroll pump has an automatic ballast that bleeds in air to help flush out particulates and gases. The ballast would in this case further dilute the small amount of hydrogen in the scroll pump exhaust. Again, using proper vacuum interlocks and vacuum operational procedures, the risk of combustion is reduced to an unlikely occurrence.

2. The ion pumps selected for both DTL and CCL vacuum systems require up to 7000 VDC. The ion pump controller can provide up to 100 mA in a short circuit, but the ion pumps are generally operated in the micro-amp range. The high voltage connector is a Fischer Type 105. The ion pump has a retaining screw on the high voltage connector to prevent accidental disconnection of the connector.

   The high voltage connection to the ion pump controller is on the rear of the controller and does not have a retaining screw. However, the ion pump controller will be mounted in an equipment rack that has a lockable rear panel. The ion pump controller has a key switch on the front panel to enable the high voltage. High voltage safety will require proper administrative control of these keys.

3. The turbomolecular pump controller outputs a 56 VAC, 3-phase, 700 Hz signal to the pump. The turbomolecular pump controller can detect an open circuit and will not output a voltage under such a condition. There is also over-current protection that will shut down the output voltage in the event of a short circuit.

4. The scroll pump operates on 208 VAC, 3-phase, 60 Hz and will be controlled by an industry approved motor control circuit with thermal overload protection.

5. Several of the vacuum valves will be electropneumatic and require compressed air up to 125 psi. The 125 psi compressed air system is the responsibility of the ORNL SNS conventional facilities, but its design should be in accordance with all applicable ASME and DOT codes and regulations. The solenoids on the electropneumatic valves will be 24 VDC, which is classified as low voltage.

   The electropneumatic vacuum valves associated with the turbo pumps and beam line will fail closed in the event of an electrical or air line failure, and thus serve to isolate the vacuum. All electropneumatic valves will supply an electrical position signal to the control system.

The control system will prevent the turbo pump valves from being opened, should a proper vacuum not exist on both sides of the valve.

6. Each DTL tank will be supplied with a gas pressurization and relief system. The gas purging source will be a standard pressurized gas cylinder containing 99.999% $N_2$. The gas cylinder will be securely mounted to a portable dolly when in use, and stored in a secure, upright position when not in use. The expanding nitrogen gas cools as it exits the gas cylinder. To prevent freezing damage to the gas regulator, the DTL system should be purged slowly and low temperature regulators, such as made for $CO_2$, will be used. To prevent over-pressurization of the DTL tank, a pressure relief valve with a cracking pressure of 1-2 psig has been included on the tank body. This valve cracking pressure was chosen to be well below the pressurization limit of the DTL tank (see Section 4). In the event that the gas pressure regulators on the gas cylinder should fail, a gas flow throttling device was added to ensure that the maximum gas flow into the tank is less than the flow dissipation rate of the relief valve. The gas pressurization lines have been provided with manual valves to vent the system to atmosphere should it be required. Since nitrogen displaces oxygen, the facility will need to determine if a confined space exists near the DTL tanks and provide the appropriate controls for such a hazard.

7. The vacuum pressures measured by the high vacuum gauges will be different from the beam line pressure. This difference has been predicted by the computer models in Section 3, and will be incorporated in the control system display and data storage.

8. The beam scattering radiation dose will damage all materials and electronics to various degrees. Only radiation hardened materials will be used for vacuum components (i.e., cables, seals, etc.). All vacuum pump and instrumentation controllers will be located in the electronics rack (klystron gallery), and thus shielded from the accelerator structure's radiation.

9. RF energy can be potentially damaging to vacuum pump and instrumentation housings/components. To prevent significant levels of RF energy from reaching these components, RF attenuation grills, where required, have been placed across pump and instrumentation ports.

10. Electronics racks will have access restrictions (locks) to prevent non-authorized personnel access. The touch screen and computer interfaces with the control systems will be password protected to limit accessibility.

11. All electrical equipment will be UL listed or equivalent and will be installed in compliance with NFPA 70, the National Electrical Code. The relays and solenoids will be of the low voltage 24 VDC type and the wiring will be installed by qualified personnel. Where high voltages are present, there will be protective connectors or shields that will be labeled "High Voltage".

Table 7.1 summarizes off-normal operating conditions or potential hazards to the vacuum system and corresponding protective measures to monitor and/or mitigate the effects of these conditions. Table 7.1 does not list all possible hazards, however, the ones mentioned were identified from standard engineering practices and applicable engineering codes. For Natural Phenomena hazards such as earthquake, wind, flood and fire, please refer to [7.2].

Table 7.1. Potential Hazards and Incorporated Protective Measures for the DTL/CCL Vacuum System.

| **System** | **Sub-System** | **Fact/Symptom** | **Protective Measures** |
|---|---|---|---|
| **Utility** | | Loss of Power | UPS provided for control system's PLC and gauge controllers<br>Fail-closed valves employed at pump ports and on beam line.<br>Safe shutdown of all active components |
| | | Loss of Air Supply | Pressure gauges monitored by facility<br>Inline reservoir of sufficient capacity will allow gate valves to close |
| | | Loss of $N_2$ Supply | $N_2$ is not used for normal vacuum operations<br>$N_2$ is used to vent/purge vacuum system - do not vent until $N_2$ supply is restored |
| | | Loss of Water Supply | Does not affect vacuum |
| ***Vacuum Pump*** | Vacuum Carts | Scroll pump failure | Vacuum gauge monitoring<br>Motor control circuit will provide safe shutdown<br>Automatic isolation valve will close to protect vacuum<br>Oil Free system |
| | | Turbo pump failure | Vacuum gauge monitoring<br>Turbo controller will provide safe shutdown<br>Automatic isolation valve will close to protect vacuum |

| | | | |
|---|---|---|---|
| | Ion Pump | High leakage current | Redundant monitoring (cold cathode gauge) |
| | | Insulation breakdown | Redundant monitoring (cold cathode gauge) |
| | | Pump Failure | Controller will shutdown pump<br>Ion pump failure does not cause immediate shutdown in beam operation |
| | NEG Pump | $H_2$ Gas | See Section 7.1 |
| **RF** | Window | High pressure causing rf breakdown | Vacuum gauge monitoring for RF power shutdown |
| **I&C** | General Gauges | Loss of power or gauge failure | UPS for gauge controller<br>Redundant monitoring |
| | High-Vacuum Gauges | Loss of power or gauge failure | UPS for gauge controller<br>Redundant monitoring |
| | Valves | Loss of electrical power or gas pressure | Fail-closed valve on turbos and beamline<br>Valve position monitoring |
| | PLC | Electrical power failure or surge | UPS provided for PLC<br>PLCs are designed for industrial use and are very reliable |

### *7.2 Personnel Safety*

In addition to the designed safety features and control safety interlocks mentioned previously in this report, the following personnel safety issues must be considered by ORNL:

- Proper ORNL safe operating procedures and hazard control plans (or similar administrative controls) will be in place at the SNS facility for the assembly, installation, testing, and operation of the vacuum systems.
- All electrical work will be carried out in compliance with ORNL ES&H policies which implement U.S. Department of Energy orders to comply with local, state and federal regulations.
- All vacuum system personnel will receive proper safety training as directed by ORNL personnel guidelines.
- All MSDS related to the vacuum equipment shall be supplied to ORNL by the vacuum hardware vendors.
- Vacuum system components will be subject to radiation activation from beam scattering. Since vacuum system components will have to be serviced, repaired or replaced, workers may be exposed to the induced radiation. The hazard of activation of the vacuum system components must be addressed in a separate Radiation Protection Plan (e.g. safety plans, training, operating procedures, etc.) in accordance with 10 CFR 835, Rev. 1, "Occupational

Radiation Protection".  The SNS Facility Manager will need to develop and implement the Radiation Protection Plan.

- ORNL/SNS will be provided with assembly, installation, operations, and maintenance manuals related to the DTL vacuum system, by LANL/SNS.

## 8.0 Procurement and Fabrication

### *8.1 Hardware Costs and Procurement Plan*

All vacuum components discussed in this final design report, with the exception of the instrumentation spool piece (which will be purchased by the DTL RF structures team), are standard catalog items that do not require any development by a vendor. Table 8.1 lists the required DTL vacuum system components and corresponding cost estimates as obtained from various vendor catalogs. Spare parts are not included in this estimate. It must be emphasized that listed vendors and hardware costs are for reference only. Similar components by other manufacturers will be considered during a competitive bidding process.

Table 8.1. Summary of DTL vacuum components and unburdened costs.

| Item | Vendor | Cat. # | Qty | Unit Cost $ | Discount % | Total Cost $ |
|---|---|---|---|---|---|---|
| Ion Pump, 300 Liter/sec | Varian | 9190405 | 18 | $4,950 | 25 | $66,825 |
| Ion Pump, Controller w/Comp. Int. | Varian | 9295000 | 18 | $1,945 | 25 | $26,258 |
| Cable 100 ft | Varian | (N/A) | 18 | $1,000 | 25 | $13,500 |
| Window Turbo Pump, 70 Liter/sec | Varian | 9699360 | 6 | $3,844 | 25 | $17,298 |
| Window Turbo Pump Controller | Varian | 9699505 | 6 | $1,508 | 25 | $6,786 |
| Window NEG pump (capacitor) | SAES | B650 | 6 | $4,200 | 25 | $18,900 |
| NEG pump controller | SAES | “ | 6 | $2,200 | 25 | $9,900 |
| Dry scroll backing pump | Varian | SH-100 | 6 | $3,000 | 25 | $13,500 |
| Extension cables 100 ft | Varian/SAES | (N/A) | 18 | $1,000 | 25 | $13,500 |
| Turbomolecular Pump Cart | Varian | MSPT9040<br>MSP0202<br>MSP90908<br>MSP0124<br>MSP0136 | 6 | $19,350 | 10 | $104,490 |
| Pneumatic All-metal Valve, 6 in. | MDC | 303006-01-03 | 6 | $2,795 | 20 | $13,416 |
| Manual Inline Valve, 1.5 in. | MDC | 302001-01-03 | 6 | $800 | 20 | $3,840 |
| Up-to-Air Valve | MDC | 420006 | 12 | $190 | 20 | $1,824 |
| Pneumatic All-metal Gate Valve, 1.5 in. | VAT | 08234-FA44 | 4 | $1,060 | 10 | $3,816 |
| Pneumatic All-metal Gate Valve, 2.5 in. | MDC | 303002-01-03 | 6 | $1,620 | 20 | $7,776 |
| Miscellaneous fittings, gaskets & fasteners | N/A | N/A | 6 | $3,500 | 20 | $16,800 |
| Pressure Relief Valve | Scientific Sales | SSA-PRV-275 | 6 | $270 | 10 | $1,620 |
| Gas throttling device | Alb. Valve & Fitting | N/A | 6 | 300 | 10 | $1,620 |
| Gas bottle & regulators | N/A | N/A | 1 | $1,000 | 0 | $1,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Basic Gauge Control Unit | Varian | L8350301 | 6 | $850 | 10 | $4,590 |
| Inverted Magnetron Gauge | Varian | R0310-303 | 12 | $375 | 10 | $4,050 |
| Computer Interface, RS232 | Varian | L6439301 | 6 | $150 | 10 | $810 |
| IMG circuit board | Varian | L9066301 | 12 | $675 | 10 | $7,290 |
| IMG Cables 100' | Varian | L11733100 | 12 | $355 | 10 | $3,834 |
| Rack Mount | Varian | L6426301 | 6 | $55 | 10 | $297 |
| ConvecTorr circuit board | Varian | L9887301 | 6 | $275 | 10 | $1,485 |
| Six setpoint process control | Varian | L8327301 | 6 | $255 | 10 | $1,377 |
| ConvecTorr Gauge | Varian | L9090302 | 6 | $129 | 10 | $697 |
| ConvecTorr Gauge Cable 100' | Varian | L91223100 | 6 | $230 | 10 | $1,242 |
| Residual Gas Analyzer, 1-100 AMU | SRS | TSP2-021120001 | 6 | $8,430 | 10 | $45,522 |
| Equipment Rack, fan, power strip, grounding | APW | N/A | 7 | $2,000 | 10 | $12,600 |
| PLC (plus cards, input & output connect) | Allen Bradley | N/A | 7 | $18,000 | 10 | $113,400 |
| Valve interface/indicator box | N/A | N/A | 7 | $200 | 0 | $1,400 |
| Local computer | N/A | N/A | 1 | $3,500 | 10 | $3,150 |
| Software (labview, PLC, etc.) | N/A | N/A | 1 | $2,000 | 10 | $1,800 |
| | | | | | **Grand Total** | **$510,598** |

Detailed performance specifications for major vacuum components have been prepared and are contained in Appendix E. These items will be sent out for bid to DOE/ORNL/LANL specified vendors and purchased by the LANL procurement department. They will be subject to Final/Approved Detail Drawings and LANL-derived selection criteria. Established LANL Quality Assurance Procedures (see Section 8.3) will be followed.

It is speculated at this time that major procurement packages (firm fixed-price contracts) will be developed for the vacuum pumps, instrumentation, and the control system hardware, cables and software. To save costs and effort, these procurements will proceed in parallel with those required for the CCL. Proposed sources will be determined based upon responses to a Commerce Business Daily advertisement or a down-sized list of ORNL pre-approved vacuum equipment vendors.

Vendor selection criteria will include:

- Cost
- Basic fabrication, assembling, and testing capabilities
- Past performance history
- Manufacturing and delivery plan (clear and concise? Risky?)
- Subcontracting plans

- Quality assurance program
- Inspection and testing capabilities
- Ability to meet staggered delivery schedule (see Section 8 of this report)
- On-site survey of contractor facilities

The vendor selection will be competitive and proposals submitted by contractors will be reviewed and judged on cost as well as above mentioned selection criteria. The University of California Technical Representative and Buyer from LANL, or a similar representative from ORNL, will select the lowest responsive and responsible offer from the bids received.

### *8.2 Delivery and Inspection*

All DTL vacuum equipment will be delivered to the SNS Receiving, Acceptance, and Testing (RATS) building at ORNL for inspection and storage prior to assembly. The delivery schedule for this equipment is presented in Section 12. The inspection at the point of delivery will be performed to check for obvious mechanical damage due to shipping problems. Operational or functional inspections will not occur until the vacuum equipment has been assembled to the DTL RF structure. Several months of storage for vacuum hardware may be required prior to assembly and equipment operational checkout. Consequently, the procurement packages will request standard warranties from the time of initial operational checkout, not from the time of delivery.

### *8.3 Quality Assurance*

To ensure the procurement and successful operation of high quality vacuum components, a quality assurance (QA) plan has been developed. The QA plan is comprised of four segments that correspond to the major activities defined in the DTL vacuum system work package; final design, procurement, delivery, assembly/installation/testing.

To initiate the QA plan, this final design report was generated to document the design parameters and requirements, vacuum equipment layouts, engineering calculations, drawings, facility interfaces, control system architecture, procurement/assembly/installation plans, safety features, costs, schedule, etc. This report and its contents will be peer reviewed by an expert committee to certify that the design is compliant with the design parameters and will meet the functional requirements of the SNS.

Upon approval of the final design, detailed procurement specifications or statements of work (SOW) will be generated for each major grouping of vacuum components. These procurement specifications will be included with Request for Proposals (RFPs) which will be sent out to pre-qualified vendors to allow them to submit bids on the various vacuum components. The exceptions to this procurement list are the vacuum system's PLCs, I/O cards, touchscreen interfaces, and electronics racks, which will come from vendors whom SNS has already qualified and established Basic Ordering Agreements with. The various vendor bids will be judged, based upon the acceptance criteria listed in Section 8.1. This will ensure that the SNS project is getting the best value equipment for the purchase price. The QA components of these SOWs will be as follows:

1) <u>QA Program and Procedures</u>: Vendor shall furnish copies of its latest quality assurance inspection and test policies and procedures. In addition, the vendor will be responsible for following University of California (UC) specified vacuum cleaning and handling procedures (see Appendix G). The QA program will be reviewed to determine its adequacy and relevance.
2) <u>Vendor Facilities</u>: To verify production, inspection, testing, and QA/certification capabilities, the vendors will be requested to submit references and provide for on-site visits by UC personnel. Such personnel shall be allowed full access to witness all operations/tests involved in the performance of the SOW. Reasonable advanced notice (24 hrs.) in writing, shall be provided to the vendor prior to any such visits. The UC, at its discretion, may assign and station resident representatives at the vendor's facility to provide program coordination. These representatives will assist in expediting actions between UC and the vendor, maintain program surveillance, and evaluate program progress. The resident representatives shall have access to all areas and information directly related to the scope of their responsibilities specified in the SOW.
3) <u>Qualification and Cerification of Personnel</u>: Vendor's personnel shall have the necessary qualifications and certifications as defined in the SOW to perform the necessary manufacturing, testing, inspection, and certification procedures (i.e., professional engineers, AVS certified vacuum welders, etc.). Qualification and certification records shall be provided by the Vendor.
4) <u>Design Review Prior to Production</u>: For other than off-the-shelf items that must be manufactured, the vendor shall provide a design review as requested by the UC. To facilitate

the design review, the vendor shall notify the UC employee of the design review at least 5 working days prior to the review. The notification shall include the proposed agenda, and reproducible paper and electronic copies of each document that constitutes the design or helps to demonstrate that the design meets the UC requirements specified in the SOW.

5) Inspection and Testing Procedures/Reports: Vendor shall prepare and maintain written and detailed inspection and testing procedures that show how the procured items will be verified that they conform to the requirements or specifications in the SOW. These procedures shall be reviewed and approved by the UC. Upon shipment, the vendor shall provide reports of inspections, tests, and certification of conformance. These reports shall be signed by the vendor's authorized personnel and shall be traceable to each shipment. Any deviations from the SOW technical requirements that are noted in these reports, must be approved by UC prior to shipment.

6) Engineering Drawings: Vendor shall provide all engineering drawings (both in electronic and paper formats) as specified in the SOW.

7) Certifications of Calibration and Conformance: Vendor shall provide with each shipment, when applicable, a certificate of calibration traceable to the shipment and the National Institute of Standards and Technology procedure for calibrating such a device. Vendor shall also provide with each shipment, a "Certificate of Conformance" that is traceable to the shipment stating that the material conforms in all respects with the SOW requirements (i.e., drawings, materials, specifications, inspections, tests, etc.). The certificate shall be signed by the vendor's authorized representative as defined in the vendor's QA program.

8) Failure/Nonconformance Reporting: The vendor shall notify the designated UC employer of each failure or nonconformance against contractually agreed upon engineering, inspection, or test requirements within three working days of the occurrence. Notice shall consist of a written description of the failure or nonconformance, an assessment of the cause, and the proposed corrective action.

9) Corrective Action to Failure/Nonconformance: Following a "notice of failure/nonconformance" from the vendor, the UC will submit a request for corrective action. The vendor shall provide written responses indicating corrective action taken within five working days of receipt of the request for corrective action from the UC.

10) Manuals: The vendor shall submit manuals/instructions that identify storage guidelines, installation procedures, installation testing procedures, special instructions, operating conditions and instructions, preventive and collective maintenance tasks, frequency of tasks,

tools and equipment required for installation and maintenance, operating procedures, safety precautions, trouble shooting guides, as well as warranty and contact information. The manuals shall be written in clear, concise language, readily understandable by a technician or craftsman, and it shall conform to the industry standards that prevail for the preparation of such documents.

11) Warranties: For standard off-the-shelf parts, vendors must supply UC with warranties that take effect from the initial time of operation of their products, not from the time of delivery. This will protect the project against buying faulty equipment that is outside a warranty period, simply because it has been in storage prior to operation. The terms of these warranties and the extent of the storage time will need to be agreed upon with the vendors. The vendors will also be required to submit a complete set of operation manuals upon delivery.

12) Packaging: Items to be shipped shall be packaged according to size, manufacturer, dimensional and manufacturer lot number. Packages of mixed lots, sizes, or products are not acceptable and will be returned to the vendor at vendor's expense. Packages shall be closed and labeled in a manner that identifies the item, dimensions (where applicable), quantity, seller's name and address, manufacturer's name, and shipment address. When required, as specified in the SOW, the packages will be provided with special handling fixtures (i.e., crane and forklift lifting fixtures), have proper insulation against damage, and have shipping insurance.

Upon delivery of the components to ORNL, a visual inspection shall be performed. This inspection will verify the quantity of items delivered including the receipt of required QA documents, MSDS sheets, engineering drawings, and manuals. The inspection will also check for damage due to shipping, and check to see that all dimensional and cleaning requirements have been met. An inspection report shall be generated to indicate the conformance/nonconformance of the shipment. If a nonconformance is indicated, the vendor shall be contacted to perform corrective action to meet the delivery requirements specified in the SOW. Upon successful delivery and inspection of the vacuum hardware, the equipment will be stored in the RATS building until required for assembly.

The vacuum equipment will be assembled on the RF structures and tested for functional and operational compliance. The specific testing and documentation procedures will be specified in the SOW by the UC. A testing report shall be generated to indicate the conformance/nonconformance of the vacuum hardware to the SOW specifications. If a nonconformance is indicated, the vendor shall be contacted to perform corrective action to meet the requirements specified in the SOW. Upon successful testing of the vacuum hardware, a certification document will be completed and signed to indicate the compliance of the vendor supplied material.

While the vendor supplied material may be certified for conformance, the integrated control system, as designed by participating SNS laboratories, will require certification of operation prior to acceptance by the SNS operations team. The testing/certification procedures and documents for this process will be generated following completion of the DTL/CCL Vacuum Systems Final Design Review.

## 9.0 Assembly, Installation, and Certification Plans

Following fabrication, delivery, and inspection of all DTL vacuum hardware, the assembly tasks for the DTL vacuum system will take place as an integrated effort in the assembly of each DTL tank. These assembly tasks will take place in the SNS Receiving, Acceptance, and Testing (RATS) building at ORNL. The anticipated assembly tasks for the DTL vacuum systems are as follows:

- Mount the vacuum spool piece to the DTL tank underside.
- Mount the vacuum pumps, valves, vacuum plumbing, and instrumentation to DTL spool piece and tank pump ports, as well as the DTL RF window waveguide transition.
- Assemble the DTL vacuum system electronics rack which includes mounting the PLC, vacuum pump and gauge controllers, touch screen, etc., and wiring up the various components to the PLC according to the rack layout and wiring diagrams.
- Connect all vacuum pumps and instrumentation to the control system's electronics rack.
- Connect the pneumatic valves to a pressurized air source and connect the DTL tank gas pressurization system.
- Certify operation of all vacuum pumps, valves, and instrumentation.
- Leak check the DTL tank. Leak checking will be performed according to the procedures and techniques outlined in [9.1].
- Sign-off on the assembly completion certification document to ensure that the assembly process, vacuum equipment check out, and leak check test have been completed per requirements.
- Repeat for the remaining five DTL tanks.

To accomplish the DTL vacuum assembly tasks, the RATS building must be equipped with the following:

- Storage space for vacuum components.
- Portable or permanent vacuum shop areas with cleanliness close to class 1000.
- Portable leak detector and helium gas source.
- Nitrogen bottles (99.999% $N_2$), equipped with coarse and fine gas regulators for purging the vacuum environments.

- Vacuum handling and cleaning procedures and equipment (i.e., cotton gloves, rinse baths, etc.). Cleaning procedures and materials for the DTL are given in Appendix G.
- Standard tools required for assembling vacuum components (i.e., open and box-end wrenches).
- Electrical power and compressed air supplies needed for a complete DTL vacuum system, as specified in Section 1.5.
- Trained and qualified vacuum technicians, capable of cleaning, assembling, inspecting, leak checking, and testing a vacuum system.

The installation of the DTL tank and supporting subsystems will take place immediately following certification of the entire DTL assembly and testing process. The installation of the DTL includes transporting the DTL tank, assorted subsystem components, and control system racks from the RATS building, over to the klystron gallery and linac tunnel. The anticipated installation tasks for the DTL vacuum systems are as follows:

- Remove the main ion pumps and turbo pump cart from the DTL tank for transportation to the linac tunnel. Seal the turbo pump cart port with the pneumatic isolation valve and cover the ion pump ports with blank flanges. Pack up the pumps for transportation as well.
- Transport main ion pumps and turbo pump cart to the linac tunnel and attach to the DTL tank once it is positioned and mounted.
- Route all pump, gauge, and valve power/communication cables through the waveguide chases or connect to the local junction boxes.
- Connect the gas pressurization source to the pneumatic vacuum valves. Connect all pump, gauge, and valve power/communication cables to the associated pieces of hardware in the linac tunnel.
- Install the DTL vacuum control system electronics rack in the klystron gallery. Connect electrical power lines to the rack. Connect all pump, gauge, and valve power/communication cables to the electronics rack.
- Perform local control system and vacuum equipment operation check-out.
- Connect local control system to the IOC and perform SNS Global Control EPICS interface tests.

- Perform vacuum leak check on the DTL tank.
- Sign-off on the installation completion certification document to ensure that the installation process, vacuum equipment check out, and leak check test have been completed per requirements.
- Repeat for the remaining five DTL tanks.

At the time of the writing of this document, the final design of the DTL RF structure has not been completed. Consequently, detailed integrated assembly and installation plans have not been written. Upon completion of both the final design of the DTL vacuum system and the DTL RF structure, a DTL Vacuum Assembly, Installation, Testing and Certification Manual will be developed to describe the above tasks and certification procedures in detail.

## 10.0 Operation, Reliability, and Maintenance

### *10.1 Operation*

During normal operations, the DTL vacuum system relies on 18 ion pumps and 6 NEG pumps to provide vacuum. Cold cathode gauges will monitor the vacuum pressures. Each DTL tank will have a PLC that will prevent an operating condition that could cause damage or determine if an abnormal conditions exists and use the appropriate interlocks to protect the system. EPICS will constantly monitor the PLC and alert the operator in the case of an abnormal event.

The expected reliability of 80000 hours at $7.5 \times 10^{-7}$ Torr for the ion pumps resulted in a decision to not use gate valves to isolate the tank from the ion pumps. Without gate valves, the normal operation of the vacuum system is straightforward. Basically, there will be two states; the high voltage to the ion pump is on and the pump current is normal or the pump current or the vacuum pressure is too high, then the pump is shut down.

When the system is pumped down from atmosphere or when the NEG pumps are activated or regenerated, additional interlocks will be in place. These interlocks will prevent an operating condition that could cause damage and protect the system in the event of an abnormal condition.

### *10.2 Reliability*

A measure of the performance in the DTL vacuum system is the ratio of the time that the vacuum system is working satisfactorily, to the time that the beam is shut down due to a vacuum system failure. This performance measure is traditionally made through a reliability, availability, maintainability, and inspectability (RAMI) program. These terms, as they apply to the DTL vacuum system, are defined below [4.4]:

- Reliabiltiy: Probability that the vacuum system will perform as expected for a period of time.
- Availability: The amount of time that the vacuum system is operating as required, divided by the operating time plus down or maintenance time.
- Maintainability: Probability that the vacuum system can be returned or restored to operating conditions when maintenance is performed.
- Inspectability: A measure of the ability to determine if or when maintenance is required to maintain the availability of the vacuum system.

A RAMI program for ensuring a high availability of 85% for the SNS was previously outlined in [4.4]. To meet the 85% availability for SNS, this program required 94.6% to 99.5% availabilities for each of the major SNS subsystems (i.e., from end, Linac, storage ring, conventional facilities, etc.). The SNS Linac was specified as needing to have an availability of 96.1%, which in turn would required even higher availabilities for each of the subsystems (i.e., RF power, LLRF controls, vacuum, water cooling, magnets, diagnostics, etc.). Unfortunately, budget and manpower restrictions eliminated the incorporation of the RAMI plan for the SNS. Consequently, there were no availability or reliability guidelines established for the DTL vacuum systems.

While there are no established reliability requirements for the DTL vacuum systems, good engineering practices were exercised in the design phase to ensure that negative impacts of equipment failure were minimized. First of all, previous particle accelerator vacuum system designs were used as a baseline to develop optimize the design and reliability of the DTL vacuum system [2.5, 2.6, 10.1]. The preliminary DTL vacuum system design was peer reviewed [10.2], as discussed previously in Section 1 of this report. The review committee consisted of accelerator vacuum engineers and technicians from six different National Laboratories. This expert committee related their vacuum design and operation experiences from several accelerator vacuum systems, including SLAC, LANSCE, APS, RHIC, and CEBAF, to strengthen the design and reliability of the SNS DTL vacuum system.

The following design features were incorporated to ensure nearly constant availability of the DTL vacuum systems:

- Ion pumps were chosen for the steady-state operation of the vacuum system. The ion pump specifications (see Appendix E) indicate that the ion pumps will have a mean time between failure of at least 80,000 hours. In the unlikely event that an ion pump fails during beam operation, there is sufficient redundancy in the available pumping speed so that the vacuum system can provide a sufficient vacuum environment until the next scheduled maintenance period.
- A valved turbo pump cart port has been provided in the design of the DTL tank. Should two ion pumps fail on a single DTL tank, a turbo cart can quickly be installed on the tank to provide extra vacuum pumping and allow the system to continue operating until the next scheduled maintenance period. In the event that a failure occurs on the turbo cart, the electropneumatic valve can be immediately closed to maintain the vacuum environment.

- Tank isolation valves and a nitrogen gasification system were incorporated on each DTL tank. Should maintenance be required on the vacuum system, the DTL tank can be quickly vented with N2. Upon completion of the maintenance procedure, a portable turbo cart can be attached to the DTL tank and bring it back to operating pressure in less than 15 hours.
- An RGA on each DTL tank serves as a redundant pressure measurement and safety interlock should the cold cathode gauge on the DTL vacuum spool piece fail.

### *10.3 Maintenance*

Since both the ion pumps and NEG pumps have no moving parts, they are maintenance free. The cold cathode gauges have no filaments to burn out and do not require any periodic maintenance. The small turbo and scroll pump used to activate and regenerate the NEG will be used only intermittently and only the scroll pump requires servicing. Its minor and major service can easily be scheduled during a planned maintenance period of the linac.

During the planned maintenance period, a visual inspection of the cables is recommended. Cable and feedthroughs are the first items to suspect in an ion pump failure. Although unlikely in the DTL, radiation could affect the integrity of the cables. Inspection of the cables for radiation damage is optional.

If an ion pump fails, there are two options. One is to continue operation of the linac until the next maintenance period if the increased pressure is still within activation limits. The second option is to shut down the linac and vent the DTL to atmospheric pressure to service the pump. At each end of the tank are isolation valves to preserve the vacuum within the remaining sections of the linac. After servicing and reinstalling the pump, the turbo pump cart will be installed and should be able to pump down the tank rather quickly so that the ion pumps can be re-started as soon as possible

If there is a problem with the turbo pump cart, then the isolation gate valve is closed and the cart removed. The cart can be repaired outside of the linac tunnel at some other time. If the additional pumping from the turbo pump cart is still required, then another cart can be installed. Because of the turbo pump cart isolation gate valve, the vacuum will not be lost and down time will be minimal.

During RF conditioning of the DTL the turbo pump cart can be operated in conjunction with the ion pumps to help expedite the conditioning. If a failure of the turbo pump cart occurs during this period, then the pump cart will need to be replaced to help overcome the pre-conditioning outgassing rate of the DTL.

Table. 10.1 Summary of Selected Vacuum Pumps

| **PUMP SYSTEM** | | **ION** | **TURBO** | **SCROLL** |
|---|---|---|---|---|
| Model | | CapTorr 300 | V-300 | PTS300 |
| Manufacturer | | Physical Electronics | Varian | Varian |
| Pump Speed | | | | |
| $N_2$ | L/s | 240 (@ $10^{-7}$ Torr) | 280 | 5 |
| $H_2$ | L/s | | 210 | |
| Weight | Kg(lb) | 70 (149) | 8 (17.6) | 34 (75) |
| Reliability Data | | | | |
| Lifetime | hrs | 400,000@ $10^{-7}$ Torr<br>80,000@$10^{-6}$ Torr | | |
| MFTF | hrs | | 80,000 | |
| MFTM | hrs | | | 9000 |

## 11.0 Decommissioning

Decommissioning of the SNS will require disconnection and recycling/disposing of the vacuum system components. It is speculated, based on operational experience on the LANSCE accelerator [11.1], that the vacuum pumps, manifolds, and instrumentation, will become radioactively contaminated and will need to be treated as low level radioactive waste. Consequently, disposal of these items will need to follow proper U.S. Department of Energy guidelines for such hardware.

## 12.0 Project Summary, Ongoing Work, Costs, and Schedule

### *12.1 Project Summary and Ongoing Work*

The design of the DTL vacuum system has been finalized and documented. In particular, the following activities have been completed:

- The vacuum hardware layouts have been completed including the types and sizes of pumps, plumbing, RF grills, and instrumentation. These layouts have been documented in the form of Piping and Instrumentation Diagrams. Specification sheets have been developed for all vacuum hardware in an effort to bring consistency between the DTL vacuum equipment and that from other SNS vacuum subsystems.
- The vacuum analyses for the drift tubes, tank volumes, RF windows, and beam diagnostics have been performed.
- The mechanical designs and analyses for the DTL vacuum system are completed. Material selections and strength issues have been studied and documented. All assembly and detail drawings have been generated.
- The control system architecture has been finalized and is consistent with control layouts from other SNS subsystems (i.e., storage ring vacuum system, linac water cooling systems, etc.). The interfaces between the local control system and global controls have been identified. The control methodology, safety interlocks, and protection equipment facets have been identified. A signal and device spreadsheet for each DTL vacuum system has been generated according to SNS standards.
- A vacuum system hazard analysis has been performed and protective measures to mitigate these hazards have been developed.
- Procurement and fabrication plans have been devised for the DTL vacuum equipment. These plans have been integrated with the CCL vacuum procurements but need to be integrated with the entire SNS vacuum system procurement plans.
- Assembly, installation, and certification plans have been developed to fit within the SNS integrated project schedule.

While the final design of the DTL vacuum system has been completed, there are a number of engineering tasks that are still ongoing or need to be initiated.

- All DTL vacuum system engineering drawings need to be checked, corrected, and signed off. All other DTL hardware drawings that require vacuum system signatures will need to be reviewed.
- A prototype control system, including the PLC, I/O Cards, touchscreen, etc. has been procured. The programming of the PLC ladder logic is under development. This prototype control system will be interfaced with EPICs and tested out on the CCL hot model vacuum system at LANL. This prototype control system will be the model for all of the DTL and CCL vacuum control systems.
- The electronics rack layouts and wiring diagrams for the DTL vacuum systems need to be generated. These will be used by the rack factory at ORNL to assemble the vacuum control systems prior to installation in the klystron gallery.
- The assembly and installation procedures for the DTL tanks are still under development. Consequently, the vacuum system assembly and installation plans may need to be adjusted to meet the needs of the DTL.
- Assembly, installation, operation, and maintenance manuals for the DTL vacuum systems need to be generated.
- Procurement specifications for the vacuum pumps, plumbing, and instrumentation need to be finalized with ORNL/SNS. Upon completion of these specifications, Basic Ordering Agreements will be established by ORNL/SNS for all vacuum equipment. Next, vacuum equipment for the DTL and CCL will be ordered and delivered to ORNL.
- Once hardware has been delivered to ORNL, the assembly, installation, and commissioning tasks will be performed.

### *12.2 Cost Summary*

The labor and hardware costs for the design and procurement of the DTL vacuum system are summarized in Tables 12.1 and 12.2, respectively. As Table 12.2 indicates, a cost variance of -$100,000 exists with the vacuum hardware needs of the final DTL vacuum system. A project change request has been drafted and submitted to ORNL for the contingency funding needed to cover the additional hardware expenses.

Table 12.1. Labor cost summaries for the design and procurement activities of the DTL vacuum systems.

| **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 | 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 |

Table 12.2. Burdened hardware procurement cost summaries for the DTL vacuum systems.

| **Equipment** | **Baseline Costs ($k)** | **New Costs base on Final Design ($k)** | **Variance ($k)** | **Reason for Variance** |
|---|---|---|---|---|
| Vacuum Pumps | 293.2 | 315.2 | -22.0 | Unforseen RF window gas loads during RF conditioning necessitates the incorporation of additional vacuum pumps/controllers and instrumentation on the RF window waveguide transition to meet the ambitious Linac commissioning schedule. |
| Plumbing | 22.8 | 60.5 | -37.7 | Evolving design of Linac has led to changes in intersegment hardware, support structures, and gaskets/fasteners. |
| 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 requirements call for the use of individual vacuum control systems for each DTL tank and CCL module (rather than a ganged approach). Concurrent assembly/checkout and commissioning activities will require independent module vacuum control systems. An additional prototype control system has been added to allow for development of the control system software and interface hardware with the global control system. Consequently, an increase in hardware cost is required for additional PLCs, electrical hardware, interfaces, etc. Note that the costs of the PLCs were dropped previously from WBS 1.9.4 to allow for incorporation in 1.4.2.4. |
| TOTAL | 513.8 | 613.8 | -100.0 | |

### *12.3 Schedule*

The project schedule for the procurement, delivery, assembly, and installation of the DTL vacuum systems is shown in Table 12.3. These dates come from a detailed and fully integrated SNS project schedule. In addition, the procurement dates of the DTL vacuum system hardware have been coordinated with similar procurements of the CCL vacuum hardware. Further coordination of the procurement dates may be required if ORNL/SNS would like to combine the DTL/CCL vacuum hardware procurements with those from other SNS subsystems (i.e, front end, super conducting Linac, storage ring, and target area).

The early start and finish dates listed in Table 12.3 are linked to project activities that occur prior in the project time-line. These are the desired dates for which the DTL vacuum system design team will strive for. The late start and end dates represent the latest time that these activities can take place without becoming an SNS project critical path activity.

Further descriptions and details regarding the procurement, assembly and installation tasks can be found in Sections 8 and 9 of this report.

Table 12.3. Schedule for the procurement, delivery, and assembly of the DTL vacuum systems.

| Activity | Early Start Date | Early Finish Date | Late Start Date | Late End Date |
|---|---|---|---|---|
| Documentation & Manuals | 23-Jan-01 | 20-Feb-01 | 23-Jan-04 | 20-Feb-04 |
| Control System Programming | 23-Jan-01 | 01-May-01 | 01-Jul-01 | 23-Oct-01 |
| Purchase Request to Purchase Order | 21-Feb-01 | 12-Jul-01 | 10-Sep-02 | 11-Feb-03 |
| Tank 1 Vacuum Fab & Ship | 1-Oct-01 | 31-Oct-01 | 12-Feb-03 | 14-Mar-03 |
| Tank 2 Vacuum Fab & Ship | 1-Nov-01 | 5-Dec-01 | 25-Jun-03 | 25-Jul-03 |
| Tank 3 Vacuum Fab & Ship | 6-Dec-01 | 14-Jan-02 | 28-Jul-03 | 26-Aug-03 |
| Tank 5 Vacuum Fab & Ship | 15-Jan-02 | 14-Feb-02 | 27-Oct-03 | 28-Nov-03 |
| Tank 6 Vacuum Fab & Ship | 15-Feb-02 | 19-Mar-02 | 1-Dec-03 | 7-Jan-04 |
| Tank 4 Vacuum Fab & Ship | 20-Mar-02 | 18-Apr-02 | 21-Jan-04 | 20-Feb-04 |
| Tank 1 Controls/Racks Fab/Ship | 23-Oct-01 | 26-Mar-02 | 25-Oct-02 | 28-Mar-03 |
| Tank 2 Controls/Racks Fab/Ship | 27-Mar-02 | 23-Apr-02 | 16-Jul-03 | 12-Aug-03 |
| Tank 3 Controls/Racks Fab/Ship | 24-Apr-02 | 21-May-02 | 13-Aug-03 | 10-Sep-03 |
| Tank 5 Controls/Racks Fab/Ship | 22-May-02 | 19-Jun-02 | 17-Nov-03 | 16-Dec-03 |
| Tank 6 Controls/Racks Fab/Ship | 20-Jun-02 | 18-Jul-02 | 17-Dec-03 | 22-Jan-04 |
| Tank 4 Controls/Racks Fab/Ship | 19-Jul-02 | 15-Aug-02 | 6-Feb-04 | 5-Mar-04 |
| Tank 1 Vacuum Assembly | 23-Sep-02 | 4-Oct-02 | 17-Mar-03 | 28-Mar-03 |
| Tank 2 Vacuum Assembly | 20-Nov-02 | 5-Dec-02 | 13-Aug-03 | 26-Aug-03 |
| Tank 3 Vacuum Assembly | 3-Feb-03 | 14-Feb-03 | 27-Aug-03 | 10-Sep-03 |
| Tank 5 Vacuum Assembly | 3-Apr-03 | 16-Apr-03 | 8-Jan-04 | 22-Jan-04 |
| Tank 6 Vacuum Assembly | 11-Jun-03 | 24-Jun-03 | 8-Jan-04 | 22-Jan-04 |
| Tank 4 Vacuum Assembly | 8-Sep-03 | 19-Sep-03 | 23-Feb-04 | 5-Mar-04 |
| Tank 1 Vacuum Installation | 31-Mar-03 | 23-May-03 | 31-Mar-03 | 23-May-03 |
| Tank 2 Vacuum Installation | 27-Aug-03 | 8-Oct-03 | 27-Aug-03 | 8-Oct-03 |
| Tank 3 Vacuum Installation | 11-Sep-03 | 23-Oct-03 | 11-Sep-03 | 23-Oct-03 |
| Tank 5 Vacuum Installation | 25-Jun-03 | 6-Aug-03 | 23-Jan-04 | 5-Mar-04 |
| Tank 6 Vacuum Installation | 25-Jun-03 | 6-Aug-03 | 23-Jan-04 | 5-Mar-04 |
| Tank 4 Vacuum Installation | 8-Mar-04 | 30-Apr-04 | 8-Mar-04 | 30-Apr-04 |

## 13.0 Appendix A – SLAC B-Factory Vacuum Outgassing Summary

# MEMORANDUM

**Memo Number:** **PPO-MEM-01948**

**To:** **Martin Schulze**

From: Alex. Harvey

Date: March 10th, 1999

SUBJECT: CONTRACT NO. DE-AC04-96AL89607;
OUTGASSING RATES FOR CU & S.S.

Here are the values and sources of the outgassing rates I would propose using for copper (CCDTL cavities), and stainless steel (expander chamber and beam-line):

Copper (OFE, machined, and subjected to hydrogen brazing):

Initial rate (for pump-down): 1.0E-9 T-l/s-cm^2
(SLAC, "Stanford 2-mile Accelerator")

Residual rate (operating): 1.0E-11 T-l/s-cm^2
(same, and Dan Wright, SLAC engineer)

Stainless Steel (degreased, not baked):

Initial rate: 1.0E-9 T-l/s-cm^2
(Varian "Review of Outgassing Results" VR-51, 1968)

Residual rate: 1.0E-10 T-l/s-cm^2
(same)

Stainless Steel (baked @ 400C for 24 hr)

Residual rate: 1.0E-12 T-l/s-cm^2
(both Varian and SLAC)

There is clearly some advantage in baking S.S., if we can do it.

Cc: George Spalek
Rick Wood
Peter Dumitriu
Chelly Weiss

## 14.0 Appendix B – RGA Analysis of the APT/LEDA CCDTL & LANSCE CCL

***Applied Research Engineering Division***
***Accelerator Technologies Engineering Group***

LLNL-ATEG-99-201
December 16, 1999

**RGA Analysis of the APT CCDTL Low-Beta Hot Model**
**For use as a Baseline for the**
**Spallation Neutron Source Linac Vacuum System Design**

K. Kishiyama, Electrical Engineer, ATEG/LLNL

## Introduction

The proposed SNS Cavity Coupled Linac (CCL) will utilize fabrication techniques similar to the existing APT CCDTL Low-Beta Hot Model (LBHM). The LBHM is a hydrogen brazed OFE copper structure and the data obtained from the LBHM vacuum system should be helpful in the design of the SNS CCL vacuum system.

The scope of this discussion will be limited to the LBHM data provided by Paul Leslie from LANSCE-1. The relative percentage of the main residual gases will be calculated from the RGA spectrums obtained from the Leybold-Inficion Transpector installed on the LBHM. The LBHM has been under vacuum for several months and has been operated with high power RF. This discussion will focus on what might be the expected composition of SNS CCL vacuum after a few thousand hours under vacuum and high power RF conditioning based on the observations from the LBHM.

## Analysis

The Leybold-Inficion Transpector RGA provides partial pressure data in the form of ion intensity versus the ion mass to charge ratio. The ion intensity is measured in amperes. A spectrum from the LBHM taken 7/29/99 is shown in Figure 1. A rough estimate to convert ion current to partial pressure (Torr) can be made using published sensitivities, ionization probabilities, fragmentation factors and ion transmission factors. However, all of these factors are dependent on the individual instrument due to variations in electron energy, mass tuning, ionizer design, etc. To accurately convert ion current to partial pressure requires careful calibration with accurate test equipment [1]. Actually calibrating the RGA would be beyond the scope of this discussion and therefore only an estimate of the partial pressures will be made here based on published values for sensitivities, ionization probabilities, fragmentation factors and ion transmission factors. [2].

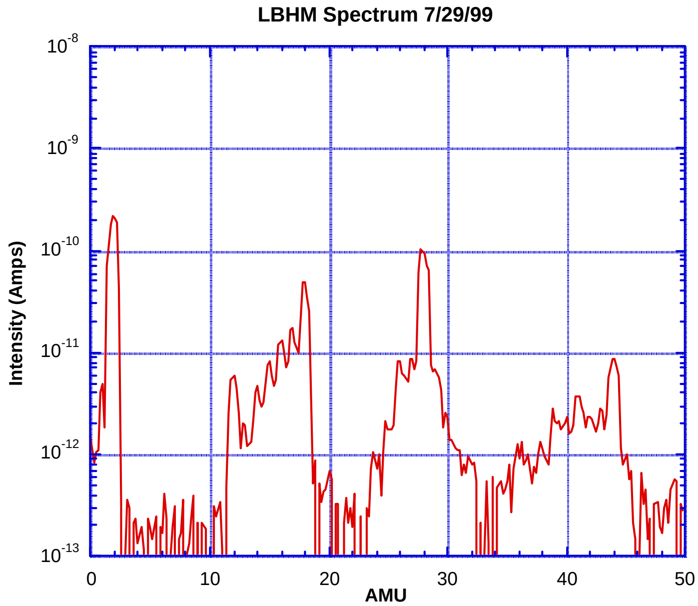



Figure 1. LBHM spectrum from 0 to 50 AMU

The Leybold-Inficon Transpector User Manual provides the following general equation for the conversion of ion current to partial pressure in units of Torr:

$PP_a = \{FF_{28} / (FF_{ab} * XF_a * TF_a * DF_a * G * S)\} * I_{ab}$

Where:

$PP_a$ = partial pressure of substance a in Torr

$FF_{28}$ = fragmentation factor for Nitrogen (typically = 0.94)

$FF_{ab}$ = fragmentation factor of substance a having mass b

$XF_a$ = ionization probability

$TF_a$ = transmission factor, the fraction of ions at mass b which pass through the mass filter relative to ions at mass 28, $TF_a = 28/a$

$DF_a$ = detection factor for mass b from substance a relative to mass 28, assumed to be 1.00 for Faraday detectors, but must be calibrated for electron multipliers

G = gain of electron multiplier for mass 28, must be calibrated

S = sensitivity of instrument for mass 28 in amps/Torr

$I_{ab}$ = ion current of mass peak b from substance a in amps

The ion currents from the spectrum shown in Figure 1 were used to calculate the partial pressures of the five main gas species typically found in a vacuum system. Table 1 summarizes the calculations. Note that the percentages do not add up to 100%. There are several other gas species present whose partial pressures were not calculated.

Table 1. Calculated percentages in LBHM.

| **RGA Spectrum Analysis of APT/LEDA CCDTL Hot Model** | | |
|---|---|---|
| **Gas species** | **AMU** | **Percent concentration** |
| | | |
| Hydrogen | 2 | 18% |
| Methane | 16 | 3% |
| Water vapor | 18 | 20% |
| Nitrogen/Carbon Monoxide | 28 | 49% |
| Carbon Dioxide | 44 | 7% |

The relative percentages generally agree with published values for OFE copper [3], [4], but there will always be variations in the exact composition of the vacuum due such factors as manufacturing processes, cleaning processes and surface finishing. Note that since hydrogen is not as soluble in copper as compared to stainless steel, it is generally not the predominate gas in a copper vacuum system while it usually is in a stainless steel vacuum system.

In examining the raw spectrum in Figure 1, it initially appears that hydrogen is the dominant gas species, but the analysis in Table 1 shows mass 28, nitrogen/carbon monoxide, constitutes the largest percentage of residual gases in the vacuum. The reason why the raw spectrum shows hydrogen as the largest peak is because the ion transmission factor is greater for smaller masses. To scale the data for the transmission factor to mass 28, the ratio of the two masses is used. For hydrogen, the ratio of mass 28 to mass 2 is 14. By taking into account the ion transmission factor, the ionization probability and the fragmentation factor, the hydrogen peak must be scaled down by a factor of 6.16 before the conversion of ion intensity to pressure.

Using data from the stabil-ion gauges on the LBHM, the base pressure reached $1.6 \times 10^{-8}$ Torr in August 1999. The LBHM had been under vacuum since the middle of January 1999. The system was only bought up to atmosphere a few times and each time it was with a nitrogen purge. By the end of July the LBHM had approximately 60 hours of RF operation. By the end of July, approximate power levels were 15 kW. The effective pump speed of the four ion pumps being used on the LBHM was calculated to be 48 liters/sec. This calculation was based on the pump speed measurements performed in January 1999 [5] on the LBHM using four ion pumps and two turbo pumps. The approximate surface area of the LBHM is 12,000 $cm^2$. The outgassing rate for the LBHM was calculated to be $6.4 \times 10^{-11}$ Torr-liters/sec/$cm^2$.

At the end of September 1999, RF power was approaching 40 kW and the base pressure of the vacuum system reached $5.0 \times 10^{-9}$ Torr. Using the same pump speed and surfaces areas as above, the outgassing rate is calculated to be $2.0 \times 10^{-11}$ Torr-liters/sec/$cm^2$. These values are within the range of values found in published data [6].

Finally, the spectrum from 0 to 100 AMU taken on June 23, 1999 shown in Figure 2 has significant hydrocarbon contamination. The hydrocarbons appear to be volatile and with the help of the RF conditioning, have generally been pumped out of the system. Peaks 39 and 41 for example are an order of magnitude less in amplitude in the spectrum taken on July 29, 1999 shown in figure 1.

The purpose of noting the hydrocarbon contamination in the LBHM is to bring to attention the need for ultrahigh vacuum handling practices for achieving the target vacuum pressures in the SNS CCL module 30 vacuum system. While the LBHM finally reached a very good outgassing rate, it required several thousand hours under vacuum and many kilowatts of RF conditioning. It is cost and time effective to design ultrahigh vacuum handling practices into the manufacturing and installation of the cavities.

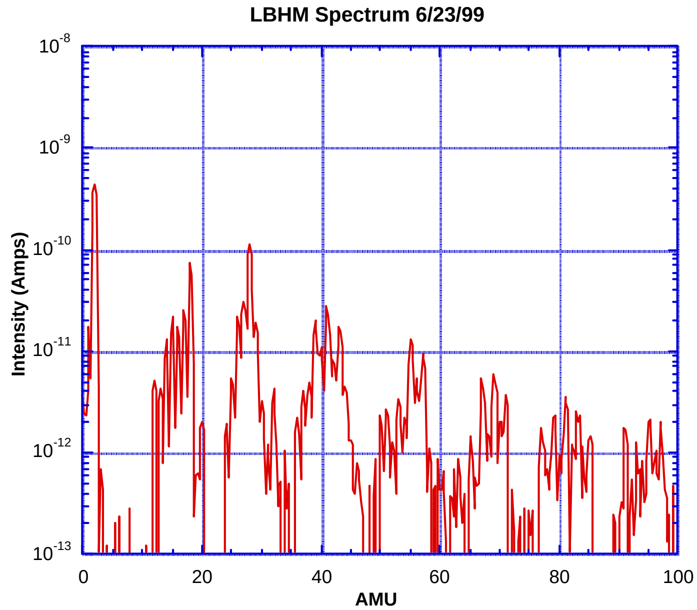



Figure 2. LBHM spectrum showing hydrocarbon contamination

[1] J. Basford *et al*., *American Vacuum Society Recommended Practice for Calibration of Mass Spectrometers for Partial Pressure Analysis*, J. Vac. Sci. Technol. A 11(3) 22 (1993)

[2] R. L. Summers, *Empirical Observations on the Sensitivity of Hot Cathode Ionization Type Vacuum Gauges*, NASA Technical Note TN D5285, (1969)

[3] S. Dushman, *Scientific Foundations of Vacuum Technique*, 2nd Edn, Wiley, New York (1962)

[4] G. F. Weston, *Materials for Ultrahigh Vacuum*, Vacuum, 25(11/12) 469 (1975)

[5] K. Kishiyama *et al*., *Test Report: Accelerator Production of Tritium/Low Energy Demonstration Accelerator CCDTL Phase 3A Low Beta Hot Model Pump Speed Tests*, LLNL-ATEG-99-203, April 13, 1999

[6] J. O'Hanlon, *A User's Guide to Vacuum Technology*, Wiley, New York, (1980)

## Residual Gas Analysis of LANCE LINAC module six

By: Cort Gautier LANL

The LANCE LINAC is one of only a few pulsed proton LINAC's operating in the world. Vacuum data obtained from the LANCE LINAC should be useful for the design of the SNS linac
A RGA spectrum of the LANCE side coupled linac module 6 has been analysed.
The spectrum was taken with a Stanford Research Systems (SRS) RGA 200.

The sum of the individual partial pressures gives a total system pressure of $5.87\times10^{-7}$ Torr.

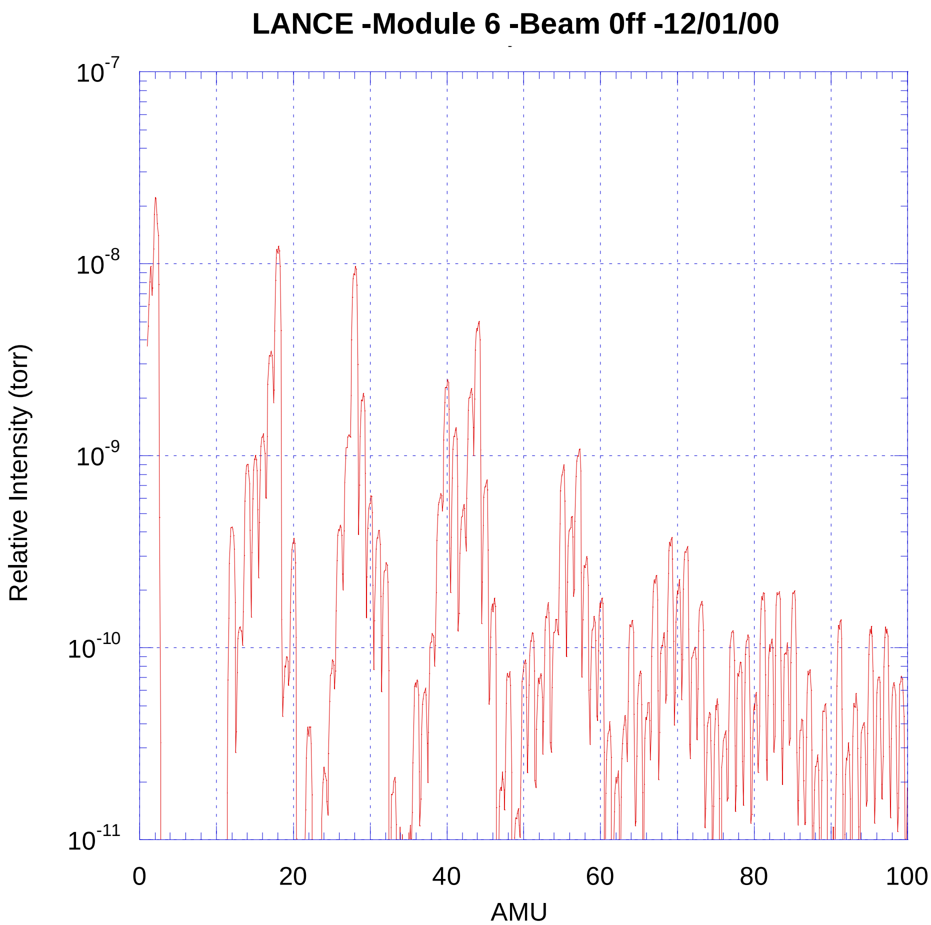
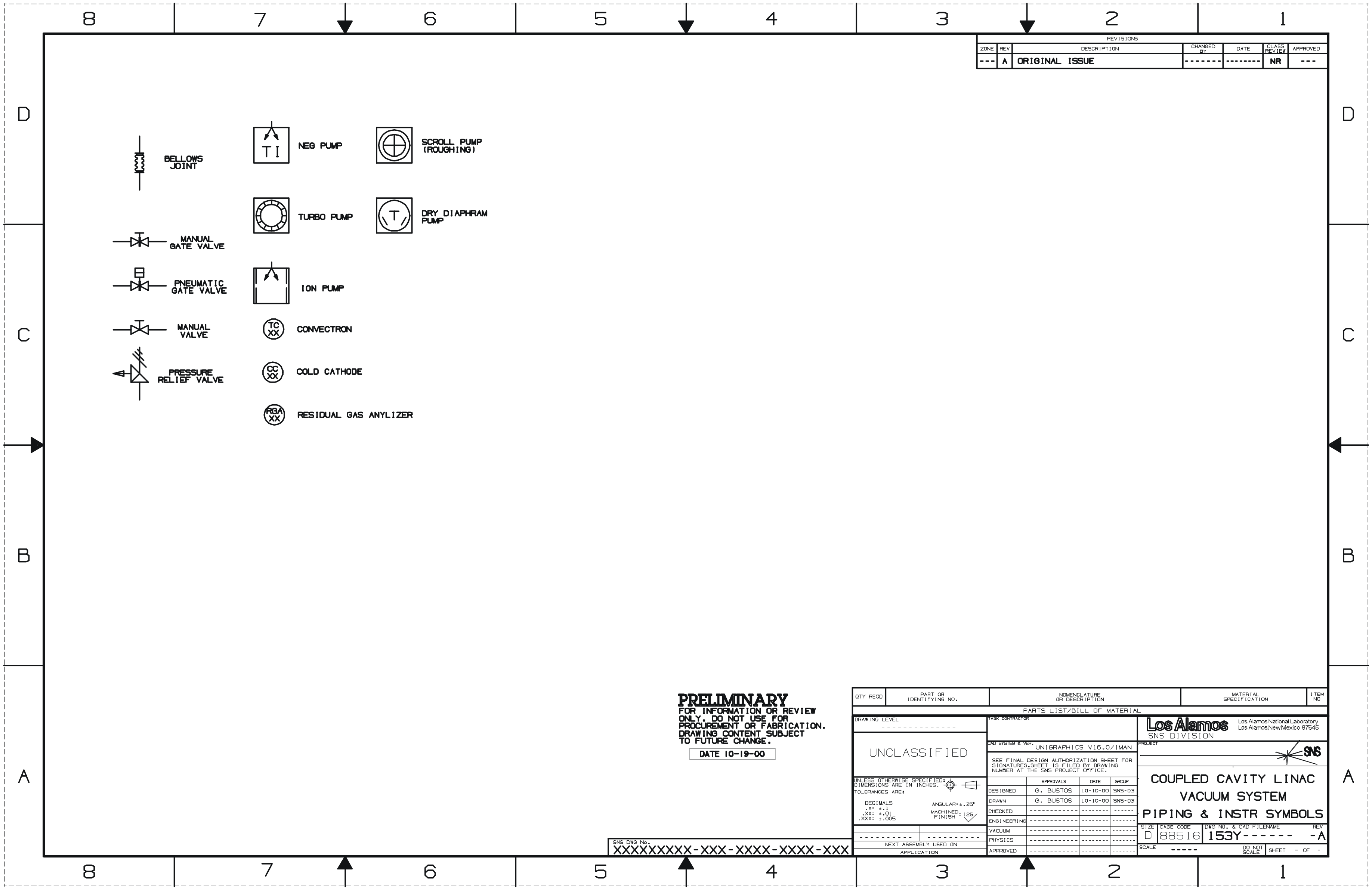



Figure B.1. RGA scan of CCL module 6 on the LANSCE Linac.

## 15.0 Appendix C – Engineering Drawings



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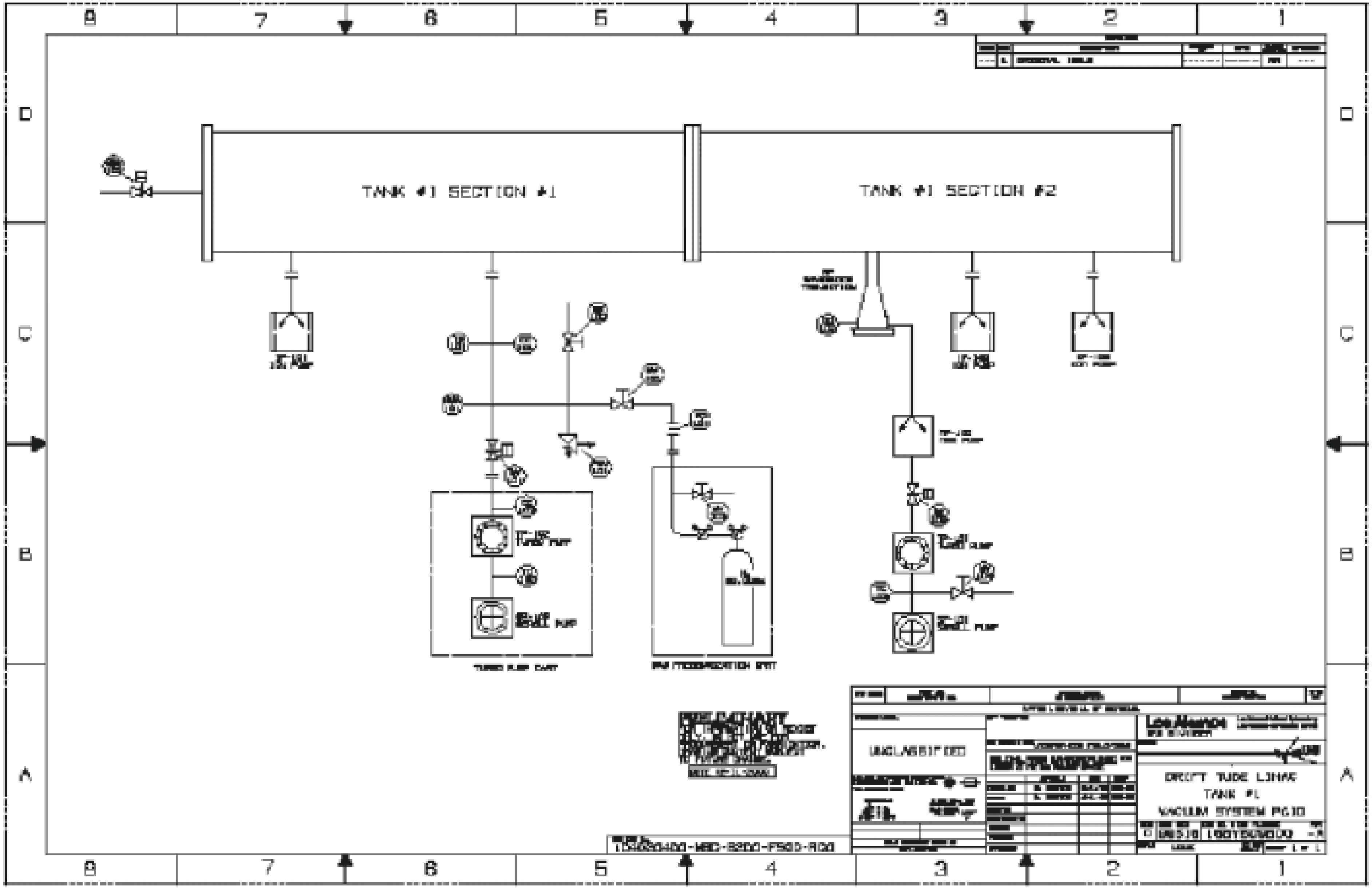
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DRIFT TUBE LINAC
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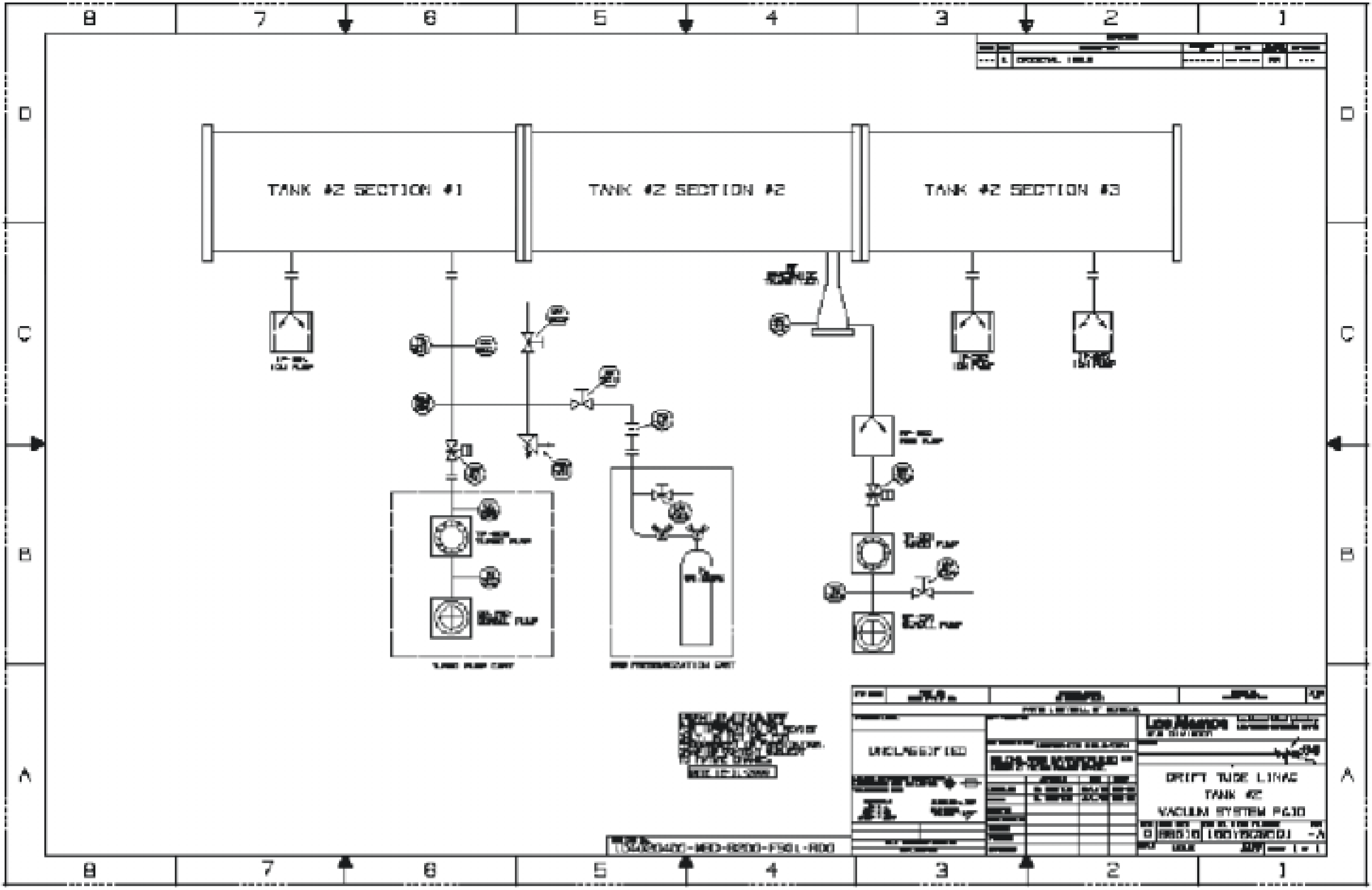

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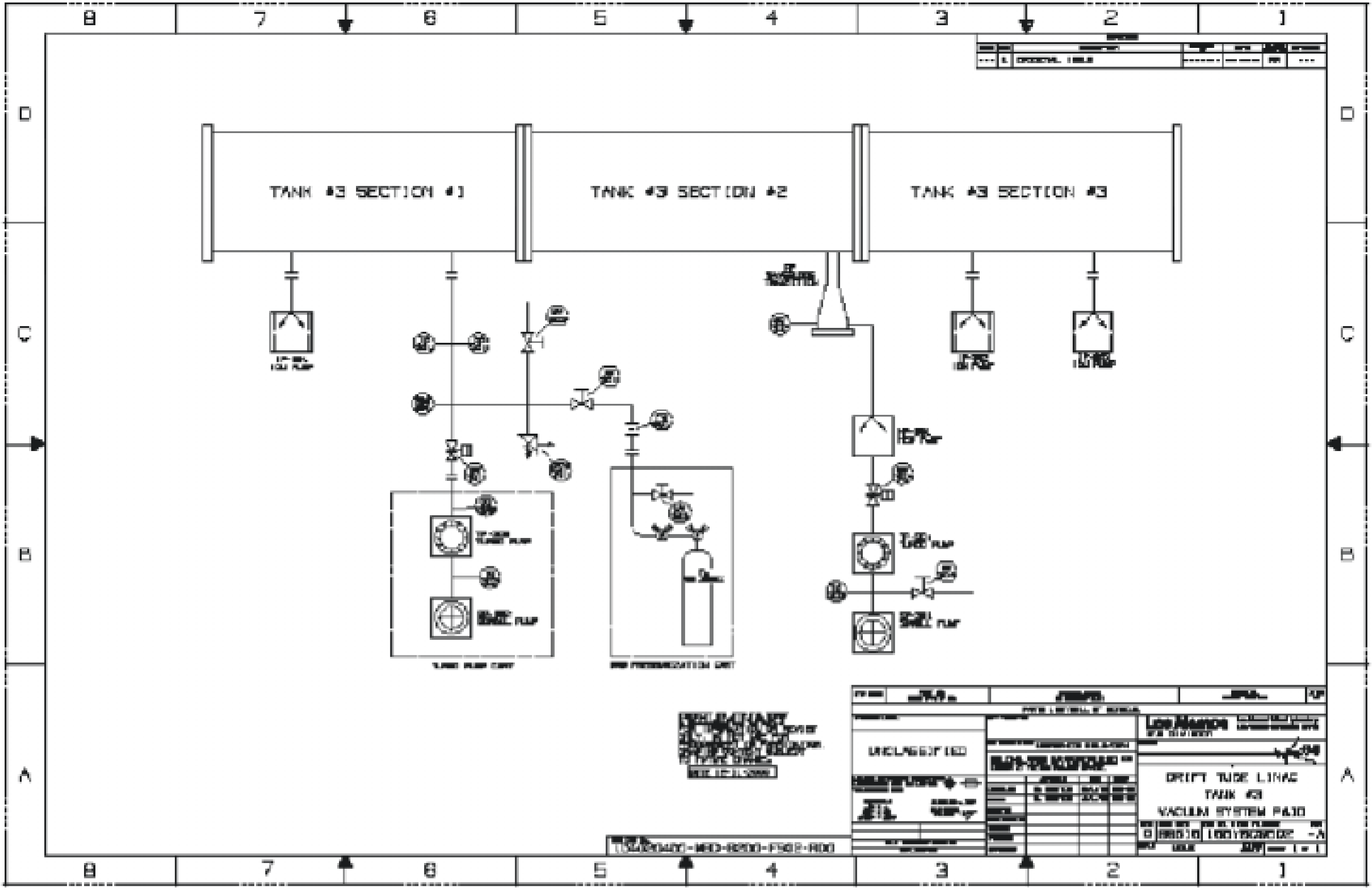
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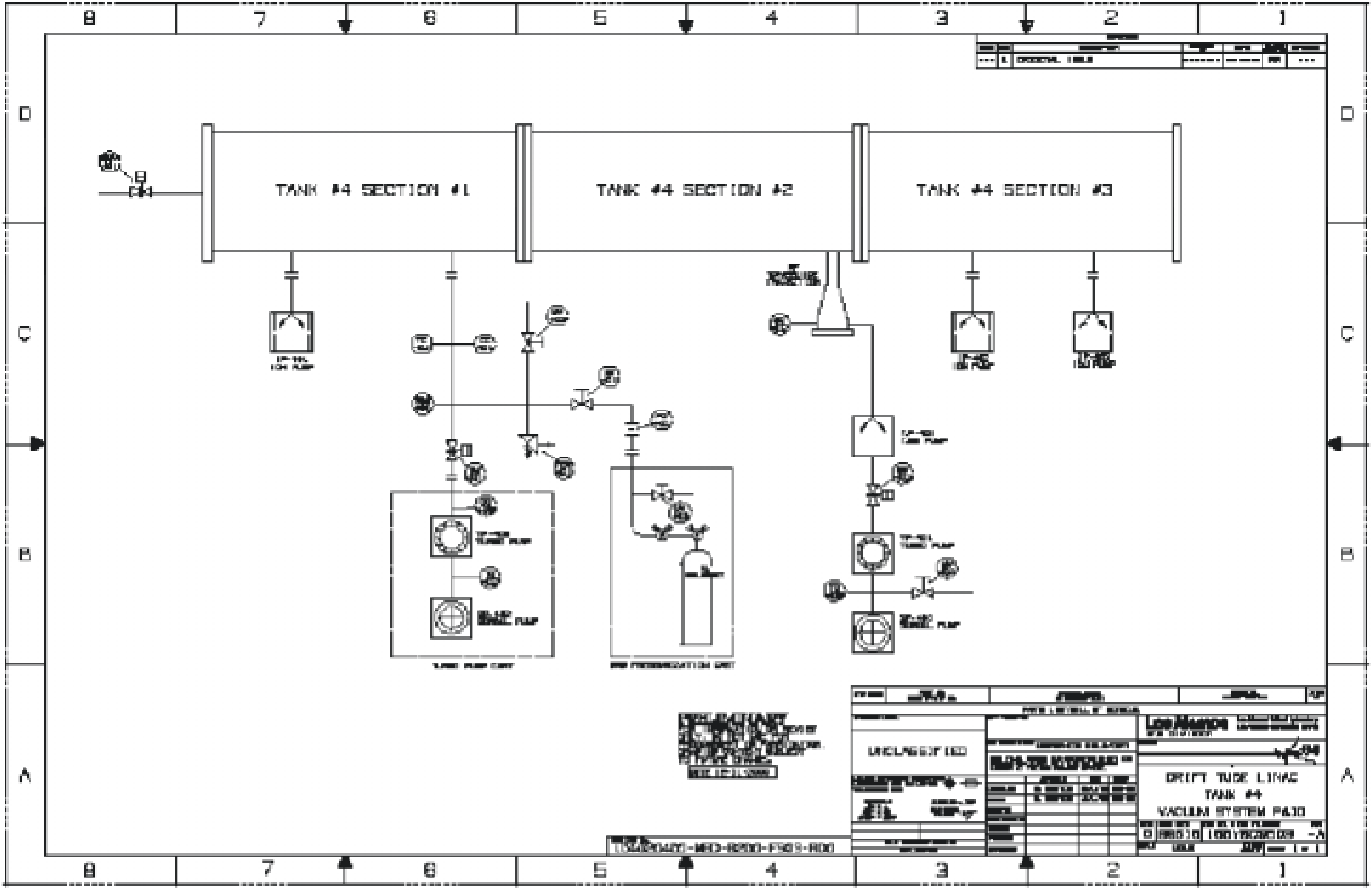

TANK #4 SECTION #1
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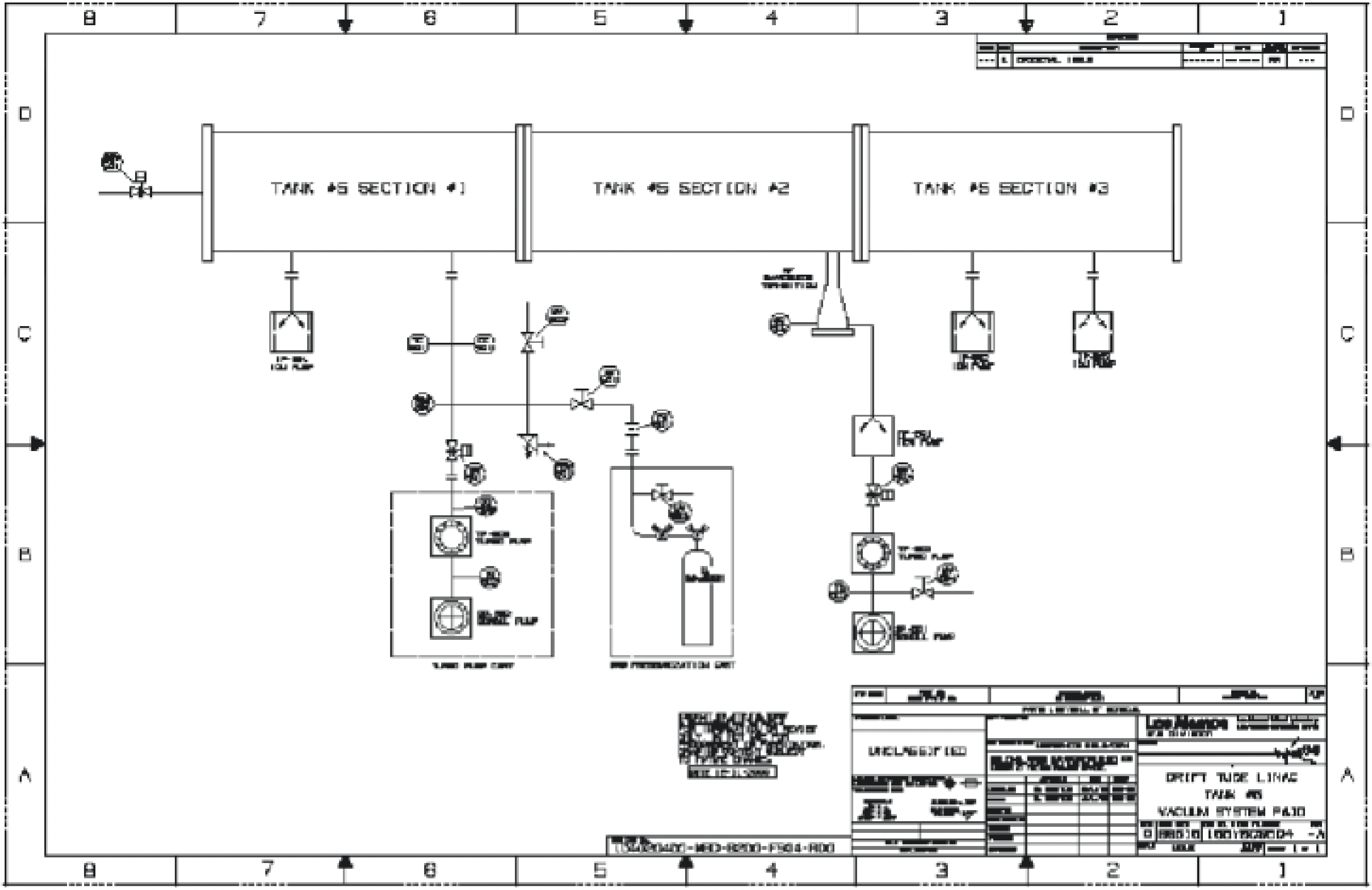
TANK #4 SECTION #3
UNCLASSIFIED
Los Alamos
DRIFT TUBE LINAC
TANK #4
VACUUM SYSTEM P&ID



TANK #5 SECTION #1
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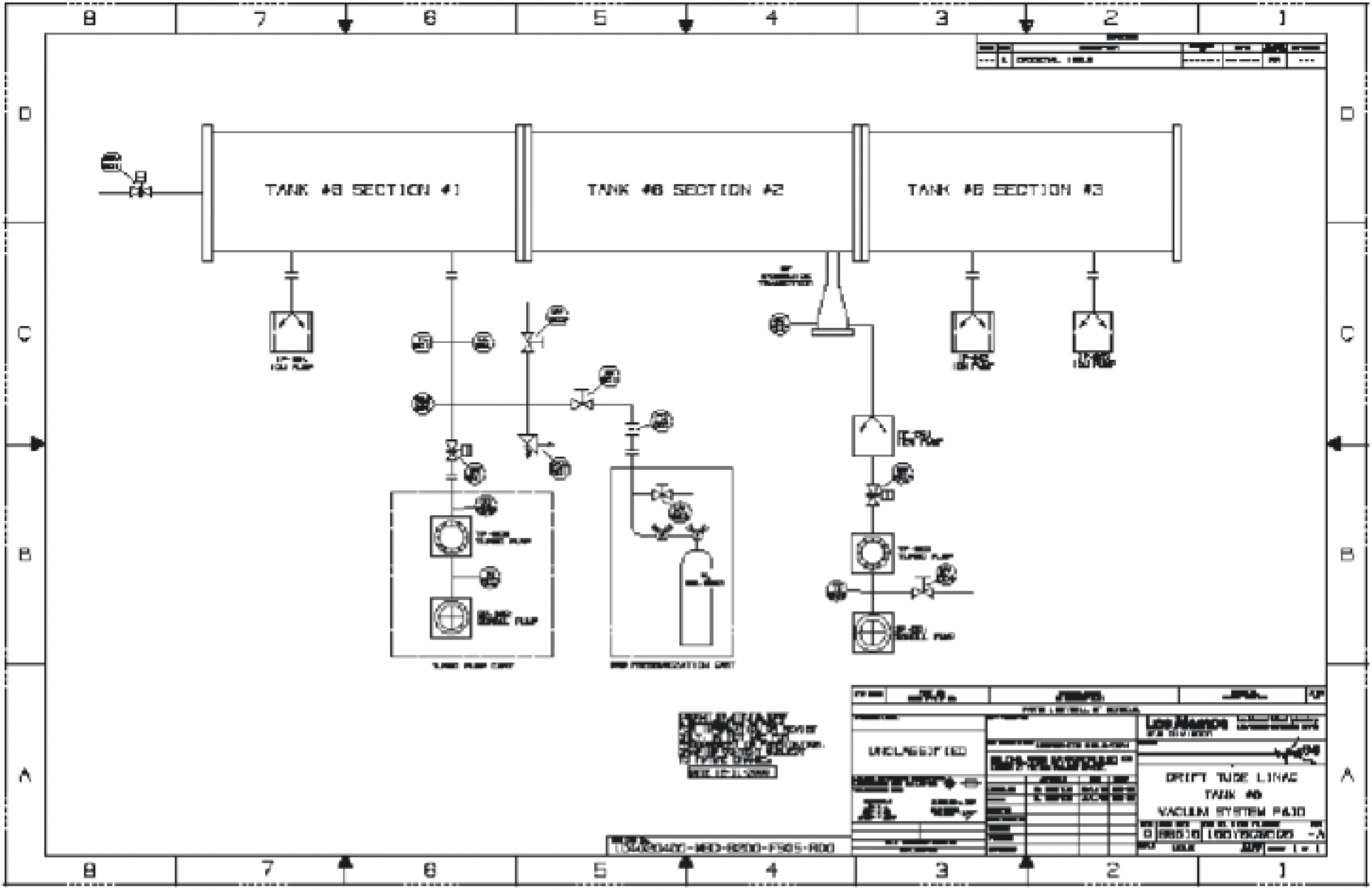
UNCLASSIFIED
Los Alamos
DRIFT TUBE LINAC
TANK #5
VACUUM SYSTEM P&ID


TANK #6 SECTION #1
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UNCLASSIFIED
DRIFT TUBE LINAC
TANK #6
VACUUM SYSTEM P&ID

## 16.0 Appendix D – Signal-Device Name List

# Device and Signal Name List for DTL Tank 1

12/11/00

| System/Subsystem | Device Name | Device | Manufacturer | Model # | Signal Type | Signal name | Location | Module info (PLC) | Cable/Pair | Comment |
|---|---|---|---|---|---|---|---|---|---|---|
| DTL_Vac1 | SP-102 | Scroll Pump | | | PLC Internal Logic | DTL_Vac1:SP-102:Cmd_str | | | | Ladder logic start pump command |
| DTL_Vac1 | SP-102 | Scroll Pump | | | PLC Internal Logic | DTL_Vac1:SP-102:Cmd_stp | | | | Ladder logic stop pump command |
| DTL_Vac1 | SP-102 | Scroll Pump | | | 24 vac | DTL_Vac1:SP-102:Ctl_run | Turbo cart | output | | Control - Start/stop pump |
| DTL_Vac1 | SP-102 | Scroll Pump | | | 24 vdc | DTL_Vac1:SP-102:Sts_aux | Turbo cart | input | | Run/Stop status |
| DTL_Vac1 | TP-102 | Turbo Pump | | | PLC Internal Logic | DTL_Vac1:TP-102:Cmd_str | | | | Ladder logic start pump command |
| DTL_Vac1 | TP-102 | Turbo Pump | | | PLC Internal Logic | DTL_Vac1:TP-102:Cmd_stp | | | | Ladder logic stop pump command |
| DTL_Vac1 | TP-102 | Turbo Pump | | | PLC Internal Logic | DTL_Vac1:TP-102:Cmd_nrm | | | | Ladder logic normal speed command |
| DTL_Vac1 | TP-102 | Turbo Pump | | | PLC Internal Logic | DTL_Vac1:TP-102:Cmd_ls | | | | Ladder logic low speed command |
| DTL_Vac1 | TP-102 | Turbo Pump | | | relay contact | DTL_Vac1:TP-102:Ctl_run | Turbo cart | output | | Control - start/stop pump |
| DTL_Vac1 | TP-102 | Turbo Pump | | | relay contact | DTL_Vac1:TP-102:Ctl_ls | Turbo cart | output | | Control - Normal/low speed |
| DTL_Vac1 | TP-102 | Turbo Pump | | | 24 vdc negative logic | DTL_Vac1:TP-102:Sts_run | Turbo cart | input | | Run/stop status |
| DTL_Vac1 | TP-102 | Turbo Pump | | | 24 vdc negative logic | DTL_Vac1:TP-102:Sts_ls | Turbo cart | input | | Normal/low speed status |
| DTL_Vac1 | TP-102 | Turbo Pump | | | 24 vdc negative logic | DTL_Vac1:TP-102:Fault | Turbo cart | input | | Normal/fault status |
| DTL_Vac1 | TP-102 | Turbo Pump | | | 24 vdc negative logic | DTL_Vac1:TP-102:Sp_01 | Turbo cart | input | | Operating speed setpoint 1 |
| DTL_Vac1 | TP-102 | Turbo Pump | | | 24 vdc negative logic | DTL_Vac1:TP-102:Sp_02 | Turbo cart | input | | Operating speed setpoint 2 |
| DTL_Vac1 | CC-103 | Cold Cathode Gauge | | | PLC Internal Logic | DTL_Vac1:CC-103:Cmd_on | | | | Ladder logic - gauge on command |
| DTL_Vac1 | CC-103 | Cold Cathode Gauge | | | PLC Internal Logic | DTL_Vac1:CC-103:Cmd_off | | | | Ladder logic - gauge off command |
| DTL_Vac1 | CC-103 | Cold Cathode Gauge | | | relay contact | DTL_Vac1:CC-103:Ctl_on | Turbo cart | output | | Control - CCG on/off |
| DTL_Vac1 | CC-103 | Cold Cathode Gauge | | | 0-10v analog | DTL_Vac1:CC-103:P | Turbo cart | input | | Logarithmic output proportional to pressure |
| DTL_Vac1 | CC-103 | Cold Cathode Gauge | | | 24 vdc | DTL_Vac1:CC-103:Sp_01 | Turbo cart | input | | Ion Gauge pressure setpoint 1 |
| DTL_Vac1 | TC-102 | Convectron | | | 0-10v analog | DTL_Vac1:TC-102:P | Turbo cart | input | | Foreline pressure, 10 milliTorr to 760 Torr |
| DTL_Vac1 | TC-102 | Convectron | | | 24 vdc | DTL_Vac1:TC-102:Sp_01 | Turbo cart | input | | Convectron pressure setpoint 1 |
| DTL_Vac1 | CC-101 | Cold Cathode Gauge | | | PLC Internal Logic | DTL_Vac1:CC-101:Cmd_on | | | | Ladder logic - gauge on command |
| DTL_Vac1 | CC-101 | Cold Cathode Gauge | | | PLC Internal Logic | DTL_Vac1:CC-101:Cmd_off | | | | Ladder logic - gauge off command |
| DTL_Vac1 | CC-101 | Cold Cathode Gauge | | | relay contact | DTL_Vac1:CC-101:Ctl_on | DTL Tank 1 Section 1 | output | | Control - CCG on/off |
| DTL_Vac1 | CC-101 | Cold Cathode Gauge | | | 0-10v analog | DTL_Vac1:CC-101:P | DTL Tank 1 Section 1 | input | | Logarithmic output proportional to pressure |
| DTL_Vac1 | CC-101 | Cold Cathode Gauge | | | 24 vdc | DTL_Vac1:CC-101:Sp_01 | DTL Tank 1 Section 1 | input | | Ion Gauge pressure setpoint 1 |
| DTL_Vac1 | TC-101 | Convectron | | | 0-10v analog | DTL_Vac1:TC-101:P | DTL Tank 1 Section 1 | input | | Foreline pressure, 10 milliTorr to 760 Torr |
| DTL_Vac1 | TC-101 | Convectron | | | 24 vdc | DTL_Vac1:TC-101:Sp_01 | DTL Tank 1 Section 1 | input | | Convectron pressure setpoint 1 |
| DTL_Vac1 | RGA-101 | Partial pressure analyzer | | | RS-232 | DTL_Vac1:RGA-101 | DTL Tank 1 Section 1 | | | Partial pressure analyzer |
| DTL_Vac1 | PSV-101 | Pressure Safety Valve | | | | | DTL Tank 1 Section 1 | | | Pressure relief for purge |
| DTL_Vac1 | MV-101 | Manual Valve | | | | | DTL Tank 1 Section 1 | | | Purge gas inlet valve |
| DTL_Vac1 | MV-102 | Manual Valve | | | | | DTL Tank 1 Section 1 | | | Vent valve to atmosphere |
| DTL_Vac1 | MV-103 | Manual Valve | | | | | Gas Press. Cart | | | Purge line vent valve to atmosphere |
| DTL_Vac1 | FO-101 | Flow Orifice | | | | | Gas Press. Cart | | | Flow restriction to prevent over-pressurization |
| DTL_Vac1 | GV-101 | Pneumatic Gate Valve | | | PLC Internal Logic | DTL_Vac1:GV-101:Cmd_opn | | | | Ladder logic open valve command |
| DTL_Vac1 | GV-101 | Pneumatic Gate Valve | | | PLC Internal Logic | DTL_Vac1:GV-101:Cmd_cls | | | | Ladder logic close valve command |
| DTL_Vac1 | GV-101 | Pneumatic Gate Valve | | | 24 vdc | DTL_Vac1:GV-101:Sol | DTL Tank 1 Section 1 | output | | Solenoid to Open/close valve |
| DTL_Vac1 | GV-101 | Pneumatic Gate Valve | | | 24 vdc | DTL_Vac1:GV-101:Pos0 | DTL Tank 1 Section 1 | input | | Position indicator |
| DTL_Vac1 | GV-101 | Pneumatic Gate Valve | | | 24 vdc | DTL_Vac1:GV-101:Pos1 | DTL Tank 1 Section 1 | input | | Position indicator |
| DTL_Vac1 | SGV-101 | Sector Gate Valve | | | PLC Internal Logic | DTL_Vac1:SGV-101:Cmd_opn | | | | Ladder logic open valve command |
| DTL_Vac1 | SGV-101 | Sector Gate Valve | | | PLC Internal Logic | DTL_Vac1:SGV-101:Cmd_cls | | | | Ladder logic close valve command |
| DTL_Vac1 | SGV-101 | Sector Gate Valve | | | 24 vdc | DTL_Vac1:SGV-101:Sol | DTL Tank 1 Section 1 | output | | Open/close valve |
| DTL_Vac1 | SGV-101 | Sector Gate Valve | | | 24 vdc | DTL_Vac1:SGV-101:Pos0 | DTL Tank 1 Section 1 | input | | Position indicator |
| DTL_Vac1 | SGV-101 | Sector Gate Valve | | | 24 vdc | DTL_Vac1:SGV-101:Pos1 | DTL Tank 1 Section 1 | input | | Position indicator |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | PLC Internal Logic | DTL_Vac1:IP-101:Cmd_str | | | | Ladder logic start pump command |
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | PLC Internal Logic | DTL_Vac1:IP-101:Cmd_stp | | | | Ladder logic stop pump command |
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-101:Ctl_HV | DTL Tank 1 Section 1 | output | | Control - Turn high voltage on/off |
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-101:Sts_HV | DTL Tank 1 Section 1 | input | | Status - High voltage on/off |
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-101:Sts_Prot | DTL Tank 1 Section 1 | input | | Start/protect status |
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-101:Fault | DTL Tank 1 Section 1 | input | | Normal/fault |
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | 0-10v analog in | DTL_Vac1:IP-101:V | DTL Tank 1 Section 1 | input | | Linear output from pump proportional to voltage |
| DTL_Vac1 | IP-101 | Ion pump 300 L/s | | | 0-5 analog in | DTL_Vac1:IP-101:I | DTL Tank 1 Section 1 | input | | Logarithmic output porportional to current |
| | | | | | | | | | | |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | PLC Internal Logic | DTL_Vac1:IP-102:Cmd_str | | | | Ladder logic start pump command |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | PLC Internal Logic | DTL_Vac1:IP-102:Cmd_stp | | | | Ladder logic stop pump command |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-102:Ctl_HV | DTL Tank 1 Section 2 | output | | Control - Turn high voltage on/off |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-102:Sts_HV | DTL Tank 1 Section 2 | input | | Status - High voltage on/off |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-102:Sts_Prot | DTL Tank 1 Section 2 | input | | Start/protect status |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-102:Fault | DTL Tank 1 Section 2 | input | | Normal/fault |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | 0-10v analog in | DTL_Vac1:IP-102:V | DTL Tank 1 Section 2 | input | | Linear output from pump proportional to voltage |
| DTL_Vac1 | IP-102 | Ion pump 300 L/s | | | 0-5 analog in | DTL_Vac1:IP-102:I | DTL Tank 1 Section 2 | input | | Logarithmic output proportional to current |
| | | | | | | | | | | |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | PLC Internal Logic | DTL_Vac1:IP-103:Cmd_str | | | | Ladder logic start pump command |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | PLC Internal Logic | DTL_Vac1:IP-103:Cmd_stp | | | | Ladder logic stop pump command |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-103:Ctl_HV | DTL Tank 1 Section 2 | output | | Control - Turn high voltage on/off |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-103:Sts_HV | DTL Tank 1 Section 2 | input | | Status - High voltage on/off |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-103:Sts_Prot | DTL Tank 1 Section 2 | input | | Start/protect status |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | 24 vdc | DTL_Vac1:IP-103:Fault | DTL Tank 1 Section 2 | input | | Normal/fault |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | 0-10v analog in | DTL_Vac1:IP-103:V | DTL Tank 1 Section 2 | input | | Linear output from pump proportional to voltage |
| DTL_Vac1 | IP-103 | Ion pump 300 L/s | | | 0-5 analog in | DTL_Vac1:IP-103:I | DTL Tank 1 Section 2 | input | | Logarithmic output proportional to current |
| | | | | | | | | | | |
| DTL_Vac1 | CC-102 | Cold Cathode Gauge | | | PLC Internal Logic | DTL_Vac1:CC-102:Cmd_on | | | | Ladder logic - gauge on command |
| DTL_Vac1 | CC-102 | Cold Cathode Gauge | | | PLC Internal Logic | DTL_Vac1:CC-102:Cmd_off | | | | Ladder logic - gauge off command |
| DTL_Vac1 | CC-102 | Cold Cathode Gauge | | | relay contact | DTL_Vac1:CC-102:Ctl_on | DTL 1 RF window | output | | Control - IG1 on/off |
| DTL_Vac1 | CC-102 | Cold Cathode Gauge | | | 0-10v analog in | DTL_Vac1:CC-102:P | DTL 1 RF window | input | | Logarithmic output proportional to pressure |
| DTL_Vac1 | CC-102 | Cold Cathode Gauge | | | 24 vdc | DTL_Vac1:CC-102:Sp_01 | DTL 1 RF window | input | | Gauge pressure setpoint 1 |
| | | | | | | | | | | |
| DTL_Vac1 | NP-101 | NEG pump | | | PLC Internal Logic | DTL_Vac1:NP-101:Cmd_Rgn_on | | | | Ladder logic start regen command |
| DTL_Vac1 | NP-101 | NEG pump | | | PLC Internal Logic | DTL_Vac1:NP-101:Cmd_Rgn_off | | | | Ladder logic stop regen command |
| DTL_Vac1 | NP-101 | NEG pump | | | 24 vdc | DTL_Vac1:NP-101:Ctl_rgn_on | DTL 1 RF window | output | | Control - start regen |
| DTL_Vac1 | NP-101 | NEG pump | | | 24 vdc | DTL_Vac1:NP-101:Ctl_rgn_off | DTL 1 RF window | output | | Control - stop regen |
| DTL_Vac1 | NP-101 | NEG pump | | | 24 vdc | DTL_Vac1:NP-101:Ctl_rgn_enb | DTL 1 RF window | output | | Control - regen enable |
| DTL_Vac1 | NP-101 | NEG pump | | | 24 vdc | DTL_Vac1:NP-101:Sts_temp | DTL 1 RF window | input | | Status - regen temperature alarm |
| DTL_Vac1 | NP-101 | NEG pump | | | 24 vdc | DTL_Vac1:NP-101:OI | DTL 1 RF window | input | | Status - regen power supply over-current alarm |
| DTL_Vac1 | NP-101 | NEG pump | | | 24 vdc | DTL_Vac1:NP-101:OT | DTL 1 RF window | input | | Status - regen power supply overtemp alarm |
| DTL_Vac1 | NP-101 | NEG pump | | | 24 vdc | DTL_Vac1:NP-101:Sts_inlk | DTL 1 RF window | input | | Status - regen interlock |
| DTL_Vac1 | NP-101 | NEG pump | | | 0-20mA analog out | DTL_Vac1:NP-101:Ctl_T | DTL 1 RF window | output | | Control - remote temperature setpoint |
| DTL_Vac1 | NP-101 | NEG pump | | | 4-20mA analog in | DTL_Vac1:NP-101:T | DTL 1 RF window | input | | NEG regen temperature |
| | | | | | | | | | | |
| DTL_Vac1 | TP-101 | Turbo pump | | | PLC Internal Logic | DTL_Vac1:TP-101:Cmd_str | | | | Ladder logic start pump command |
| DTL_Vac1 | TP-101 | Turbo pump | | | PLC Internal Logic | DTL_Vac1:TP-101:Cmd_stp | | | | Ladder logic stop pump command |
| DTL_Vac1 | TP-101 | Turbo pump | | | PLC Internal Logic | DTL_Vac1:TP-101:Cmd_nrm | | | | Ladder logic normal speed command |
| DTL_Vac1 | TP-101 | Turbo pump | | | PLC Internal Logic | DTL_Vac1:TP-101:Cmd_ls | | | | Ladder logic low speed command |
| DTL_Vac1 | TP-101 | Turbo pump | | | relay contact | DTL_Vac1:TP-101:Ctl_run | DTL 1 RF window | output | | Control - start/stop pump |
| DTL_Vac1 | TP-101 | Turbo pump | | | relay contact | DTL_Vac1:TP-101:Ctl_ls | DTL 1 RF window | output | | Control - Normal/low speed |
| DTL_Vac1 | TP-101 | Turbo pump | | | 24 vdc negative logic | DTL_Vac1:TP-101:Sts_run | DTL 1 RF window | input | | Run/stop status |
| DTL_Vac1 | TP-101 | Turbo pump | | | 24 vdc negative logic | DTL_Vac1:TP-101:Sts_ls | DTL 1 RF window | input | | Normal/low speed status |
| DTL_Vac1 | TP-101 | Turbo pump | | | 24 vdc negative logic | DTL_Vac1:TP-101:Fault | DTL 1 RF window | input | | Normal/fault status |
| DTL_Vac1 | TP-101 | Turbo pump | | | 24 vdc negative logic | DTL_Vac1:TP-101:Sp_01 | DTL 1 RF window | input | | Operating speed setpoint 1 |
| DTL_Vac1 | TP-101 | Turbo pump | | | 24 vdc negative logic | DTL_Vac1:TP-101:Sp_02 | DTL 1 RF window | input | | Operating speed setpoint 2 |
| | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DTL_Vac1 | GV-102 | Pneumatic Gate Valve | | | PLC Internal Logic | DTL_Vac1:GV-102:Cmd_opn | | | | Ladder logic open valve command |
| DTL_Vac1 | GV-102 | Pneumatic Gate Valve | | | PLC Internal Logic | DTL_Vac1:GV-102:Cmd_cls | | | | Ladder logic close valve command |
| DTL_Vac1 | GV-102 | Pneumatic Gate Valve | | | 24 vdc | DTL_Vac1:GV-102:Sol | DTL 1 RF window | output | | Solenoid to Open/close valve |
| DTL_Vac1 | GV-102 | Pneumatic Gate Valve | | | 24 vdc | DTL_Vac1:GV-102:Pos0 | DTL 1 RF window | input | | Position indicator |
| DTL_Vac1 | GV-102 | Pneumatic Gate Valve | | | 24 vdc | DTL_Vac1:GV-102:Pos1 | DTL 1 RF window | input | | Position indicator |
| | | | | | | | | | | |
| DTL_Vac1 | TC-103 | Convectron | | | 0-10v analog in | DTL_Vac1:TC-103:P | DTL 1 RF window | input | | Foreline pressure, 10 milliTorr to 760 Torr |
| DTL_Vac1 | TC-103 | Convectron | | | 24 vdc | DTL_Vac1:TC-103:Sp_01 | DTL 1 RF window | input | | Convectron pressure setpoint 1 |
| | | | | | | | | | | |
| DTL_Vac1 | MV-104 | Manual Valve | | | | | DTL 1 RF window | | | RF window vent valve to atmosphere |
| | | | | | | | | | | |
| DTL_Vac1 | SP-101 | Scroll Pump | | | PLC Internal Logic | DTL_Vac1:SP-101:Cmd_str | | | | Ladder logic start pump command |
| DTL_Vac1 | SP-101 | Scroll Pump | | | PLC Internal Logic | DTL_Vac1:SP-101:Cmd_stp | | | | Ladder logic stop pump command |
| DTL_Vac1 | SP-101 | Scroll Pump | | | 24 vac | DTL_Vac1:SP-101:Ctl_run | DTL 1 RF window | output | | Control - Start/stop pump |
| DTL_Vac1 | SP-101 | Scroll Pump | | | 24 vdc | DTL_Vac1:SP-101:Sts_aux | DTL 1 RF window | input | | Run/Stop status |
| | | | | | | | | | | |
| | | | | | | | | | | |
| **Totals DTL Tank #1 I/O** | | | | | | | | | | |
| relay output | | 7 channels | | | | | | | | |
| 24 vdc output | | 11 channels | | | | | | | | |
| 24 vdc input | | 28 channels | | | | | | | | |
| 24 vdc input negative logic | | 10 channels | | | | | | | | |
| analog input | | 14 channels | | | | | | | | |
| analog output | | 1 channel | | | | | | | | |
| | | | | | | | | | | |

## 17.0 Appendix E – Hardware Specification Sheets

## Preliminary Specification for Turbomolecular Pump Cart

**1.0 Scope**
The following preliminary specifications are based on the current (9/8/00) vacuum system design. This design uses four turbo pumps per CCL module (based on 6" diameter manifolds for the CCL) and one turbo pump per DTL tank during the initial pump down.

**2.0 Mechanical specifications/requirements**
The turbo pump cart shall be versatile enough to pump down both the CCL modules and the DTL tanks. Adequate space shall be provided during cart use to allow technicians access to the gate valve/cart interface; this space shall allow the use of standard tools to connect the cart to the gate valve flange. The cart shall be small enough to allow safe passage of personnel through the tunnel during cart use.

**2.1 Cart space constraints**
The cart space constraints are based on the support structure geometry, the turbo pump port locations, and vacuum system geometry. Other systems (e.g., cooling systems) are not included in the space constraints; hence, interference problems may still exist even if these space constraints are met. Figure 1 gives the space constraints for DTL access. Figure 2 gives the space constraints for CCL access.

Details describing a preliminary quote from Varian based on a modified version of their standard turbo cart are given in Appendix A.

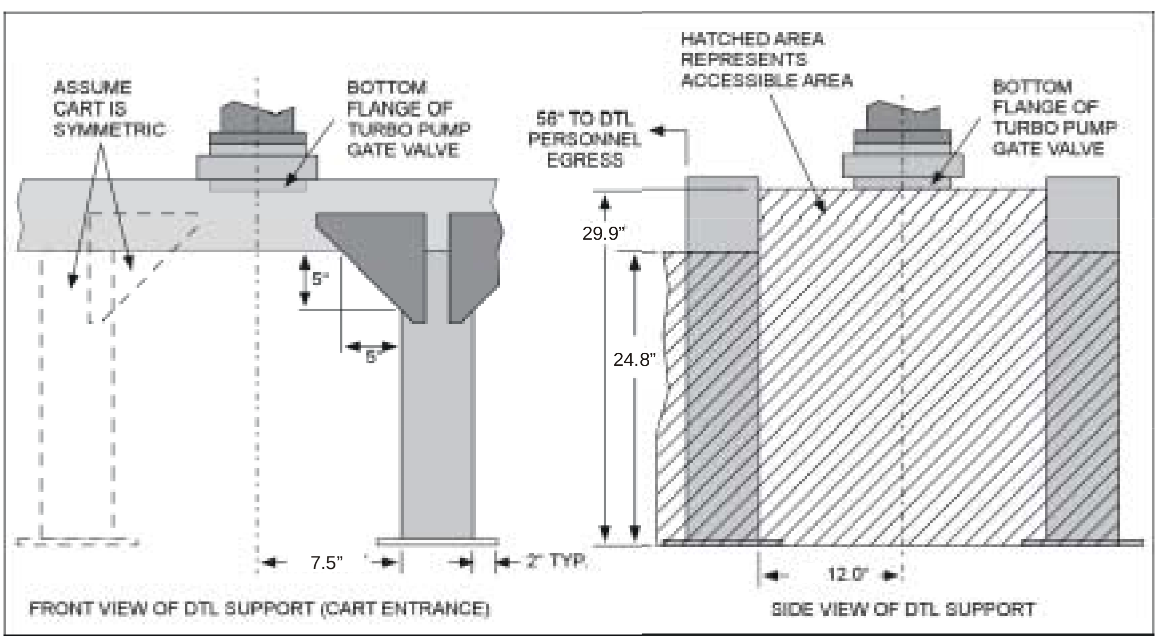



Figure 1: DTL space constraints

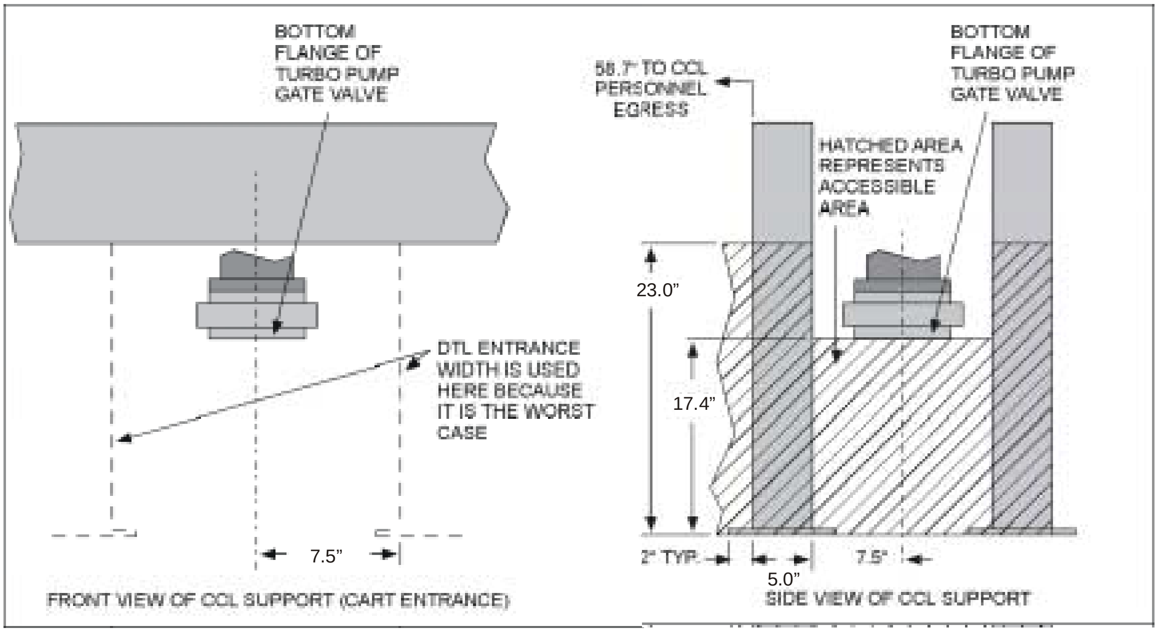



Figure 2: CCL space constraints

### 2.2 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the turbomolecular pump, primary pump, vacuum gauge, foreline and associated vacuum hardware shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

### 3.0 Primary (roughing) pump

The primary pump will be oil-free. The primary pump will have a pumping speed of 250 liters/minute while operating at 120 VAC and 60 Hz. The primary pump will have an ultimate base pressure below 10 milliTorr. The mean time between minor maintenance shall be 6000 hours or more. The mean time between major maintenance shall be 12,000 hours or more.

### 3.1 Primary pump controls

The Primary pump will have an approved (UL or CE) motor starter circuit. A remote normally open contact will control the start/stop function. A closed contact will start the primary pump. If the closed contact were to open, then the primary pump will stop. The motor starter will have an auxiliary contact that is open when the pump is stopped and closed when the pump is running. The motor starter will have a thermal overload that has a normally closed contact. If an overload condition occurs, the contact will open.

### 4.0 Low vacuum gauge

The turbo pump cart will have a low vacuum gauge mounted on the foreline between the turbo and the scroll pump. This gauge will measure the vacuum pressure by a combination of thermal conductivity and convection. The measurement range of the low vacuum gauge will be from 1000 Torr to $1x10^{-3}$ Torr.

## 4.1 High vacuum gauge

The turbo pump cart will have a high vacuum gauge mounted above the turbo. The high vacuum gauge will be an inverted magnetron cold cathode gauge. . The high vacuum gauge will have a 2.75" conflat flange. The measurement range of the high vacuum gauge will be from $1x10^{-3}$ Torr to $1x10^{-10}$ Torr.

A reducing tee with a 1.75" port will be mounted on the inlet of the turbo. The 1.75" port will have a 2.75" conflat flange. The high vacuum gauge will be mounted to this 2.75" conflat flange.

## 4.2 Vacuum gauge controller

The gauge controller will be able to read both the low and high vacuum gauges simultaneously and will have a local digital display where both pressures are shown. The gauge controller will have an adjustable setpoint for the pressure of each gauge. The setpoint will have a normally open contact that will close when the pressure goes below the setpoint. The gauge controller will have analog outputs each gauge. The analog outputs will be proportional to the pressure that each gauge is reading.

## 5.0 Turbomolecular pump

The turbomolecular pump will have a pump speed of at least 280 liters/second for nitrogen and 210 liters/second for hydrogen. The turbomolecular pump shall have a compression ratio of at least $2x10^8$ for nitrogen and $1x10^4$ for hydrogen. The turbomolecular pump will have an 8 inch "conflat" inlet flange. The turbomolecular pump will have ceramic bearings and will be able to operate in any orientation. The turbomolecular pump will have a throughput of at least 60 liters/second at 75 milliTorr for nitrogen. The turbomolecular pump will have a base pressure of $1.5x10^{-10}$ Torr when the foreline pressure is below 7.5 milliTorr.

The turbomolecular pump will have forced air cooling. Water-cooling is not acceptable. The turbomolecular pump will have an automatic fixed delay vent valve.

## 5.1 Turbomolecular pump controls

The turbomolecular pump will have a controller that can start and stop the pump by a remote contact. When the contact is closed the pump will start and when the contact opens the pump will stop.

The controller will have +24VDC outputs that indicate the status of the turbo pump. One output will indicate the turbomolecular pump is in the startup mode. During startup, the +24 VDC will be present on the output and will return back to 0 VDC once the pump has reached normal operation. One output will indicate that the RPMs of the turbomolecular pump are higher than a programmable setpoint. One output will indicate if there is a fault condition in the turbomolecular pump. The +24 VDC will be present on the output if there is a fault and will be 0 VDC if the pump is operating correctly.

See Figure 3 for a block diagram of the turbo cart.

## 6.0 Remote Control Interface

The various remote control signals discussed in sections 3.1, 4.0 and 5.1 will be available on a single panel mounted connector on the turbo cart. This connector shall be a multi-pin circular connector that meets military specification MIL-C-26482.

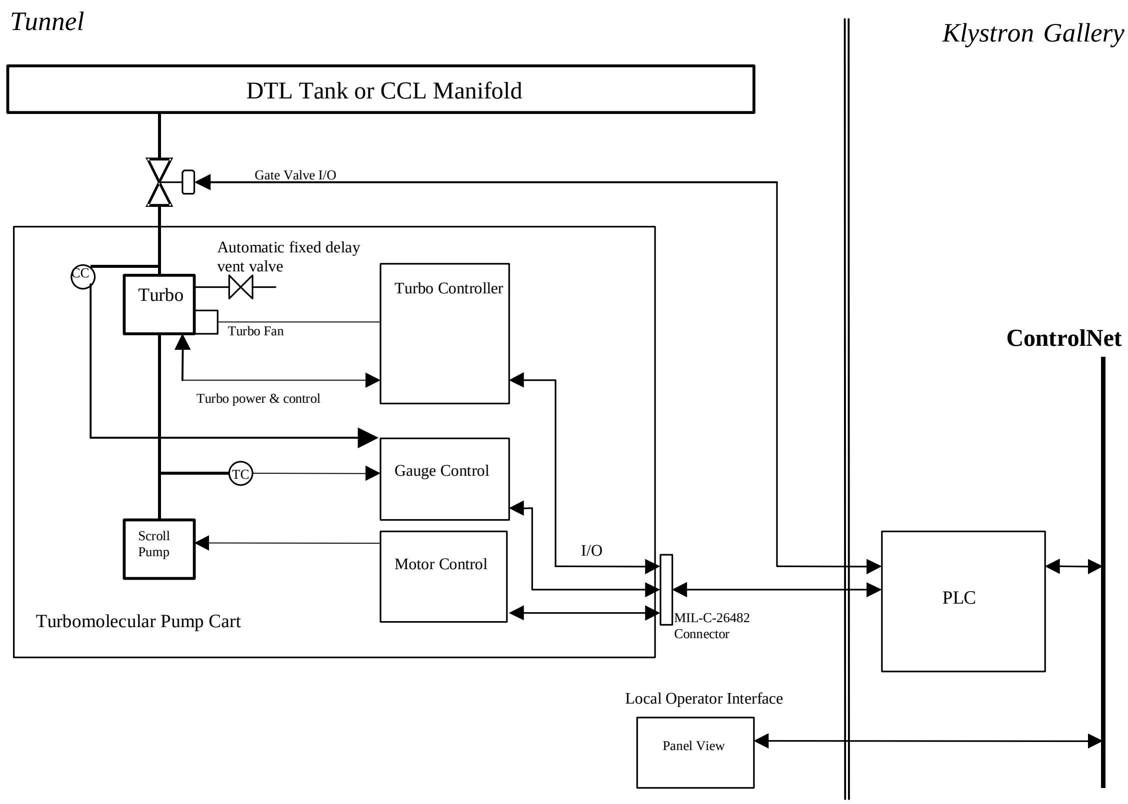



Figure 3. Block diagram of the turbo cart.

# Turbo cart quote from Varian

A preliminary cost estimate for a modified Varian turbo cart has been obtained. The cart design was modified to work with the most recent DTL/CCL geometric models available at that time. (Note: These are not the same as LANL's current CCL/DTL geometric models.) The modifications were designed based on the Varian T-series turbo cart (Model number MSPT9040/MSP1505 – 300 l/s turbo & 300 l/min dry scroll primary pump).

The standard T-series cart (Figure A-6) does not fit under the DTL or CCL support structures based on the Varian catalog dimensions and the geometric model of the support structures. Moreover, the DTL and CCL ports were are at different heights. Therefore, modifications to the standard cart are necessary.

Since the standard cart will not fit under the accelerator regardless of orientation, the preliminary specification proposed the simplest changes necessary to get the cart to work with both the DTL and CCL turbo ports.

Figure A-1 shows the modified turbo cart under the CCL structure. Figures A-2 and A-3 show the cart with the turbo pump in both the upper-most and lowermost positions. The range of motion satisfies the installation clearances for both the DTL and CCL configurations. Figure A-4 and A-5 give cart dimensions. Figure A-6 shows the cart in its original, unmodified state.

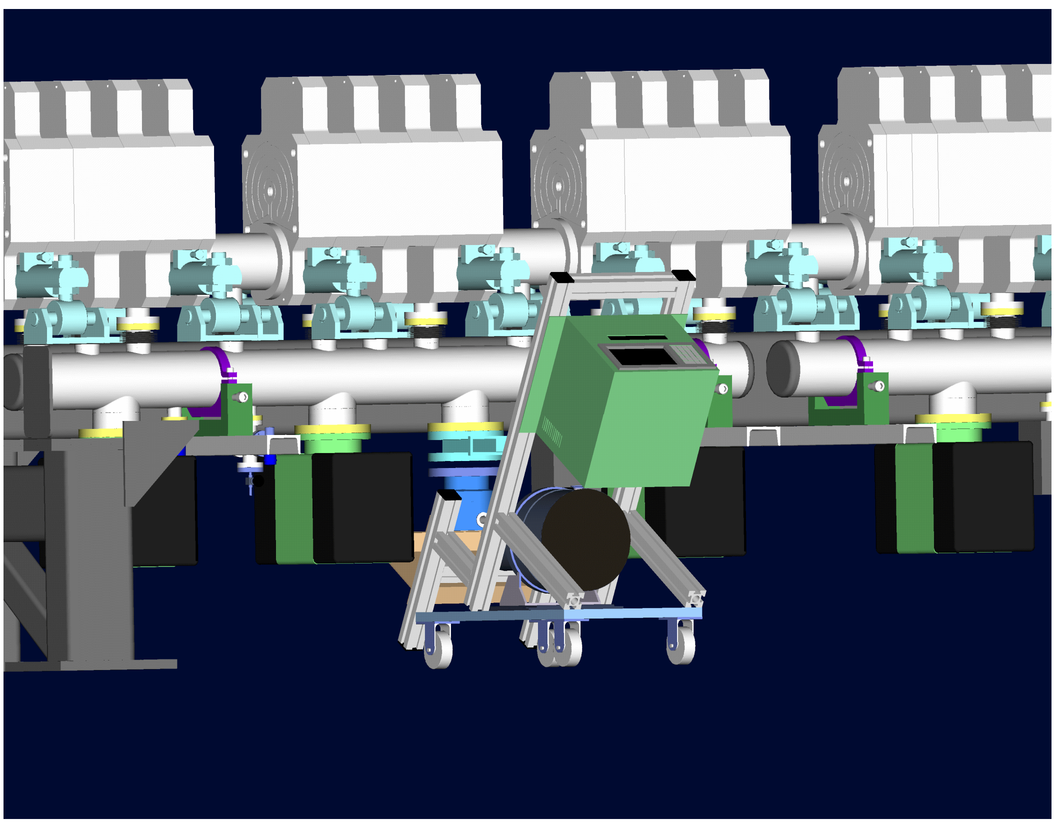


Figure A-1: Modified cart under the CCL structure

## Varian turbo cart cost estimate:

Description: Basic turbo cart (T-series turbo pumping cart) with a V300HT turbo pump with 8" CF connection, turbo pump controller and a Triscroll 300 primary pump. Note: the prices listed here are for a turbo pump cart without accessories. These prices do not include quantity discounts.

**Unmodified turbo cart:**

| | |
|---|---|
| Turbo pump & cart (MSPT9040) | $10,660 |
| Scroll pump (MSP0202) | $5,195 |
| TOTAL | $15,855 |

**Modified turbo cart:**

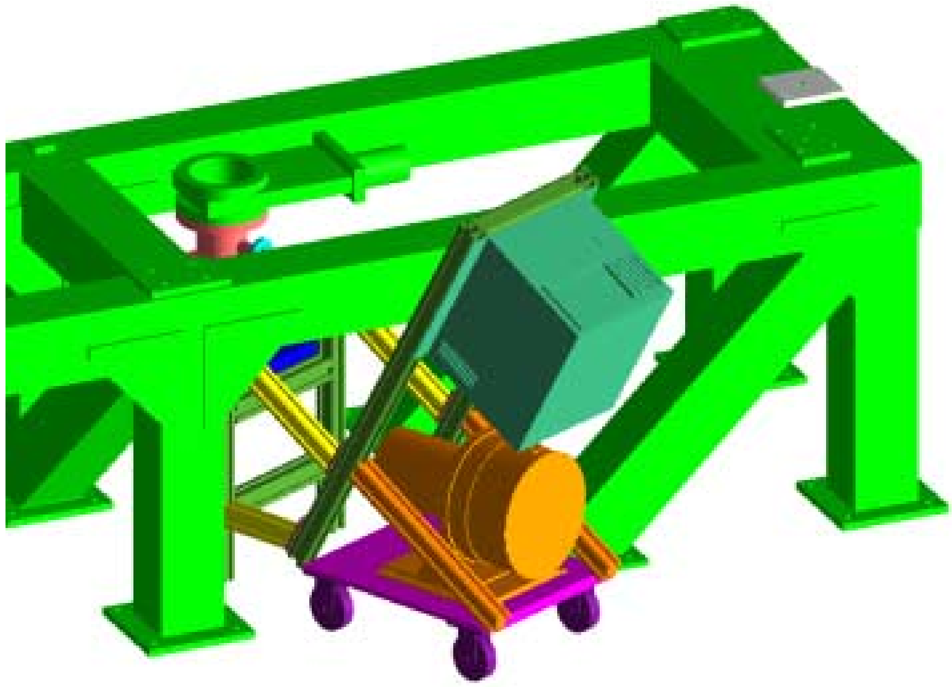
| | |
|---|---|
| Modified standard product (quote from Varian) | $16,589 |

**Pumps alone:**

| | |
|---|---|
| Turbo pump (V300HT) | $7,260 |
| Controller for turbo | $2,355 |
| Scroll pump (PTS03001) | $5,450 |
| TOTAL | $15,065 |

**Cart costs alone:**

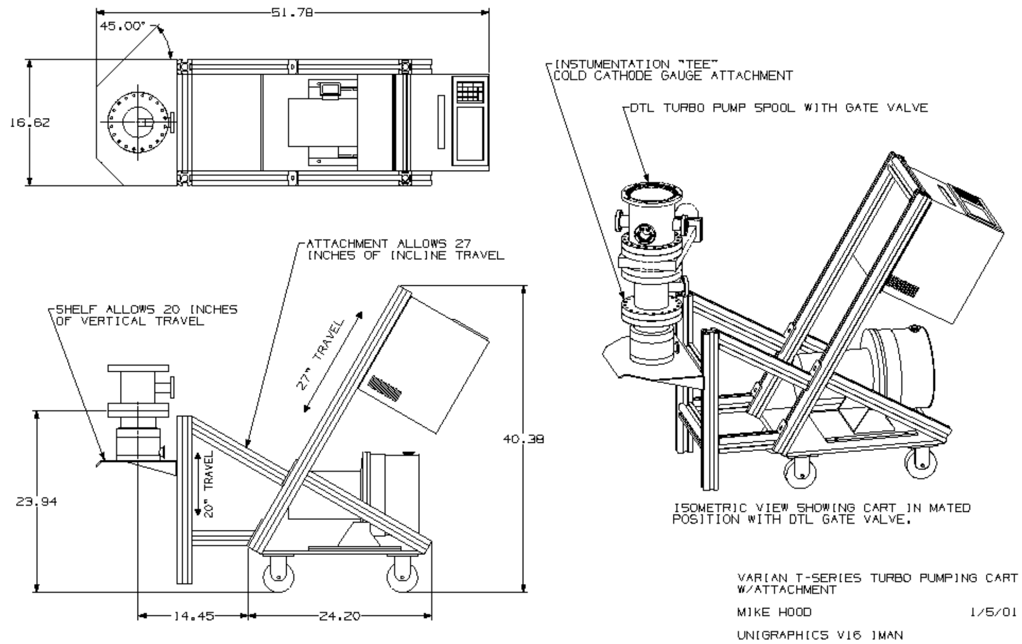
| | | |
|---|---|---|
| Unmodified: | $15,855-$15,065= | $790 |
| Modifications: | $16,589-$15,855= | $734 |
| TOTAL | | $1,524 |



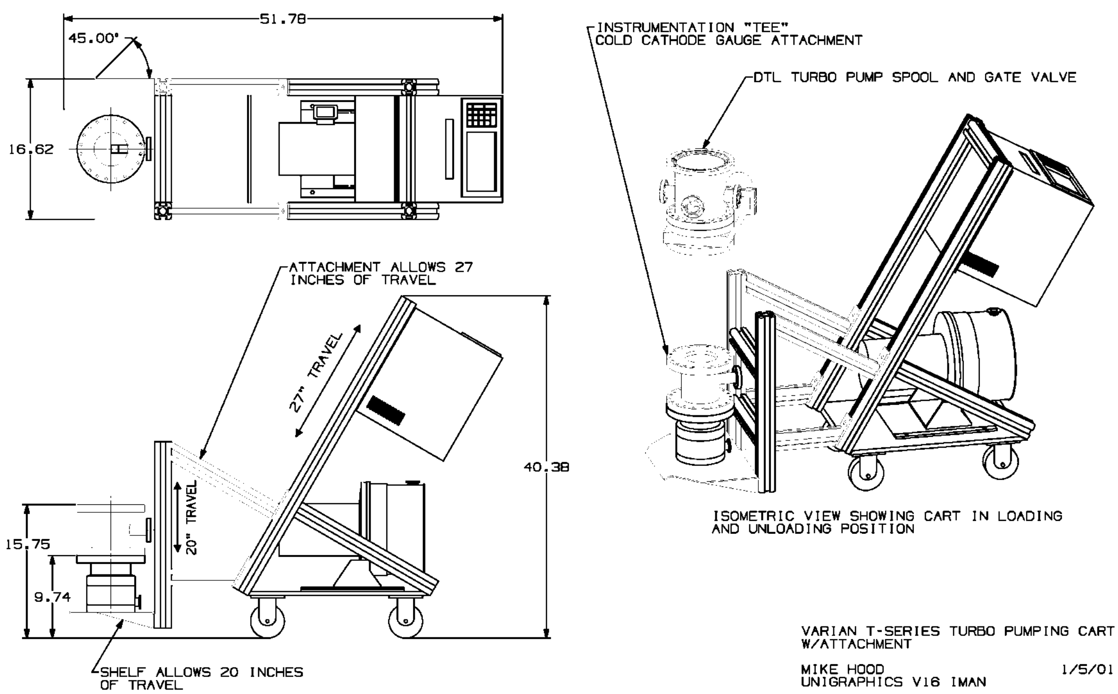
Appendix A-2: Varian Turbo Pumping Cart with support attachment in mated position with the DTL gate valve. Also shown is cart clearance under DTL support structure interference area.

Appendix A-3: Varian Turbo Cart with support attachment in mated position.

Appendix A-4  Varian Turbo Cart with support attachment in mobile position.




Appendix A-5: Detail drawing of Varian Turbo Cart with support attachment mated to the DTL spool and gate valve.




Appendix A-6: Detail drawing of Varian Turbo Cart with support attachment in moblile position.

Appendix A-7: Standard T-series turbo cart.

## Ion Pump Specification

**1.0 Scope**

The following specifications are based on the final DTL and CCL vacuum system designs. These designs uses ten 300 l/s ion pumps per CCL module (modules use 6" diameter vacuum manifolds) and three 300 l/s ion pumps per DTL tank.

**2.0 Mechanical specifications/requirements**

The same size ion pumps shall be used on both the CCL modules and the DTL tanks. Adequate space shall be provided during pump installation to allow technicians access to the ion pump ports; this space shall allow the use of standard tools to connect the pumps to their flanges. The ion pumps shall have a stainless steel case. The flange on the ion pumps shall be strong enough to support the weight of the pumps. The flanges shall be eight-inch non-rotatable CF flanges. The weight of each ion pump shall not exceed 160 pounds.

***2.1 Ion pump space constraints***

The ion pump space constraints are based on the support structure geometry, the ion pump port locations, and vacuum system geometry. The height of the ion pumps shall not exceed 17.0 inches. The width of the ion pumps shall not exceed 13.5 inches. The depth of the ion pumps shall not exceed 20.0 inches

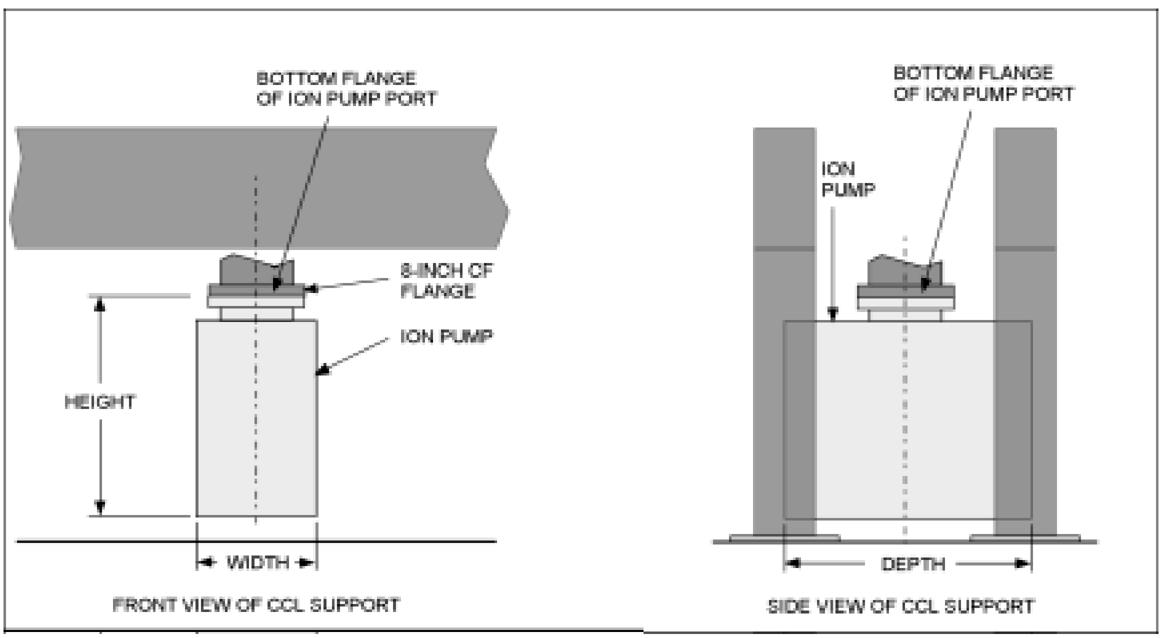



Figure 1: Ion pump dimensions

***2.2 Parts, Materials and Processes***

The parts, materials and processes used in the manufacturing of the ion pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source

Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

**3.0 Ion Pump Design and Performance**

The ion pump will be a diode configuration and have a pump speed of at least 300 liters/second for nitrogen at $1x10^{-6}$ Torr. The ion pump shall have a nominal operating life of 40,000 hours at $1x10^{-6}$ Torr.

The ion pump body shall have a leak rate less than $1x10^{-11}$ atm-cc/sec of helium. The ion pump shall have a base pressure below $2x10^{-10}$ Torr.

The cathode shall be operated at ground potential. The ion pump can operate in the range from 3500 to 7000 volts.

The pump shall be capable of withstanding a bakeout to 300º C with the magnets and high voltage connector in place. (The magnetic field strength or pump speed shall not degrade as a result of the 300º C bake.)

***3.1 Ion Pump Controller***

The ion pump controller output voltage shall be programmable from +3500 to +7000 volts and have an output of at least 100 watts. The ion pump controller output voltage shall have a ripple of less than 0.1%. The ion pump controller shall be able to measure the ion pump current from less than or equal to 100 nA to greater than or equal to 100 mA.

The ion pump controller shall have a remote control option. The remote control option shall have at least the following functions:

> The high voltage shall be turned on and off by a remote normally open contact closure. (When the remote contact closes the high voltage is turned on and when the contact closure opens the voltage is turned off.)
>
> A remote contact closure will select the start mode or protect mode. In the start mode the pump controller will provide its maximum current to start the ion pump at high pressure. In the protect mode the controller will shutdown the high voltage if the current exceeds a preset limit.
>
> The controller will have a normally open contact closure will indicate that the high voltage is off. When the high voltage is on, the contact will be closed.
>
> A setpoint contact closure provided. When the pump current goes below a preset limit, the setpoint contact closure will close.
>
> A normally closed contact will indicate that operating status of the pump. If there is a fault, then the contact closure will open.

A logarithmic analog output voltage that is proportional to the pump current will be provided.

## RF Window Turbomolecular Pump Specification

### 1.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the turbomolecular pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

### 2.0 Turbomolecular pump

#### *2.1 Pump Performance*

The turbomolecular pump shall have a pump speed of at least 65 liters/second for nitrogen and 45 liters/second for hydrogen. The turbomolecular pump shall have a compression ratio of at least $5x10^8$ for nitrogen and $1x10^4$ for hydrogen. The turbomolecular pump shall have a throughput of at least 10 liters/second when the pressure at the inlet to the pump is 75 milliTorr for nitrogen. The turbomolecular pump shall have a base pressure of $2x10^{-10}$ Torr when the foreline pressure is below 7.5 milliTorr.

#### *2.2 Physical Specifications*

The turbomolecular pump shall have a 4.5 inch "conflat" flange on its inlet port. The turbomolecular pump shall be able to operate in any orientation.

The bearings shall be lubricated with an ultra-low vapor pressure solid lubricant to prevent bearing lubricant hydrocarbons from backstreaming into the vacuum system.

The turbomolecular pump shall have forced air cooling. Water cooling is not acceptable.

#### *2.3 Pump Reliability*

The turbomolecular pump should have ceramic bearings for long life. The nominal Mean Time To Failure shall be at least 80,000 hours.

### 3.0 Turbomolecular pump controller

It is highly recommended that the turbomolecular pump controller be mircorprocessor based. The pump controller shall provide self-diagnostics and protection from accidental air vent, pump over-temperature or over-current.

The pump controller shall be able to operate the turbomolecular pump from distances up to 250 feet away.

The pump controller shall have an alphanumeric display on the front panel to indicate pump status and display error messages.

The pump controller shall operate on 120 VAC at 60 Hz and be CE and/or UL approved.

### *3.1 Remote Control Interface*

The pump controller shall have a remote control interface that can start and stop the pump by a remote contact closures. When the contact is closed the pump will start and when the contact opens the pump will stop.

The pump controller shall have +24VDC outputs that indicate the status of the turbo pump. One output will indicate the turbomolecular pump is in the startup mode. During startup, the +24 VDC will be present on the output and will return back to 0 VDC once the pump has reached normal operating speed. One output will indicate that the RPMs of the turbomolecular pump are higher than a programmable setpoint. One output will indicate if there is a fault condition in the turbomolecular pump or controller. The +24 VDC will be present on the output if there is a fault and will be 0 VDC if the pump and controller are operating correctly.

The various remote control signals discussed in sections 3.1 shall be available on panel mounted connectors on the rear of the controller. Separate connectors may be used for input and output functions.

# RF Window Primary (Scroll) Pump Specification

## 1.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the scroll pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

## 2.0 Primary Pump

### *2.1 Pump Performance*

The small primary pump shall be oil-free. The small primary pump shall have a pumping speed of 100 liters/minute while operating at 120 VAC and 60 Hz. The primary pump shall have an ultimate base pressure below 50 milliTorr.

### *2.2 Physical Specifications*

The primary pump shall use a NW25 connection at the pump inlet with a protective screen. The connection at the outlet shall be a NW16.

The primary pump shall be equipped with an automatic isolation valve. An internal timer shall open the valve 10 seconds after the pump has been started. In the event of power loss or when the pump is switched off, the isolation valve shall close immediately.

The primary pump shall be equipped with an automatic gas ballast system to help flush out water vapor, other condensable gases and particulates. The gas ballast port shall have a standard pipe thread so that a dry nitrogen line may be attached if the ambient humidity is too high.

The primary pump shall be air cooled. Water cooling is not acceptable. The primary pump shall be able to operate in an ambient temperature range of +5° to +40° C.

The primary pump motor shall operate on 120 VAC at 60 Hz and be CE and/or UL approved.

### *2.3 Pump Reliability*

The primary pump shall have teflon based tip seals for high reliability. When the base pressure is inadequate for backing the small turbo, the tip seals shall be easily field replaceable.

The mean time between maintenance shall be 9000 hours or more.

The primary pump motor shall automatic over-current and over-temperature protection.

## RF Window Non Evaporable Getter (NEG) Pump Specification

### 1.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the NEG pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

### 2.0 NEG pump

#### *2.1 Pump Performance*

The NEG pump will have a pump speed of at least 1000 liters/second for CO and 1300 liters/second for hydrogen. The NEG pump shall be constructed with sintered titanium-vanadium alloys and have a getter mass of at least 600 grams. The NEG pump shall have a capacity of at least 6000 Torr liters for hydrogen.

#### *2.2 Physical Specifications*

The NEG pump housing shall have a 4.5 inch "conflat" inlet flange. The pump housing shall have an internal heater for NEG activation or regeneration. The pump housing shall have an internal type "K" thermocouple to monitor the temperature during NEG activation or regeneration. The pump housing shall use ultra-high vacuum compatible electrical feedthroughs for the internal thermocouple and power for the heater.

#### *2.3 Pump Reliability*

Since NEG pumps are completely passive with no moving parts, there is no specification for Mean Time To Failure.

### 3.0 Activation/Regneration Power Supply/Controller

The NEG pump shall have a power supply/controller for activation/regeneration of the pump. The power supply/controller shall provide self-diagnostics and protection from pump heater over-temperature or over-current.

The pump controller shall be able to operate the NEG pump heater from distances up to 250 feet away.

The pump controller will have an alphanumeric display on the front panel to indicate pump activation or regeneration status and error messages.

The pump controller will operate on 120 VAC at 60 Hz and be CE and/or UL approved.

#### *3.1 Remote Control Interface*

The power supply/controller for activation/regeneration shall have a remote interface that can start and stop the heater power supply by a remote contact closures. When the contact is closed the power supply will be turned on and when the contact opens the power supply will be turned.

The power supply/controller shall accept a remote 0-20 milliAmpere analog signal for the activation/regeneration temperature setpoint. The activation/regeneration temperature shall be regulated to within $\pm 5^{\circ}$ C of the temperature requested by the remote analog setpoint input.

The power supply/controller shall provide a 4-20 milliAmpere analog output signal that represents the temperature read by the NEG pump housing internal thermocouple.

The power supply/controller will have a contact closure input, which will be used as an interlock. When an external contact is open, the power supply output to the NEG pump heater is disabled.

The power supply/controller will have contact closure outputs that indicate the status of the activation or regeneration. One output will indicate the NEG pump housing is over-temperature. One output will indicate the NEG pump housing internal heater is over-current. One output will indicate that the power supply output is disabled because the interlock is open.

The various remote control signals discussed in Section 3.1 will be available on panel mounted connections such as a terminal strip on the rear of the controller.

## Vacuum Valve Specifications

### 1.0 Scope

The following valve specifications are based on the final DTL and CCL vacuum system designs. The valves employed by the DTL and CCL consist of two principle types, those physically located along the beamline to isolate the accelerator sections, and located off-axis to isolate pump components from the accelarator elements. Technical specifications for four types of valves are given here. Specifically, specifications are provided for DTL beamline valves, CCL beamline valves, RF window turbo pump isolation valves, and turbo cart isolation valves.

### 2.0 Mechanical specifications/requirements

All vacuum isolation valves will utilize a gate design for sealing. Each component isolation valve may have a preferential installation orientation to minimize leak rates from the high pressure side to the vacuum side. If so, this orientation will be clearly marked on the valve body.

With the exception of the beam line valves, the same types of RF window turbo pump isolation valves and turbo cart isolation valves shall be used on both the CCL modules and the DTL tanks. The valve space constraints, material requirements, and methods of connection, are discussed below.

### 2.1 Valve space constraints

The valve space constraints are based on the support structure geometry, the valve port locations, and vacuum system geometry. (List valve space constraints and show figures here) The limiting valve space envelopes are summarized in Table 1.

### 2.2 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing of the valves shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00). The valves shall have a body formed from stainless steel (turbo isolation and CCL beamline) or aluminum (DTL beamline) and may contain either metal or polymer (Viton, Neoprene, or Buna are acceptable) seals for the valve seat and valve body connections.

The design feature requirements for the valves are given in Table 1. These features are driven by the design of the vacuum systems and RF structures.

Table 1. Design features/requirements for the DTL and CCL vacuum system isolation valves.

| Valve Type | Body Connection Type & Seal | Gate Seal | Limiting Space Envelope (H*W*T)(in*in*in) | Valve Power Failure Position | Representative Vendor/ Catalog # |
|---|---|---|---|---|---|
| DTL Beam Line | Insertable with Viton O-rings between DIN flanges | Viton O-ring | 12*6*1.6 | Closed | VAT / 08234-FA44 |
| CCL Beam Line | Welded connections to beam tube | Viton O-ring | 14*5*2 | Closed | MDC / 303010-01-03 (or similar with weld connections rather than conflat flanges) |
| RF Window Turbo Isolation | 4.5" Conflat flanges | Viton O-ring | 14*5*4 | Closed | MDC / 303002-01-03 |
| Turbo Cart Isolation | 8" Conflat flanges | Viton O-ring | 24*10*6 | Closed | MDC / 303006—01-03 |

**3.0 Valve Operation**

All valves shall be electropneumatic in their operation, capable of functioning from a 125 psig pressurized air source. Each valve will give an output signal by way of a contact closure to indicate the position of the valve. The electrical power requirements of all valves will be 24 VDC.

The beam line and turbo pump isolation valves shall fail in the closed position in the event of a power failure.

## Specification for Convection Gauge, Cold Cathode Gauge and Gauge Controller

**1.0 Scope**
The following specifications are based on the current (1/8/01) vacuum system design for the CCL modules and DTL tanks for the SNS normal conducting linac.

**2.0 Parts, Materials and Processes**
The parts, materials and processes used in the manufacturing of the vacuum gauges shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

**3.0 Low vacuum gauge**
The low vacuum gauge will measure the vacuum pressure by a combination of thermal conductivity and convection. The measurement range of the low vacuum gauge will be from 1000 Torr to $1x10^{-3}$ Torr, calibrated for nitrogen. The accuracy of the gauge must be at least $\pm$20%. The low vacuum gauge will be available with either a 2.75 inch conflat flange or a 1.33 inch mini-conflat flange.

**4.0 High vacuum gauge**
The high vacuum gauge will be an inverted magnetron cold cathode ion gauge. . The high vacuum gauge will have a 2.75" conflat flange. The measurement range of the high vacuum gauge will be from $1x10^{-3}$ Torr to $1x10^{-11}$ Torr, calibrated for nitrogen. The accuracy of the gauge must be at least $\pm$50%. The connector shall be a locking type high voltage connector such as SHV.

**5.0 Vacuum gauge controller**
The gauge controller will be able to read at least two low vacuum and two high vacuum gauges simultaneously and will have a local digital display where al least one low vacuum and one high vacuum gauge pressures are shown.

The gauge controller shall have a user accessible adjustment for each low vacuum gauge. There will be an adjustment for the maximum scale reading (atmoshpere) and the minimunm scale reading (less than $1x10^{-4}$ Torr).

The gauge controller will have an adjustable setpoint for the pressure of each gauge. The setpoint will have a normally open contact that will close when the pressure goes below the setpoint. The rating of the contact must be at least 30 vdc and 50 milliamps.

The gauge controller will have an analog output for each gauge. The analog outputs will be proportional to the pressure that each gauge is reading.

The controller will have +24VDC outputs that indicate the status of the high voltage for the high vacuum gauges.

The gauge controller will have a RS-485 serial communication port. The serial port shall communicate at a rate of at least 9600 baud. The serial port shall provide the latest pressure readings from all the gauges and access to all parameters that are available on the front panel.

## Specification for Residual Gas Analyzer

**1.0 Scope**

The following specifications are based on the current (1/8/01) vacuum system design for the CCL modules and DTL tanks for the SNS normal conducting linac. The residual gas analyzer (RGA) shall consist of a sensor unit, electronics control unit and the appropriate software to program the RGA and read its data.

**2.0 Parts, Materials and Processes**

The parts, materials and processes used in the manufacturing of the sensor unit of the RGA shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

**3.0 Sensor Unit**

The sensor unit will measure the partial pressure of gases of the vacuum system from 1 to 100 Atomic Mass Units (AMU). The maximum operating pressure of the sensor unit shall be at least $1 \times 10^{-4}$ Torr.

The minimum detectable partial pressure shall be $5 \times 10^{-11}$ Torr. The minimum sensitivity of the detector shall be at least $2 \times 10^{-4}$ Amps/Torr. The resolution shall be greater than 0.5 AMU at 10% peak height per American Vacuum Society (AVS) standard 2.3.

The sensor unit shall be mounted on a 2.75 inch conflat flange.

**4.0 Electronics Control Unit**

The electronics control unit shall contain all the necessary electronics to control the sensor unit and shall have the ability to be mounted remotely (approximately 100 ft) from the sensor unit. The electronics control unit shall be able to read the data from the sensor unit and process the data. The electronics control unit will monitor the status of the sensor unit and shut down the sensor if over-pressurized or if there is an error condition

The electronics control unit shall have a RS-232 serial communication port. The serial port shall communicate at a rate of at least 9600 baud. The serial port shall provide the latest partial pressure data that the electronics control unit has processed from the sensor unit. The serial port shall provide access to all the necessary programmable parameters of the sensor unit and provide up to date diagnostic information on the sensor unit and electronics control unit.

**5.0 Software**

The RGA shall be supplied with software that is compatible with Microsoft Windows NT version 4.0. The RGA software will communicate with the electronics control unit and provide an application environment to program all the necessary RGA parameters and read, display and store the RGA data. The RGA software will also read the sensor and electronics control unit diagnostics and inform the user of any problems.

The source code for the RGA software will be provided. SNS will port some sections of this code to run under EPICS.

## 18.0 Appendix F – Technical Note: Scroll Pump vs. Dry Piston Pump Operation

***Applied Research Engineering Division***
***Accelerator Technologies Engineering Group***

LLNL-ATEG-00-205
January 24, 2000

**Technical Note: Scroll Pump vs. Dry Piston Pump Operation**

Keith Kishiyama, Electrical Engineer, ATEG/LLNL

## 1.0 Pump specifications

The Varian Dry Scroll pump utilizes an orbiting scroll moving within a stationary scroll, forming crescent shaped pockets that progressively decrease in volume towards the center of the scrolls. As the volume decreases, gases are compressed and moved from inlet to exhaust. The seals on the vane tips of the orbiting scroll are PTFE-based and are oil-free. The scroll pump provides a very high pumping speed and a very good ultimate base pressure at reasonable cost. There are two models, one is rated at 20.5 cfm and the smaller one is rated at 10.6 cfm.

The VRC Dry Piston pump available through Kurt Lesker Co. operates with a high compression reciprocating piston that is also PTFE based with precision machined cylinder walls. There are two sizes in the standard models and two sizes in the soft start model. The standard models are rated at 28 cfm and 14 cfm. The soft start models offer programmable motor speed control. One feature of the soft start reduces the pumping speed in half when lower steady state gas loads are reached, thus extending the maintenance free period. The two soft start models are rated 10 cfm/5 cfm and 20 cfm/10 cfm.

A comparison of specifications from the vendor catalogs shows that in general, the scroll pump can reach a lower ultimate base pressure, but the single speed (standard) dry piston pump has greater pump speed. The soft start dry piston models operating at their normal speed have about the same pump speed as the scroll pumps. The catalog prices shows that the standard model 28 cfm dry piston costs 179% more than the 20.5 cfm scroll pump. The cost of a 20 cfm soft start dry piston is 193% more than the 20.5 cfm scroll pump. The standard 14 cfm dry piston costs 197% more than the 10.6 cfm scroll pump. The 10 cfm soft start dry piston costs 212% more than the10.6 cfm scroll pump.

One clarification of terminology must be made here; the statistics shown in both catalogs are not Mean Time Between Failure (MTBF). A more appropriate term should be Mean Time Between Maintenance (MTBM). The recommended maintenance schedule for the scroll pump is every 6,000 hours for a minor maintenance and 12,000 hours for a major maintenance. In general, LLNL has been performing only the major maintenance with very good reliability and performance from the pumps.

The standard speed dry piston states a maintenance free period of 10,000 hours. The soft start feature can extended the maintenance free period to between 25,000 to 30,000 hours depending on the vacuum system gas loads.

## 2.0 Pump operation

To obtain a "clean" vacuum system, it is absolutely essential that the pumps, valves and interlocks are correctly designed and operational procedures strictly followed. This discussion will focus on the apparent contamination of the forelines from backstreaming of condensed vapors and/or particulates from scroll pumps.

LLNL does not currently have any VRC dry piston pumps in operation and cannot comment directly on backstreaming from these pumps. However, it can be stated that any of these pumps if operated improperly, will backstream and that the VRC is not immune from this problem.

Since both these pumps are oil-free pumps, they do not have any fluids to flush out condensed vapors or accumulated particulates. Particulates will be generated as part of the normal operation of both pumps as the sealing surfaces move against each other. When backing a turbo at high vacuum, some natural flushing will occur in these pumps due to the throughput of gases pumped by the turbo. The amount of flushing obviously depends on the gas load that the turbo is pumping against.

VRC recommends a periodic purge of the dry piston pump to help flush out the condensed vapors and particulates. Older Varian scroll pumps were manufactured by Iwata Inc. and Varian also recommends a periodic purge for these pumps. Newer Varian Tri-scroll pumps have a gas ballast system near the center of the scrolls to automatically bleed air into the pump to help flush out the pump.

The particulates generated by the wear of the sealing surfaces in a scroll pump are not a problem under normal vacuum operations. The particulates generally do not migrate upstream against the decreasing volumes of the orbiting scroll. In the newer TriScroll pumps, the gas ballast system further reduces the probability of particulate migration by helping to flush particulates out of the pump and into the exhaust vent. In addition, the newer TriScroll pumps have a port available for a nitrogen purge in critical applications. In the older scroll pumps without the gas ballast or external periodic purge, the particulates will tend to accumulate in the pump near the exhaust port, but still can not backstream under normal vacuum operations as stated before. However, this accumulation could present a problem under abnormal vacuum conditions in a vacuum system without proper interlocks.

If the scroll pump is shut down by a power outage for example, but still remains open to the foreline, the vacuum in the foreline will cause backstreaming of the particulates into the foreline. Varian addresses this in a Product Information Bulletin #914S, "Isolation and Venting of TriScroll Pumps". Varian recommends an automatic isolation and venting valve (P/N VP25-120-50-60 for NW25) that isolates the scroll pump from the foreline during a loss of power and then vents the foreline at the inlet of the pump to prevent backstreaming.

## 3.0 LEDA Vacuum Systems Experience

There are four scroll pumps on the LEDA RFQ vacuum system. Two older model scroll pumps are used to regenerate the cryopumps and pump down the RFQ from atmosphere. Both operations are short term, high gas load operations and because of this high gas load, do not require a periodic purge and have never shown any contamination of the forelines.

The other two scroll pumps are the newer TriScroll pumps and back a total of six turbo pumps used for the regeneration of the NEGs on the RF windows. The turbos also operate full time to help pump the non-getterable gases in the RF window vacuum. The RF window vacuum system on the LEDA RFQ has been operational for over a year and there is no evidence of backstreaming of condensed vapors or particulates in the forelines of the RF window vacuum system.

The contamination in the LEDA power coupler test bed could have occurred during a period when the interlocks were disabled. It was observed that the interlocks were disabled on the power coupler test bed during one of the visits to LANL. Upon further investigation, it was found that one of the turbos had shut down due to an over temperature alarm. (It was later determined the turbo shutdown was due to a faulty bearing causing it to overheat.). It is unknown how long the interlocks had been disabled or how long the turbo had been shutdown. Also, during this time period the LEDA power coupler test bed had borrowed an older 610DS scroll pump since its TriScroll had been damaged due to a mis-wired electrical connection.

Since the interlocks were disabled, the gate valve that isolates the turbo from high vacuum did not close. Also, the foreline valve did not close and the still running scroll pump was then looking at high vacuum through the static turbo. This condition could have caused backstreaming of particulates and condensed vapors into the foreline. The worst case now would be to shutdown the vacuum system from this state, which would cause the high vacuum region to be vented to atmosphere through the stopped scroll pump. With the interlocks disabled, this condition could have occurred. This would most certainly guarantee backstreaming of particulates from the scroll pump.

**4.0 Conclusion and recommendation**

Both pumps if used properly in a properly designed vacuum system will provide for a "clean" vacuum system. In general, the roughing system should be designed with a foreline valve as close as practical to the pump to minimize the volume that will be vented when the pump is shut down. Proper interlocks are essential for the operation of a "clean" vacuum system. Interlocks should only be disabled by knowledgeable personnel who will be absolutely sure of the results. Any of these pumps (even the newer TriScroll) will backstream particulates and condensed vapors into the foreline if operated incorrectly.

The Mean Time Between Maintenance for the standard dry piston is roughly the same as the scroll pump. The additional cost of the soft start dry piston will extend the Mean Time Between Maintenance by a factor of 2.5 to 3.

The main factor in recommending a pump is to consider the requirements of vacuum system. For the SNS CCL, the scroll pumps will be used on carts to back turbos that will be used for the initial pumpdown of the linac and RF conditioning. Long term operation of the turbo cart will only be necessary in the very unusual failure mode where two ion pumps on a manifold are not operational since the CCL has redundant pumping for ion pumps. Therefore the Mean Time Between Maintenance is not the critical determining factor in which pump to recommend for the CCL.

The APT ED&D cryomodule vacuum system will utilize scroll pumps on turbo carts that will pump down the insulating vacuum. Once the insulating vacuum system is pumped down, then the cryomodule will be chilled down. When the cryomodule is cold, the turbo cart will removed since the system will cryopump itself. Because the scroll pump is not used for long term operation on the insulating vacuum the Mean Time Between Maintenance is not the critical determining factor.

The APT ED&D Cryomodule Power Coupler vacuum system will also use scroll pumps to back turbos. This design does call for continuous long-term operation of the scroll pump. However, to realize a reduced maintenance schedule over the scroll pump, a soft start dry piston pump would have to be specified. The initial purchase cost of the soft start dry piston pump is about twice the cost of a scroll pump, but does provide a Mean Time Between Maintenance that could be 2 to 2.5 times the scroll pump.

However, the cost of major maintenance for the scroll pump is approximately $1,400 for the 610DS scroll pump. The major maintenance kit is essentially a complete rebuilt pump head. There are five bolts that connect the head to the motor and it takes a technician 10 minutes to replace the head. The catalog price of the 610DS scroll pump is $8,250 and the catalog price of the cost of the 1201 soft start dry piston is $15,900. Therefore, the scroll pump must be operated at least five maintenance periods before the additional cost of the soft start dry piston pump is justified.

The maintenance period of the 610DS scroll pump is 12,000 hours, so five maintenance periods equals 60,000 hours. If we assume the maintenance period of the 1201 soft start dry piston pump is 30,000 hours, then the 610DS scroll pump can be operated for twice as long for the same cost as the 1201 soft start dry piston. The APT ED&D cryomodule program will be completed long before 30,000 operating hours are logged on the pumps, so it is doubtful whether the higher initial purchase cost of the soft start dry piston pump can be recovered during the life of the program.

Because the cost the scroll pumps are significantly less for comparable pump speed and ultimate base pressure, scroll pumps are still the recommended pumps.

## 19.0 Appendix G – Vacuum Handling and Cleaning Procedures

AW95-106130-00

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| MEL95-001817-00 |

**SPECIFICATIONS**

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE



| TITLE | WRITTEN BY / DATE |
|---|---|
| Welding of Stainless Steel Components for Ultra-High Vacuum Environment | Michael R. McDaniel 9/1/95 |
| | APPROVED-SPEC. & STDS.<br>N/A 12/4/95 |
| | APPROVED-DIVISION HEAD<br>[signature] 9/1/95 |

1. SCOPE

1.1 Purpose This specification defines the procedures for controlling the quality of material to be used and the welds to be made on stainless steel components subject to Ultra-High Vacuum (UHV) environment for Lawrence Livermore National Laboratory (LLNL). Extreme care is required in the design fabrication and assembly of said components. This specification is applicable to the welding of austenitic, chromium-nickel steels (ASTM 300 series) using gas metal arc welding (GMAW) and/or gas tungsten arc welding (GTAW) processes. This is a general specification and not all sections necessarily apply to all drawings which refer to this specification. Refer to section 5.0 for required documentation for LLNL information and approval.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue used shall be the one in effect on the date of request for quotation. Any conflicts between this specification and the referenced documents shall be brought to the attention of LLNL in writing for resolution before any action is taken by the seller.

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| | | CLASSIFICATION |
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| | | |
| REV. A BY | DATE | |

AAN 93-104962-0A

**SPECIFICATION** ENC-93-912-REV 01



UNIVERSITY OF CALIFORNIA

LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE

| TITLE | WRITTEN BY | DATE |
|---|---|---|
| Cleaning Copper and Copper alloys | C.P. Steffani | 9-1-1993 |
| | CHECKED BY J. W. Dini | 9-1-1993 |
| | APPROVED BY J.C. Whitehead | 9-1-1993 |

SEQUENCE

1. Remove all tape, inks, and other residue using Acetone and a clean cotton rag or paper wiper. Other solvents may be used as long as they are permitted for use in the shop and the requester is aware of the change.

2. Pressure wash using RELEASE D'GREASE @ 10 vol. % and 3-5 KSI setting.
*** FOR FRAGILE PARTS IMMERSE IN ACETONE OR BRULIN 815GD. For components having tubes, blind holes, and passageways cleaning/rinsing agents will be fed into these areas at low pressure.**

3. Spray water rinse.

4. Immerse in ENTHONE NS-35 non-silicated cleaner (30 gm/L @ 65 C) for a minimum of 10 minutes.

5. Spray water rinse until all traces of cleaner are removed. If water breaks are present repeat step 4.

6. Descale in 50 % vol. HCL.

7. Spray water rinse.

8. Acid dip in ENTHONE ACTANE 97 (10 gm/L "A", 12 gm/L "B" @ 25 C) until surface is clean and bright.

**SPECIFICATION**

UNIVERSITY OF CALIFORNIA

LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE

| TITLE | WRITTEN BY | DATE |
|---|---|---|
| Cleaning Stainless Steel Alloy Components | C.P. Steffani | 9-1-1993 |
| | CHECKED BY J. W. Dini | 9-1-1993 |
| | APPROVED BY J.C. Whitehead | 9-1-1993 |

**SEQUENCE**

1. Remove all tape, inks, and other residue using Acetone and a clean cotton rag or paper wiper. Other solvents may be used as long as they are permitted for use in the shop and the requester is aware of the change.

2. Pressure wash* using RELEASE D'GREASE @ 10 vol. % and 3-5 KSI setting.
*** FOR FRAGILE PARTS IMMERSE IN ACETONE OR BRULIN 815GD. For components having tubes, blind holes, and passageways cleaning/rinsing agents will be fed into these areas at low pressure.**

3. Immerse in ENTHONE NS-35 non-silicated cleaner (30 gm/L @ 65 C) for a minimum of 10 minutes.

4. Spray water rinse until all traces of cleaner are removed. If water breaks are present repeat step 2.

5. Acid pickle (50 % vol. $HNO_3$ = 5 % vol. HF @ 25C) for:
   A. 10 minutes or until all mill scale is removed.
   B. 30 seconds to remove all traces of alkaline film.

6. Spray water rinse. All but welds and blind holes should be given special attention to remove all traces of trapped chemicals. The air water aspirator can be used to help rinse these hard places. Ultrasonic rinsing in DI water can also remove trapped material.

7. Cold water rinse. ($2x10^6$ ohm resistivity). Resistivity is monitored and maintained by automatic additions of fresh DI water.

**SPECIFICATIONS**

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE



| TITLE | WRITTEN BY | DATE |
|---|---|---|
| Fabrication and Handling of Components for Ultra-High Vacuum Environment | Michael R. McDaniel | 9/1/95 |
| | APPROVED-SPEC. & STDS. N/A | 12/95 |
| | APPROVED-DIVISION HEAD [signature] | 9/1/95 |

1. SCOPE

1.1 Purpose This specification defines the procedures for controlling the cleaning and handling of material and components subject to Ultra-High Vacuum (UHV) environment for Lawrence Livermore National Laboratory (LLNL). Extreme care is required in obtaining clean components that will not produce contamination at the end use machine. This specification will cover machining and cleaning techniques required before, during and after fabrication of said components. This is a general specification and not all sections necessarily apply to all drawings which refer to this specification. Refer to section 5.0 for required documentation for LLNL information and approval.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue used shall be the one in effect on the date of request for quotation. Any conflicts between this specification and the referenced documents shall be brought to the attention of LLNL in writing for resolution before any action is taken by the seller.

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| REV. A BY | DATE | |

## 20.0 Appendix H – Vacuum Seal Lists for DTL Tanks 2-6

**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) |
|---|---|---|---|---|---|---|---|
| Endwalls | Vacuum | 4 | Viton | 18.00 | 0.188 | 45.720 | 0.476 |
| Endwalls | RF | 4 | silver plated inconel | 17.30 | 0.250 | 43.942 | 0.635 |
| Drift tube tank interface | RF / vacuum | 48 | silver plated inconel | 1.44 | 0.125 | 3.658 | 0.318 |
| 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 |
| vacuum spool pump interface | Vacuum | 4 | copper- conflat type | 6.00 | 0.250 | 15.240 | 0.635 |
| Iris waveguide tank interface | Vacuum | 1 | Viton | 19.25 | 0.125 | Not a diameter | 0.318 |
| Iris waveguide tank interface | RF | 2 | silver plated inconel | 6.75 | 0.125 | Not a diameter | 0.318 |
| Waveguide window | RF / vacuum | 1 | alum | 55.00 | 0.157 | Not a diameter | 0.399 |
| Vat series 08 gate valve | Vacuum | 2 | Viton | 3.50 | 0.125 | 8.890 | 0.318 |
| 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 | 107.451 | 1.14E-08 | 1.04E-10 | 1.22E-06 | 1.494E-07 | 5.497E-06 |
| Endwalls | 0.500 | 137.696 | 5.00E-10 | 3.70E-10 | 6.88E-08 | 5.108E-07 | 2.318E-06 |
| Drift tube tank interface | 0.500 | 5.731 | 5.00E-10 | 3.70E-10 | 2.87E-09 | 4.252E-08 | 2.178E-06 |
| Drift tube stem interface | 0.500 | 2.736 | 5.00E-10 | 3.70E-10 | 1.37E-09 | 4.060E-08 | 2.014E-06 |
| Drift tube lock screw | 0.500 | 0.563 | 5.00E-10 | 3.70E-10 | 2.82E-10 | 8.355E-09 | 4.146E-07 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Post couplers | 0.500 | 5.969 | 5.00E-10 | 3.70E-10 | 2.98E-09 | 4.429E-08 | 1.135E-06 |
| Post couplers | 0.500 | 2.217 | 1.14E-08 | 1.04E-10 | 2.53E-08 | 1.452E-08 | 9.551E-07 |
| Slug tuners | 0.500 | 7.284 | 1.14E-08 | 1.04E-10 | 8.30E-08 | 4.772E-08 | 1.569E-06 |
| Slug tuners | 0.500 | 18.406 | 5.00E-10 | 3.70E-10 | 9.20E-09 | 1.366E-07 | 1.749E-06 |
| vacuum spool tank interface | 0.500 | 7.917 | 1.14E-08 | 1.04E-10 | 9.03E-08 | 5.187E-08 | 5.685E-07 |
| vacuum spool tank interface | 0.500 | 36.951 | 5.00E-10 | 3.70E-10 | 1.85E-08 | 1.828E-07 | 8.049E-07 |
| 6" gate valve / turbo pump | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 3.831E-08 |
| vacuum spool pump interface | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 1.532E-07 |
| Iris waveguide tank interface | 0.500 | 24.385 | 1.14E-08 | 1.04E-10 | 2.78E-07 | 5.085E-08 | 3.288E-07 |
| Iris waveguide tank interface | 0.500 | 8.551 | 5.00E-10 | 3.70E-10 | 4.28E-09 | 6.344E-08 | 1.354E-07 |
| Waveguide window | 0.500 | 87.508 | 6.00E-10 | 2.00E-08 | 5.25E-08 | 2.794E-05 | 2.799E-05 |
| Vat series 08 gate valve | 0.500 | 4.434 | 1.14E-08 | 1.04E-10 | 5.05E-08 | 2.905E-08 | 1.592E-07 |
| Endwall to gate valve | 0.500 | 3.800 | 1.14E-08 | 1.04E-10 | 4.33E-08 | 2.490E-08 | 6.822E-08 |
| | | | | | | | 4.808E-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 |

**DTL tank 3**

**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) |
|---|---|---|---|---|---|---|---|
| Endwalls | Vacuum | 4 | Viton | 18.00 | 0.188 | 45.720 | 0.476 |
| Endwalls | RF | 4 | silver plated inconel | 17.30 | 0.250 | 43.942 | 0.635 |
| Drift tube tank interface | RF / vacuum | 34 | silver plated inconel | 1.44 | 0.125 | 3.658 | 0.318 |
| Drift tube stem interface | Vacuum | 34 | silver plated inconel | 1.38 | 0.063 | 3.493 | 0.159 |
| Drift tube lock screw | Vacuum | 34 | silver plated inconel | 0.28 | 0.063 | 0.719 | 0.159 |
| Post couplers | RF | 16 | silver plated inconel | 1.50 | 0.125 | 3.810 | 0.318 |
| Post couplers | Vacuum | 16 | 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 |
| Vacuum spool pump interface | Vacuum | 4 | copper- conflat type | 6.00 | 0.250 | 15.240 | 0.635 |
| Iris waveguide tank interface | Vacuum | 1 | Viton | 19.25 | 0.125 | Not a diameter | 0.318 |
| Iris waveguide tank interface | RF | 2 | silver plated inconel | 6.75 | 0.125 | Not a diameter | 0.318 |
| Waveguide window | RF / vacuum | 1 | alum | 55.00 | 0.157 | Not a diameter | 0.399 |
| Vat series 08 gate valve | Vacuum | 2 | Viton | 3.50 | 0.125 | 8.890 | 0.318 |
| 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 | 107.451 | 1.14E-08 | 1.04E-10 | 1.22E-06 | 1.494E-07 | 5.497E-06 |
| Endwalls | 0.500 | 137.696 | 5.00E-10 | 3.70E-10 | 6.88E-08 | 5.108E-07 | 2.318E-06 |
| Drift tube tank interface | 0.500 | 5.731 | 5.00E-10 | 3.70E-10 | 2.87E-09 | 4.252E-08 | 1.543E-06 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Drift tube stem interface | 0.500 | 2.736 | 5.00E-10 | 3.70E-10 | 1.37E-09 | 4.060E-08 | 1.427E-06 |
| Drift tube lock screw | 0.500 | 0.563 | 5.00E-10 | 3.70E-10 | 2.82E-10 | 8.355E-09 | 2.937E-07 |
| Post couplers | 0.500 | 5.969 | 5.00E-10 | 3.70E-10 | 2.98E-09 | 4.429E-08 | 7.563E-07 |
| Post couplers | 0.500 | 2.217 | 1.14E-08 | 1.04E-10 | 2.53E-08 | 1.452E-08 | 6.367E-07 |
| Slug tuners | 0.500 | 7.284 | 1.14E-08 | 1.04E-10 | 8.30E-08 | 4.772E-08 | 1.569E-06 |
| Slug tuners | 0.500 | 18.406 | 5.00E-10 | 3.70E-10 | 9.20E-09 | 1.366E-07 | 1.749E-06 |
| vacuum spool tank interface | 0.500 | 7.917 | 1.14E-08 | 1.04E-10 | 9.03E-08 | 5.187E-08 | 5.685E-07 |
| vacuum spool tank interface | 0.500 | 36.951 | 5.00E-10 | 3.70E-10 | 1.85E-08 | 1.828E-07 | 8.049E-07 |
| 6" gate valve / turbo pump | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 3.831E-08 |
| Vacuum spool pump interface | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 1.532E-07 |
| Iris waveguide tank interface | 0.500 | 24.385 | 1.14E-08 | 1.04E-10 | 2.78E-07 | 5.085E-08 | 3.288E-07 |
| Iris waveguide tank interface | 0.500 | 8.551 | 5.00E-10 | 3.70E-10 | 4.28E-09 | 6.344E-08 | 1.354E-07 |
| Waveguide window | 0.500 | 87.508 | 6.00E-10 | 2.00E-08 | 5.25E-08 | 2.794E-05 | 2.799E-05 |
| Vat series 08 gate valve | 0.500 | 4.434 | 1.14E-08 | 1.04E-10 | 5.05E-08 | 2.905E-08 | 1.592E-07 |
| Endwall to gate valve | 0.500 | 3.800 | 1.14E-08 | 1.04E-10 | 4.33E-08 | 2.490E-08 | 6.822E-08 |
| | | | | | | | 4.604E-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 | 0 | 0.000E+00 |
| | | 1.227E-06 |

**DTL tank 4**

**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) |
|---|---|---|---|---|---|---|---|
| Endwalls | Vacuum | 4 | Viton | 18.00 | 0.188 | 45.720 | 0.476 |
| Endwalls | RF | 4 | silver plated inconel | 17.30 | 0.250 | 43.942 | 0.635 |
| Drift tube tank interface | RF / vacuum | 28 | silver plated inconel | 1.44 | 0.125 | 3.658 | 0.318 |
| Drift tube stem interface | Vacuum | 28 | silver plated inconel | 1.38 | 0.063 | 3.493 | 0.159 |
| Drift tube lock screw | Vacuum | 28 | silver plated inconel | 0.28 | 0.063 | 0.719 | 0.159 |
| Post couplers | RF | 14 | silver plated inconel | 1.50 | 0.125 | 3.810 | 0.318 |
| Post couplers | Vacuum | 14 | 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 |
| vacuum spool pump interface | Vacuum | 4 | copper- conflat type | 6.00 | 0.250 | 15.240 | 0.635 |
| Iris waveguide tank interface | Vacuum | 1 | Viton | 19.25 | 0.125 | Not a diameter | 0.318 |
| Iris waveguide tank interface | RF | 2 | silver plated inconel | 6.75 | 0.125 | Not a diameter | 0.318 |
| Waveguide window | RF / vacuum | 1 | alum | 55.00 | 0.157 | Not a diameter | 0.399 |
| Vat series 08 gate valve | Vacuum | 2 | Viton | 3.50 | 0.125 | 8.890 | 0.318 |
| 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 | 107.451 | 1.14E-08 | 1.04E-10 | 1.22E-06 | 1.494E-07 | 5.497E-06 |
| Endwalls | 0.500 | 137.696 | 5.00E-10 | 3.70E-10 | 6.88E-08 | 5.108E-07 | 2.318E-06 |
| Drift tube tank interface | 0.500 | 5.731 | 5.00E-10 | 3.70E-10 | 2.87E-09 | 4.252E-08 | 1.271E-06 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Drift tube stem interface | 0.500 | 2.736 | 5.00E-10 | 3.70E-10 | 1.37E-09 | 4.060E-08 | 1.175E-06 |
| Drift tube lock screw | 0.500 | 0.563 | 5.00E-10 | 3.70E-10 | 2.82E-10 | 8.355E-09 | 2.418E-07 |
| Post couplers | 0.500 | 5.969 | 5.00E-10 | 3.70E-10 | 2.98E-09 | 4.429E-08 | 6.618E-07 |
| Post couplers | 0.500 | 2.217 | 1.14E-08 | 1.04E-10 | 2.53E-08 | 1.452E-08 | 5.571E-07 |
| Slug tuners | 0.500 | 7.284 | 1.14E-08 | 1.04E-10 | 8.30E-08 | 4.772E-08 | 1.569E-06 |
| Slug tuners | 0.500 | 18.406 | 5.00E-10 | 3.70E-10 | 9.20E-09 | 1.366E-07 | 1.749E-06 |
| Vacuum spool tank interface | 0.500 | 7.917 | 1.14E-08 | 1.04E-10 | 9.03E-08 | 5.187E-08 | 5.685E-07 |
| Vacuum spool tank interface | 0.500 | 36.951 | 5.00E-10 | 3.70E-10 | 1.85E-08 | 1.828E-07 | 8.049E-07 |
| 6" gate valve / turbo pump | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 3.831E-08 |
| vacuum spool pump interface | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 1.532E-07 |
| Iris waveguide tank interface | 0.500 | 24.385 | 1.14E-08 | 1.04E-10 | 2.78E-07 | 5.085E-08 | 3.288E-07 |
| Iris waveguide tank interface | 0.500 | 8.551 | 5.00E-10 | 3.70E-10 | 4.28E-09 | 6.344E-08 | 1.354E-07 |
| Waveguide window | 0.500 | 87.508 | 6.00E-10 | 2.00E-08 | 5.25E-08 | 2.794E-05 | 2.799E-05 |
| Vat series 08 gate valve | 0.500 | 4.434 | 1.14E-08 | 1.04E-10 | 5.05E-08 | 2.905E-08 | 1.592E-07 |
| Endwall to gate valve | 0.500 | 3.800 | 1.14E-08 | 1.04E-10 | 4.33E-08 | 2.490E-08 | 6.822E-08 |
| | | | | | | | 4.529E-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 | 0 | | | | | | 0.000E+00 |
| | | | | | | | 1.227E-06 |

**DTL tank 5**

**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) |
|---|---|---|---|---|---|---|---|
| Endwalls | Vacuum | 4 | Viton | 18.00 | 0.188 | 45.720 | 0.476 |
| Endwalls | RF | 4 | silver plated inconel | 17.30 | 0.250 | 43.942 | 0.635 |
| Drift tube tank interface | RF / vacuum | 24 | silver plated inconel | 1.44 | 0.125 | 3.658 | 0.318 |
| Drift tube stem interface | Vacuum | 24 | silver plated inconel | 1.38 | 0.063 | 3.493 | 0.159 |
| Drift tube lock screw | Vacuum | 24 | silver plated inconel | 0.28 | 0.063 | 0.719 | 0.159 |
| Post couplers | RF | 12 | silver plated inconel | 1.50 | 0.125 | 3.810 | 0.318 |
| Post couplers | Vacuum | 12 | 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 |
| vacuum spool pump interface | Vacuum | 4 | copper- conflat type | 6.00 | 0.250 | 15.240 | 0.635 |
| Iris waveguide tank interface | Vacuum | 1 | Viton | 19.25 | 0.125 | Not a diameter | 0.318 |
| Iris waveguide tank interface | RF | 2 | silver plated inconel | 6.75 | 0.125 | Not a diameter | 0.318 |
| Waveguide window | RF / vacuum | 1 | alum | 55.00 | 0.157 | Not a diameter | 0.399 |
| Vat series 08 gate valve | Vacuum | 2 | Viton | 3.50 | 0.125 | 8.890 | 0.318 |
| 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 | 107.451 | 1.14E-08 | 1.04E-10 | 1.22E-06 | 1.494E-07 | 5.497E-06 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Endwalls | 0.500 | 137.696 | 5.00E-10 | 3.70E-10 | 6.88E-08 | 5.108E-07 | 2.318E-06 |
| Drift tube tank interface | 0.500 | 5.731 | 5.00E-10 | 3.70E-10 | 2.87E-09 | 4.252E-08 | 1.089E-06 |
| Drift tube stem interface | 0.500 | 2.736 | 5.00E-10 | 3.70E-10 | 1.37E-09 | 4.060E-08 | 1.007E-06 |
| Drift tube lock screw | 0.500 | 0.563 | 5.00E-10 | 3.70E-10 | 2.82E-10 | 8.355E-09 | 2.073E-07 |
| Post couplers | 0.500 | 5.969 | 5.00E-10 | 3.70E-10 | 2.98E-09 | 4.429E-08 | 5.673E-07 |
| Post couplers | 0.500 | 2.217 | 1.14E-08 | 1.04E-10 | 2.53E-08 | 1.452E-08 | 4.775E-07 |
| Slug tuners | 0.500 | 7.284 | 1.14E-08 | 1.04E-10 | 8.30E-08 | 4.772E-08 | 1.569E-06 |
| Slug tuners | 0.500 | 18.406 | 5.00E-10 | 3.70E-10 | 9.20E-09 | 1.366E-07 | 1.749E-06 |
| vacuum spool tank interface | 0.500 | 7.917 | 1.14E-08 | 1.04E-10 | 9.03E-08 | 5.187E-08 | 5.685E-07 |
| vacuum spool tank interface | 0.500 | 36.951 | 5.00E-10 | 3.70E-10 | 1.85E-08 | 1.828E-07 | 8.049E-07 |
| 6" gate valve / turbo pump | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 3.831E-08 |
| vacuum spool pump interface | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 1.532E-07 |
| Iris waveguide tank interface | 0.500 | 24.385 | 1.14E-08 | 1.04E-10 | 2.78E-07 | 5.085E-08 | 3.288E-07 |
| Iris waveguide tank interface | 0.500 | 8.551 | 5.00E-10 | 3.70E-10 | 4.28E-09 | 6.344E-08 | 1.354E-07 |
| Waveguide window | 0.500 | 87.508 | 6.00E-10 | 2.00E-08 | 5.25E-08 | 2.794E-05 | 2.799E-05 |
| Vat series 08 gate valve | 0.500 | 4.434 | 1.14E-08 | 1.04E-10 | 5.05E-08 | 2.905E-08 | 1.592E-07 |
| Endwall to gate valve | 0.500 | 3.800 | 1.14E-08 | 1.04E-10 | 4.33E-08 | 2.490E-08 | 6.822E-08 |
| | | | | | | | 4.473E-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 | 0 | 0.000E+00 |
| | | 1.227E-06 |

**DTL tank 6**

**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) |
|---|---|---|---|---|---|---|---|
| Endwalls | Vacuum | 4 | Viton | 18.00 | 0.188 | 45.720 | 0.476 |
| Endwalls | RF | 4 | silver plated inconel | 17.30 | 0.250 | 43.942 | 0.635 |
| Drift tube tank interface | RF / vacuum | 22 | silver plated inconel | 1.44 | 0.125 | 3.658 | 0.318 |
| Drift tube stem interface | Vacuum | 22 | silver plated inconel | 1.38 | 0.063 | 3.493 | 0.159 |
| Drift tube lock screw | Vacuum | 22 | silver plated inconel | 0.28 | 0.063 | 0.719 | 0.159 |
| Post couplers | RF | 11 | silver plated inconel | 1.50 | 0.125 | 3.810 | 0.318 |
| Post couplers | Vacuum | 11 | 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 |
| Vacuum spool pump interface | Vacuum | 4 | copper- conflat type | 6.00 | 0.250 | 15.240 | 0.635 |
| Iris waveguide tank interface | Vacuum | 1 | Viton | 19.25 | 0.125 | Not a diameter | 0.318 |
| Iris waveguide tank interface | RF | 2 | silver plated inconel | 6.75 | 0.125 | Not a diameter | 0.318 |
| Waveguide window | RF / vacuum | 1 | alum | 55.00 | 0.157 | Not a diameter | 0.399 |
| Vat series 08 gate valve | Vacuum | 2 | Viton | 3.50 | 0.125 | 8.890 | 0.318 |
| 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 | 107.451 | 1.14E-08 | 1.04E-10 | 1.22E-06 | 1.494E-07 | 5.497E-06 |
| Endwalls | 0.500 | 137.696 | 5.00E-10 | 3.70E-10 | 6.88E-08 | 5.108E-07 | 2.318E-06 |
| Drift tube tank interface | 0.500 | 5.731 | 5.00E-10 | 3.70E-10 | 2.87E-09 | 4.252E-08 | 9.984E-07 |
| Drift tube stem interface | 0.500 | 2.736 | 5.00E-10 | 3.70E-10 | 1.37E-09 | 4.060E-08 | 9.232E-07 |

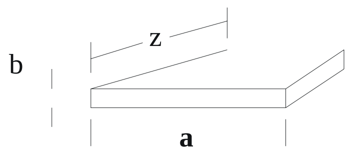
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Drift tube lock screw | 0.500 | 0.563 | 5.00E-10 | 3.70E-10 | 2.82E-10 | 8.355E-09 | 1.900E-07 |
| Post couplers | 0.500 | 5.969 | 5.00E-10 | 3.70E-10 | 2.98E-09 | 4.429E-08 | 5.200E-07 |
| Post couplers | 0.500 | 2.217 | 1.14E-08 | 1.04E-10 | 2.53E-08 | 1.452E-08 | 4.377E-07 |
| Slug tuners | 0.500 | 7.284 | 1.14E-08 | 1.04E-10 | 8.30E-08 | 4.772E-08 | 1.569E-06 |
| Slug tuners | 0.500 | 18.406 | 5.00E-10 | 3.70E-10 | 9.20E-09 | 1.366E-07 | 1.749E-06 |
| vacuum spool tank interface | 0.500 | 7.917 | 1.14E-08 | 1.04E-10 | 9.03E-08 | 5.187E-08 | 5.685E-07 |
| vacuum spool tank interface | 0.500 | 36.951 | 5.00E-10 | 3.70E-10 | 1.85E-08 | 1.828E-07 | 8.049E-07 |
| 6" gate valve / turbo pump | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 3.831E-08 |
| Vacuum spool pump interface | 0.500 | 30.402 | 1.26E-09 | 0.00E+00 | 3.83E-08 | 0.000E+00 | 1.532E-07 |
| Iris waveguide tank interface | 0.500 | 24.385 | 1.14E-08 | 1.04E-10 | 2.78E-07 | 5.085E-08 | 3.288E-07 |
| Iris waveguide tank interface | 0.500 | 8.551 | 5.00E-10 | 3.70E-10 | 4.28E-09 | 6.344E-08 | 1.354E-07 |
| Waveguide window | 0.500 | 87.508 | 6.00E-10 | 2.00E-08 | 5.25E-08 | 2.794E-05 | 2.799E-05 |
| Vat series 08 gate valve | 0.500 | 4.434 | 1.14E-08 | 1.04E-10 | 5.05E-08 | 2.905E-08 | 1.592E-07 |
| Endwall to gate valve | 0.500 | 3.800 | 1.14E-08 | 1.04E-10 | 4.33E-08 | 2.490E-08 | 6.822E-08 |
| | | | | | | | 4.445E-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 |

## 21.0 Appendix I – Vacuum Engineering Calculation Sheets

## *RF Attenuation for the DTL Ion Vacuum Pump System*

Calculate the RF field attenuation in the rectangular grill slots  This will be treated as a rectangular wave guide below cutoff.  The grill is made up of various length slots, but the longest slot lets the most energy through, so that is the one that will be modeled as the worst case.  A slot is shown below.




Field strength attenuates as $E := E_0 \cdot e^{-\alpha z}$

The essential grill dimensions in cm are:

$a := 5 \cdot 2.54$ $\quad a = 12.7$

$z := 0.84 \cdot 2.54$ $\quad z = 2.134$

For the dominate TE10 mode through the slot; the cutoff wavelength,$\lambda c$, is:

$\lambda_c := 2 \cdot a$ $\quad \lambda_c = 25.4$ cm

Calculate the wave length of the RF power in the DTL tank in cm

$$\lambda := \frac{\left(3 \cdot 10^{10}\right)}{201.25 \cdot 10^{6}} \qquad \lambda = 149.068 \text{ cm}$$

$\varepsilon_1 := 1.0$ for air

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

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

$\alpha_g = 2.118$

The attenuation through the grill is:

$$\alpha_g := \left[8.69 \sqrt{\left(2 \cdot \frac{\pi}{\lambda_c}\right)^2 - \varepsilon_1 \cdot \left(2 \cdot \frac{\pi}{\lambda}\right)^2}\right] \cdot z \qquad \alpha_g = 4.519 \text{ db}$$

The attenuation in the Ion Pump nipple (pipe) is:

Attenuation in the pipe (nipple) section, where D = diameter and L= Length. The length includes the spool, vacuum valve and the distance from the vacuum pump flange down to the pump.

$$D := 5.7 \cdot 2.54 \quad \text{cm}$$

$$L := 11.279 \cdot 2.54 \quad \text{cm}$$

The dominate mode in a circular waveguide is TE11 and the attenuation formula for that mode is, where $\alpha c$ stands for attenuation in a circular waveguide beyond cutoff:

$$\alpha_c := \left[ 8.69 \cdot \sqrt{\left( \frac{1.841}{\frac{D}{2}} \right)^2 - \left[ \frac{(2 \cdot \pi)}{\lambda} \right]^2} \right] \cdot L$$

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

$$\alpha_c = 62.438 \quad \text{db}$$

The total attenuation, in db, for the vacuum system is:

$$\alpha\_total := \alpha_g + \alpha_c$$

$$\alpha\_total = 66.958 \quad \text{db}$$

The peak RF power is 2.5 Mega Watts, but the duty factor is only 10%. So the average power is 250,000 watts. Calculate the power at the Ion Pump.

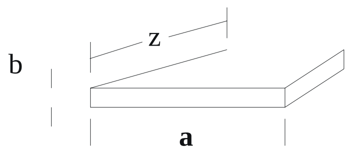
$$db := 10 \cdot \log\left( \frac{2.5 \cdot 10^5}{0.05} \right)$$

$db = 66.99$ close enough

So the power that reaches the Ion Pump is ***50 milliwatts.***

# *RF Attenuation for the DTL Turbo Vacuum Pump System*

Calculate the RF field attenuation in the rectangular grill slots  This will be treated as a rectangular wave guide below cut-off..  The grill is made up of various length slots, but the longest slot lets the most energy through, so that is the one that will be modeled as the worst case.




Field strength attenuates as $E := E_0 \cdot e^{-\alpha z}$

The essential grill dimensions in cm are:

$a := 5 \cdot 2.54 \qquad a = 12.7$

$z := 0.84 \cdot 2.54 \qquad z = 2.134$

For the dominate TE10 mode through the slot; the cut-off wavelength,λc, is:

$\lambda_c := 2 \cdot a \qquad \lambda_c = 25.4 \quad \text{cm}$

Calculate the wave length of the RF power in the DTL tank in cm

$$\lambda := \frac{\left(3 \cdot 10^{10}\right)}{201.25 \cdot 10^{6}} \qquad \lambda = 149.068 \text{ cm}$$

$\varepsilon_1 := 1.0$ for air

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

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

$\alpha_g = 2.118$

The attenuation through the grill is:

$$\alpha_g := \left[ 8.69 \sqrt{\left(2 \cdot \frac{\pi}{\lambda_c}\right)^2 - \varepsilon_1 \cdot \left(2 \cdot \frac{\pi}{\lambda}\right)^2} \right] \cdot z \qquad \alpha_g = 4.519 \quad \text{db}$$

The attenuation in the Ion Pump nipple (pipe) is:

Attenuation in the pipe (nipple) section, where D = diameter and L= Length. The length includes the spool, vacuum valve and the distance from the vacuum pump flange down to the pump.

$D := 5.7 \cdot 2.54$ cm

$L := 11.29 \cdot 2.54$ cm

The dominate mode in a circular waveguide is TE11 and the attenuation formula for that mode is, where $\alpha c$ stands for attenuation in a circular waveguide beyond cut-off:

$$\alpha_c := \left[ 8.69 \cdot \sqrt{\left(\frac{1.841}{\frac{D}{2}}\right)^2 - \left[\frac{(2 \cdot \pi)}{\lambda}\right]^2} \right] \cdot L$$

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

$\alpha_c = 62.499$ db

The total attenuation, in db, for the vacuum system is:

$\alpha\_total := \alpha_g + \alpha_c$

$\alpha\_total = 67.019$ db

The peak RF power is 2.5 Mega Watts, but the duty factor is only 10%. So the average power is 250,000 watts. Calculate the power at the turbo Pump.

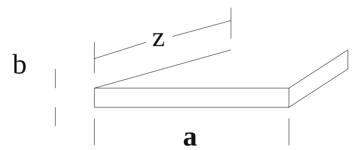
$$P_{db} := 10 \cdot \log\left(\frac{2.5 \cdot 10^5}{0.049}\right)$$

$P_{db} = 67.077$ close enough

So the power that reaches the Ion Pump is ***49 milliwatts.***

# *RF Attenuation for the DTL Window Vacuum Pump System*

Calculate the RF field attenuation in the rectangular grill slots  This will be treated as a rectangular wave guide below cut-off..  The grill is made up of various length slots, but the longest slot lets the most energy through, so that is the one that will be modeled as the worst case.




Field strength attenuates as $E := E_0 \cdot e^{-\alpha z}$

The essential grill dimensions in cm are:

$$a := 1.688 \cdot 2.54$$

$$z := 0.25 \cdot 2.54$$

For the dominate TE10 mode in a rectangular waveguide, the cut-off wavelength $\lambda c$, is:

$$\lambda_c := 2 \cdot a \qquad \lambda_c = 8.575$$

Calculate the wave length of the RF power in the waveguide in cm

$$\lambda := \frac{\left(3 \cdot 10^{10}\right)}{201.25 \cdot 10^{6}} \qquad \lambda = 149.068 \text{ cm}$$

$\varepsilon_1 := 1.0$ for air

The attenuation through the grill is:

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

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

$$\alpha_g = 4.037 \quad \text{db}$$

Attenuation in the small pipe (nipple) section, where D = diameter and L= Length

$$D_s := 3.844 \cdot 2.54$$

$$L_s := 3.2 \cdot 2.54$$

The dominate mode in a circular waveguide is TE11 and the attenuation formula for that mode is, where $\alpha$c stands for attenuation, circular:

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

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

$\alpha_{cs} = 26.469$ db

Attenuation in the large pipe (nipple) section, where D = diameter and L= Length

$D_l := 5.76 \cdot 2.54$

$L_l := 5.743 \cdot 2.54$

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

$\alpha_{cl} = 47.504$ db

The total attenuation, in db, for the vacuum system is:

$\alpha\_total := \alpha_g + \alpha_{cs} + \alpha_{cl}$

$\alpha\_total = 78.01$ db

This gives the following power levels at the beginning of the NEG pump cartridge (closest to the window grill):

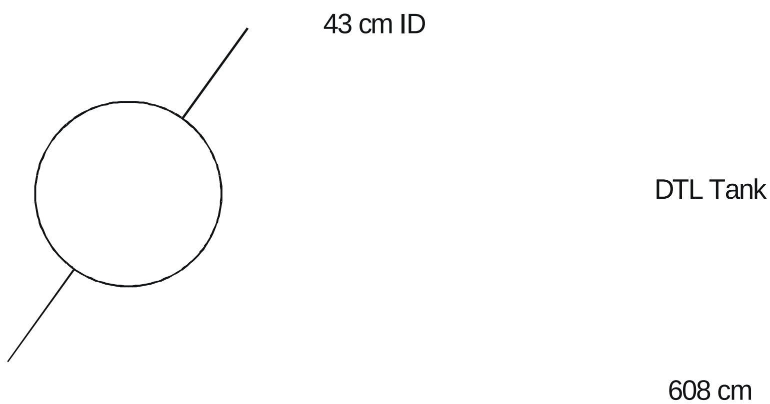
The peak RF power is 2.5 Mega Watts, but the duty factor is only 10%. So the average power is 250,000 watts. Calculate the power at the NEG Pump.

$$db := 10 \cdot \log\left( \frac{2.5 \cdot 10^5}{.0039} \right)$$

$db = 78.069$ close enough

So the power that reaches the Ion Pump is ***4 milliwatts.***

**DTL tank back fill with dry N2 pressurization. Calculate the hole size in a Restrictive Flow Orifice Device to restrict the flow rate to a safe value. (Note, DTL tanks are isolated by vacuum valves in groups of 2.)**




Using Roger Shrouf's Sandia National Laboratory's paper "Gas Flow Characterization of Restrictive Flow Orifices Devices" (SANDIA97-1670), a 0.020 inch diameter hole in the restrictive flow orifice in the gas line is needed to keep the flow rate to no greater than 13.5 scfm.


Restrictive Flow Orifice - Not to scale

Assumptions

Keep the gas back fill flow rate low to be sure the DTL tank isn't over pressurized. A CTI Cryogenics Pressure Relief Valve (PRV) or equivalent is used, with a 1 inch line. This PRV can stand a 13.5 scfm flow rate and not exceed 2 psi. Therefore, use the 13.5 scfm back fill flow rate.

A standard N2 gas bottle holds 220 standard cubic feet of gas and has a pressure of 2,000 to 2,200 psig. (I called the gas facility and got this information.)

Calculate the internal volume of the largest DTL tank

$$ID := 43cm$$

$$Length := 608cm$$

$$Volume := 2\left(\pi\cdot\frac{ID^2}{4}\right)\cdot Length$$ Volume of two tanks.

$$Volume = 62.361ft^3$$

$$P1 := 2200\cdot psi$$

$$V1 := 220\cdot ft^3$$

$$V2 := 220\cdot ft^3 - Volume$$

$$V2 = 157.639ft^3$$ Cubic feet of gas left in the nitrogen bottle after back filling 2 DTL tanks at once, which will be the general case.

Calculate the approximate pressure in a new N2 bottle after 2 DTL tanks are pressurized to, not greater then 2 psig. I am doing this to see what the average flow rate into the tanks will be after 2 DTL tanks are back filled with dry N2.

$$P2 := \left(\frac{V2}{V1}\right)\cdot P1$$

$$P2 = 1.576\times 10^3 psi$$ At this pressure, the flow rate will average to about 11 scfm. However, if the gas bottle isn't refilled, it will take longer to back fill another set of DTL tanks.

$$Q_{ave} := 11\frac{ft^3}{min}$$

$$Back\_fill\_time := \frac{Volume}{Q_{ave}}$$

$$Back\_fill\_time = 5.669min$$

# DTL RF window pumping calculations for vacuum grill slot, in molecular flow region

**I did not include the window and waveguide area calculations in this paper:** ***The details of this particular calculation are not given in this paper.***

$a1 := 711.3\ cm^2$ a1 is the outgas area of the window

$a2 := 4701\ \ cm^2$ a2 is the outgas area of the waveguide

$q1 := \left(5 \cdot 10^{-8}\right)$ This is the expected outgas rate of the unconditioned window in (torr-liters)/sec.

$q2 := \left(1 \cdot 10^{-10}\right) \quad torr - \frac{liter}{sec}$

$steady\_state\_pressure := 1.0 \cdot 10^{-7}\ torr$

$Q := \frac{(a1 \cdot q1 + a2 \cdot q2)}{steady\_state\_pressure}$ $\qquad a1 \cdot q1 + a2 \cdot q2 = 3.604 \times 10^{-5}\ \frac{(torr - liters)}{sec}$

$Q = 360.351\ \frac{liter}{sec}$

$grill\_diam := 9.8425$

$slot\_width := 0.3175$

$grill\_thick := 0.635$

$average\_slot\_length := 3.215$

$slots\_per\_grill := 38$

## Calculate the grill conductance using the formulas from the books "Roth" and "Vacuum Engineering Calculations." Both books use the same formula.

$$c\_grill\_roth := 30.9 \cdot \left(average\_slot\_length^{2} \cdot slot\_width^{2}\right) \cdot \frac{1.297}{[(average\_slot\_length + slot\_width) \cdot grill\_thick]}$$

$c\_grill\_roth = 18.616\ \frac{liters}{sec \cdot slot}$

$total\_c\_grill\_roth := (c\_grill\_roth) \cdot (slots\_per\_grill)$

$total\_c\_grill\_roth = 707.417\ \frac{liters}{sec}$ Total conductance of the grill

## Select a NEG pump size

$$pump := 1370 \ \frac{liters}{sec}$$ This pump size includes the turbo as well as the NEG pump.

## Calculate the effective pumping speed from the vacuum RF grill to the pump.

The tube size of A in centermeters is:

$$A\_diam := 9.843 \qquad A\_length := 7.62$$

The conductance of tube A is:

$$con\_A := 12.12 \cdot \frac{A\_diam^3}{A\_length + \frac{4}{3} \cdot A\_diam} \ \frac{liters}{sec}$$

The tube size of B in centermeters is:

$$B\_diam := 14.63 \qquad B\_length := 15.24$$

The conductance of tube B is:

$$con\_B := 12.12 \cdot \frac{B\_diam^3}{B\_length + \frac{4}{3} \cdot B\_diam} \ \frac{liters}{sec}$$

$$inverse\_Ctotal := \left(\frac{1}{con\_A}\right) + \left(\frac{1}{con\_B}\right) + \left(\frac{1}{total\_c\_grill\_roth}\right)$$

$$Ctotal := \frac{1}{inverse\_Ctotal}$$

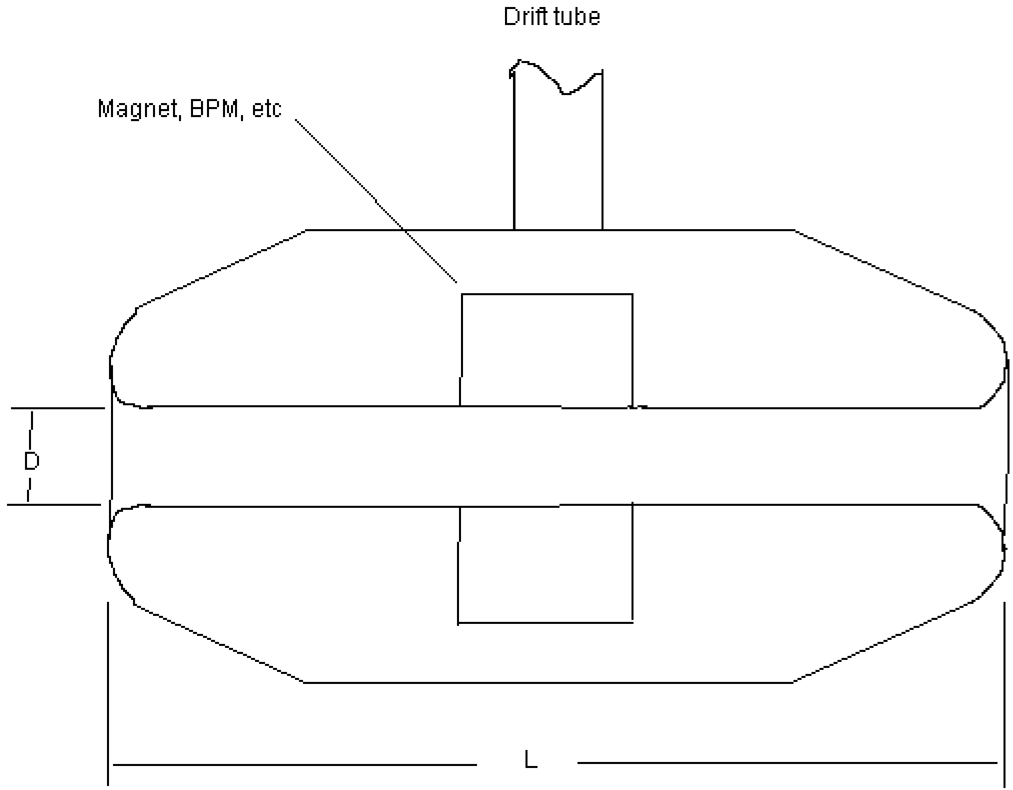
$$Ctotal = 242.489 \ \frac{liters}{sec}$$

$$q\_effec := Ctotal \cdot \frac{pump}{(Ctotal + pump)}$$

$$q\_effec = 206.023 \ \frac{liters}{sec}$$

**The outgas rate is 386 liters/second during conditioning, and the effective pumping speed is 206 liters/second. It would be nice to have a higher pumping speed, but because of the geometry of the wave guide feed, we can't get any additional cost effective pumping. However, the base pressure will rise from 1.0*10^-7 to 1.7*10^-7 to meet the effective pumping speed, but this will only be while conditioning the window. If the window is preconditioned at the factory to an outgas rate of no greater than 3.5X10^-8, then the q_effec (206 l/s) would meet the demands of the system.**

## The maximum outgas rate of any diagnostic equipment in a drift tube such as magnets, beam positioning monitors etc..




$pmax := 1.87 \cdot 10^{-7}$ torr, Maximum allowed pressure in the DTL (Beam Loss From H minus Stripping in Residual Gas, by Robert Shafer, 5/1/99, TN:LANSCE - 1:99-085)

$pmin := 9.2 \cdot 10^{-8}$ torr, Design vacuum pressure in the DTL (Preliminary Design Report II, page 12)

$D := 2.54$ cm, Diameter of the drift tube bore

$L := 19.05$ cm, Length of drift tube

$OD := 10.795$ cm, Outside diameter of the drift tube

$\alpha := 0.64$ L/D End correction factor in a pipe for molecular flow. See last page for graph

$copper := 1 \cdot 10^{-10} \quad torr \cdot \frac{liters}{sec \cdot cm^2}$ Outgassing rate for OFHC copper

**Since the outgassing will flow out of the inside of the drift tube in both directions, model the conductance of half of the length of the drift tube. To be conservative, assume all of the gas has to flow from the center of the drift tube out both ends.**

$$\text{conductance} := 12\cdot\alpha\cdot\frac{(D)^3}{\left(\frac{L}{2}\right)}$$

Conductance of a pipe in molecular flow with an end correction factor ($\alpha$).

$$\text{conductance} = 13.213\ \frac{\text{liters}}{\text{second}}$$

**We have to account for the copper outgas load of the drift tube body. Since the drift tube is hollow, this encompasses the cavity that surrounds the drift tube plus the drift tube ID itself. Although the drift tub shape is not a cylinder, I will be conservative and treat it as such.**

**Calculate the inside outgassing surface of half the drift tube:**

$$\text{major\_diam\_surface} := \pi\cdot OD\cdot\frac{L}{2} \qquad \text{major\_diam\_surface} = 323.026\ \text{cm}^2$$

$$\text{minor\_diam\_surface} := \pi\cdot(2.54)\cdot\frac{L}{2} \qquad \text{minor\_diam\_surface} = 76.006\ \text{cm}^2$$

$$\text{drift\_tube\_ID} := \pi\cdot(2.54)\cdot\frac{L}{2} \qquad \text{drift\_tube\_ID} = 76.006\ \text{cm}^2$$

$$\text{end} := \left(\left(\pi\cdot\frac{OD^2}{4} - \pi\cdot\frac{2.54^2}{4}\right)\right) \qquad \text{end} = 86.457\ \text{cm}^2$$

$$\text{half\_total\_outgas\_surface} := \text{major\_diam\_surface} + \text{minor\_diam\_surface} + \text{drift\_tube\_ID} + \text{end}$$

$$\text{half\_total\_outgas\_surface} = 561.495\ \text{cm}^2$$

$$\text{half\_total\_cu\_outgas} := (\text{half\_total\_outgas\_surface})\cdot(\text{copper}) \qquad \text{half\_total\_cu\_outgas} = 5.615\times 10^{-8}\ \text{torr}\cdot\frac{\text{liters}}{\text{sec}}$$

**Calculate half of the maximum capacity outgas rate for the drift tube**

$$Q := \text{conductance}\cdot(\text{pmax} - \text{pmin})$$

$$Q = 1.255\times 10^{-6}\ \frac{\text{torr}\cdot\text{liters}}{\text{sec}}$$

**Subtract the outgas load from the copper drift tube from the maximum capacity of the drift tube**

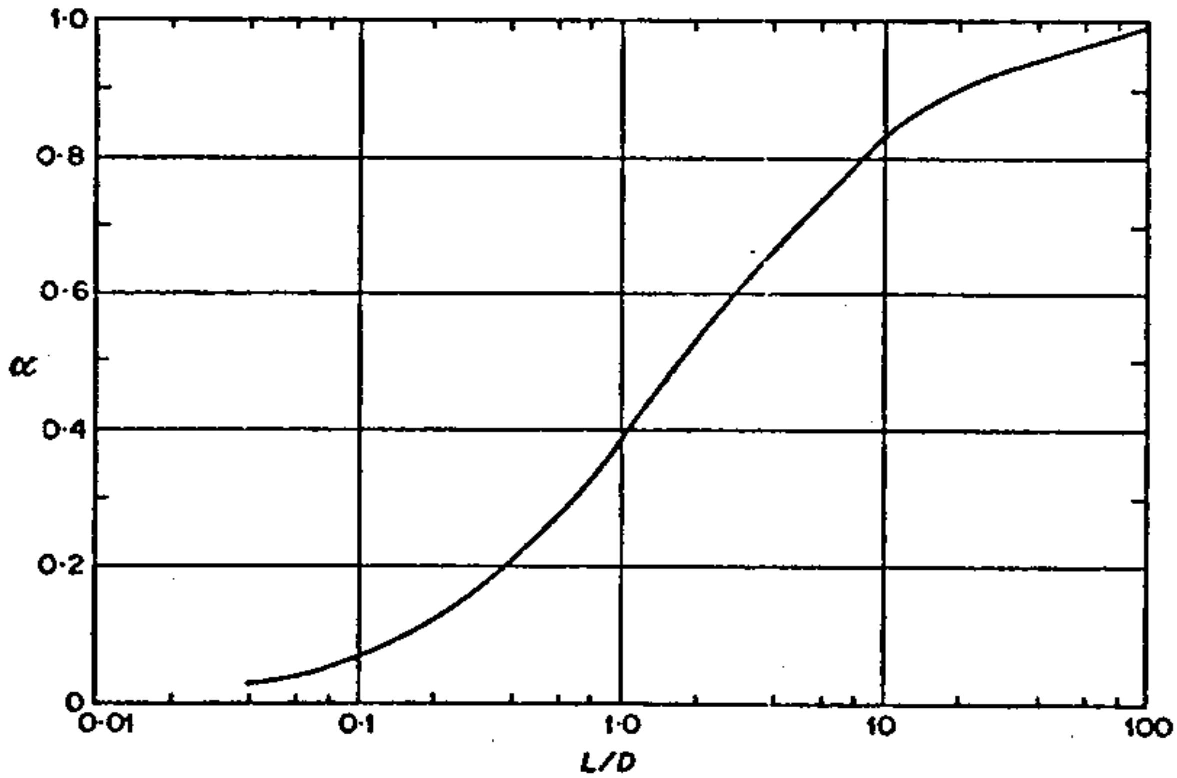
$$\text{half\_gasload\_diagnostic} := Q - \text{half\_total\_cu\_outgas}$$

**The total outgas rate for any diagnostic equipment in the drift tube is**

$$\text{total} := 2\cdot\text{half\_gasload\_diagnostic}$$

$$\text{total} = 2.398\times 10^{-6}\ \text{torr}\cdot\frac{\text{liters}}{\text{sec}}$$

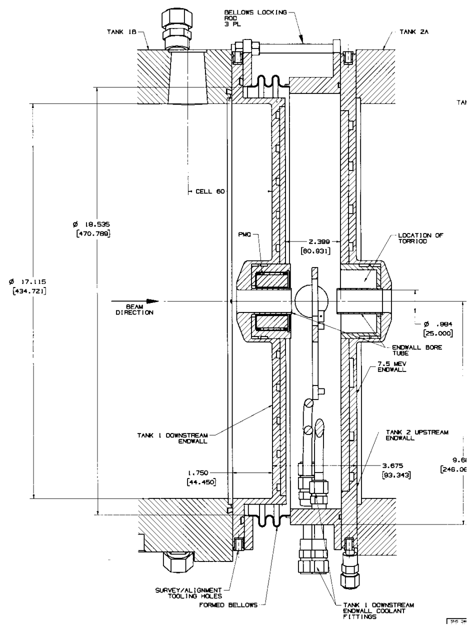
***The outgassing of any diagnostic equipment in the drift tube can not exceed this limit.***

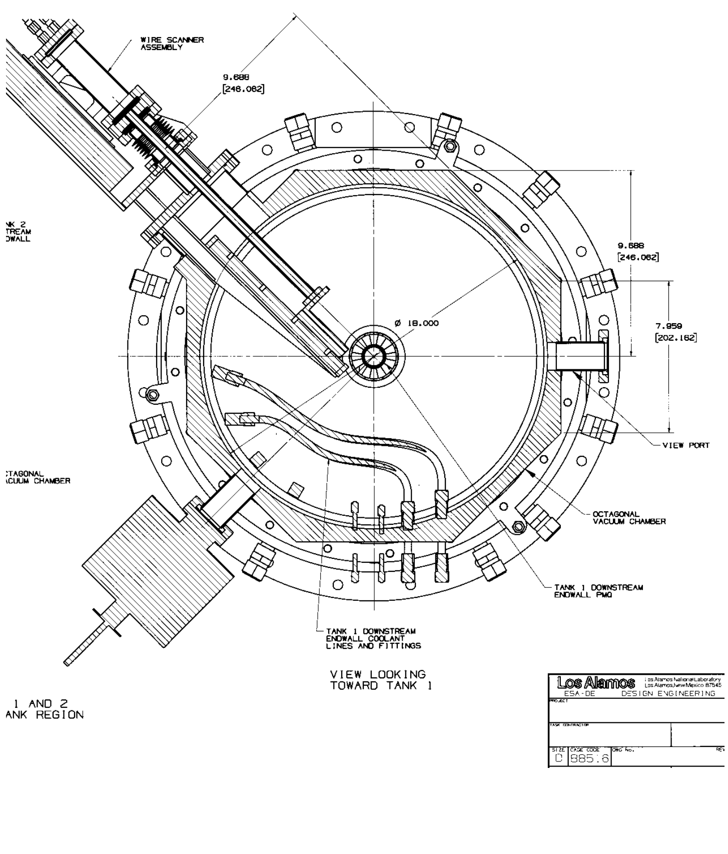



End-correction for molecular flow in short cylindrical pipe

This graph was copied from notes I received when attending a class, in the early 1970's, called " DESIGNING VACUUM SYSTEMS".

# DTL - End tank diagnostic space



## Inputs; Not show in pictures are Faraday Cup and Beam Degrader.

Material outgas rates torr-liters/sec-cm^2:

$ss\_outgas := 1 \cdot 10^{-10}$

$cu\_outgas := 1 \cdot 10^{-10}$

Diagnostic outgas rates torr-liters/sec:

$outgas\_wirescanner := 1.72 \cdot 10^{-7}$

$outgas\_faraday\_cup := outgas\_wirescanner \cdot 2.5$

$outgas\_quad\_magnet := 1.25 \cdot 10^{-7}$

$outgas\_toroid := 4.10 \cdot 10^{-7}$

Dimension of DTL Beam Box:

$end\_tank\_diam := 18$ inches

$end\_tank\_depth := 4.237$ inches

$end\_tank\_diam\_cm := end\_tank\_diam \cdot 2.54$

$end\_tank\_diam\_depth := end\_tank\_depth \cdot 2.54$

$base\_pressure := 9.2 \cdot 10^{-8}$ torr

$pump\_base\_pressure := 1 \cdot 10^{-9}$

$pump\_speed := 30 \ \frac{liters}{sec}$ This pump may not be required

## Calculations

**Calculate the inside area of the diagnostic space.**

$$\text{area\_one} := \pi \cdot \frac{(\text{end\_tank\_diam\_cm})^2}{4}$$

$$\text{area\_two} := \pi \cdot (\text{end\_tank\_diam\_cm}) \cdot (\text{end\_tank\_diam\_depth})$$

$$\text{total\_area} := (\text{area\_one}) \cdot 2 + \text{area\_two}$$

$$\text{total\_area} = 4.829 \times 10^{3} \quad \text{cm}^{3}$$

**Calculate the outgas load "Q". Include wire scanner, faraday cups, toroid, magnet, etc. Note, at the time of this calculation, the Faraday cup and Beam Degrader had not been designed so an outgas guess of 2.5 times the outgas of a wire scanner will be assumed.**

$$\text{Qwalls} := \text{total\_area} \cdot \text{ss\_outgas}$$

$$\text{Qwalls} = 4.829 \times 10^{-7} \quad \frac{\text{torr} - (\text{liters})}{\text{sec}}$$

$$\text{Qtotal} := \text{Qwalls} + \text{outgas\_wirescanner} + 2 \cdot (\text{outgas\_faraday\_cup}) \ldots + \text{outgas\_toroid} + \text{outgas\_quad\_magnet}$$

$$\text{Qtotal} = 2.05 \times 10^{-6} \quad \frac{(\text{torr} - \text{liters})}{\text{sec}}$$

**Calculate the required pumping speed for the Beam Box**

$$\text{req\_pump} := \frac{\text{Qtotal}}{\text{base\_pressure}}$$

$$\text{req\_pump} = 22.282 \quad \frac{\text{liters}}{\text{sec}}$$

Calculate the conductance of the pipe that Tom Ilg added to the beam box for a ion pump. Use the formulas in "**Vacuum Engineering Calculations, Formulas and Solved Exercises**". The author bases this calculation on the conductance through an aperture.

The inputs are:

$\text{temp} := 296$ deg K

$$\text{M\_air} := 28.98 \quad \frac{\text{g}}{\text{mole}}$$

$$\text{area\_cm2} := \pi \frac{(\text{pipe\_diam})^2}{4}$$

where (area_cm^2) is the area of the aperture

$\text{pipe\_length} := 2 \cdot 2.54$ Scaled from drawings

$\text{pipe\_diam} := 1.25 \cdot 2.54$ Scaled from drawings

$$\left(\frac{\text{pipe\_length}}{\text{pipe\_diam}}\right) = 1.6$$

Molecular conductance of an aperture is:

$$C_{ma} := 3.64\sqrt{\frac{temp}{M\_air}}\cdot area\_cm2 \qquad C_{ma} = 92.103 \quad \frac{liters}{sec}$$

Molecular conductance of a short pipe. The Pr dimensionless ratio it taken from table 6.5 on page 136.

$$Pr := 0.57$$

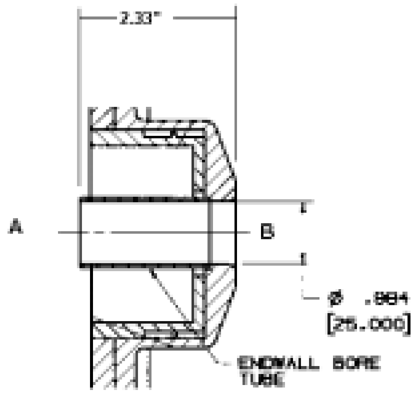
$$C_{mT} := C_{ma}\cdot Pr \qquad C_{mT} = 52.499 \quad \frac{liters}{sec}$$

Based on a pump (see inputs at the top of page 1) calculate the effective pumping speed for the Beam Box space.

$$p\_effect := \frac{\left(C_{mT}\cdot pump\_speed\right)}{\left(C_{mT} + pump\_speed\right)} \qquad pump\_speed = 30$$

$$p\_effect = 19.091 \quad \frac{liters}{sec}$$

This pump may not be necessary. Check to see if the Beam Box can be pumped out through the half drift tubes into the DTL tanks.




Calculate the pressure "A" from the known pressure "B" due to the outgassing from the toroid in the drift tube. All of the outgas passes through the half drift tube bores. Use the relationship of Q=[(Press_A)-(Presss_B)]C

$$\text{base\_pressure} = 9.2\times 10^{-8}$$ Design pressure at "B"

The conductance of the bore tube is

The inputs are:

$$\text{temp} := 296$$ deg K

$$\text{M\_air} := 28.98 \ \frac{g}{mole}$$

$$\text{bore\_area\_cm2} := \pi \frac{(\text{bore\_pipe\_diam})^2}{4}$$

where (area_cm^2) is the area of the aperture

$$\text{bore\_pipe\_length} := 2.33 \cdot 2.54$$

$$\text{bore\_pipe\_diam} := 0.984 \cdot 2.54$$

$$\left(\frac{\text{bore\_pipe\_length}}{\text{bore\_pipe\_diam}}\right) = 2.368$$

Molecular conductance of an aperture is:

$$C_{bore\_.ma} := 3.64 \sqrt{\frac{\text{temp}}{\text{M\_air}}} \cdot \text{bore\_area\_cm2} \qquad C_{bore\_.ma} = 57.075 \frac{liters}{sec}$$

Molecular conductance of a short pipe. The Pr dimensionless ratio it taken from table 6.5 on page 136.

$$\text{Pr} := 0.48$$

$$C_{bore\_.mT} := C_{bore\_.ma} \cdot \text{Pr}$$

$$\text{pump\_speed} = 30 \ \frac{liters}{sec}$$

$$C_{bore\_.mT} = 27.396 \ \frac{liters}{sec}$$

Find out what the pressure rise will be from the DTL through the half drift tubes into the DTL beam box.

$$base\_pressure = 9.2\times 10^{-8} \text{ torr}$$

Design pressure at "B"

$$\frac{Qtotal}{2\cdot C_{bore\_.mT}} + base\_pressure = 1.294\times 10^{-7} \text{ torr}$$

Pressure inside the beam box at "A".

Maximum allowable pressure is 1.84x10^-7 (Nitrogen) so this will meet the pressure requirements. Therefore, an ion pump is not needed on the Beam Box to meet the vacuum pressure requirements in the Beam Box.

=================================================================

Calculate the total maximum outgas rates from all of the diagnostics that are allowed in the DTL Beam Box at the same time.

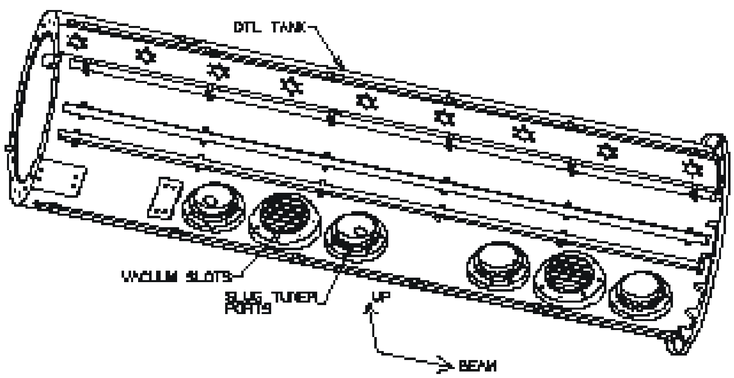
$$Qtotal_{diagnostics} := \left[2\cdot C_{bore\_.mT}\cdot\left(1.84\cdot 10^{-7} - base\_pressure\right)\right] - Qwalls$$

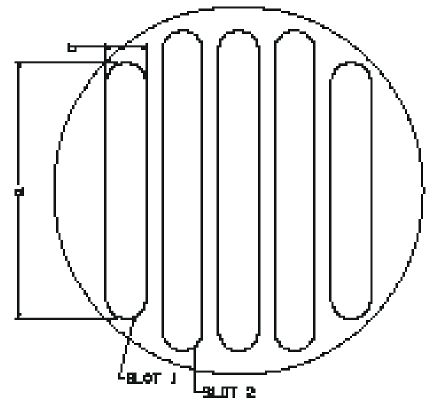
$$Qtotal_{diagnostics} = 4.558\times 10^{-6}$$

# DTL Pump Port RF Grill Conductance Calculations

## DTL vacuum pumping conductance calculation

2/1/00
T. Ilg
SNS-PO




DTL tank vacuum pumping slot configuration

Ref: Roth, "Vacuum technology",
Don Liska, "AT-4 tech note 92:04, Vacuum system design"

Conductance for a rectangular slot is:

$$C := 9.71\cdot\sqrt{\frac{T}{M}}\cdot a^2\cdot b^2\cdot\left[\frac{k}{(a+b)\cdot L+(2.66\cdot a\cdot b)}\right]$$

$a_1 := 10.6$ Slot 1 length, cm

$b_1 := 1.6$ Slot 1 width, cm

$a_2 := 12.7$ Slot 2 length, cm

$b_2 := 1.6$ Slot 2 width, cm

$L_g := 1.27$ Slot depth, cm

Correction factor for k, ( ref: Roth, 2nd revision, page 85 )

1.297 < k > 1.444 for 5 < a/b > 10

$\frac{a_1}{b_1} = 6.625$ $\frac{a_2}{b_2} = 7.937$

$k_1 := 1.444$

$k_2 := 1.444$

For air, $(T/M)^{1/2} = 3.181$

$$C_{g1} := 30.9\cdot a_1^2\cdot b_1^2\cdot\left[\frac{k_1}{(a_1+b_1)\cdot L_g+(2.66\cdot a_1\cdot b_1)}\right]$$ Conductance of rectangular slot 1, liters/sec

$$C_{g2} := 30.9\cdot a_2^2\cdot b_2^2\cdot\left[\frac{k_2}{(a_2+b_2)\cdot L_g+(2.66\cdot a_2\cdot b_2)}\right]$$ Conductance of rectangular slot 2, liters/sec

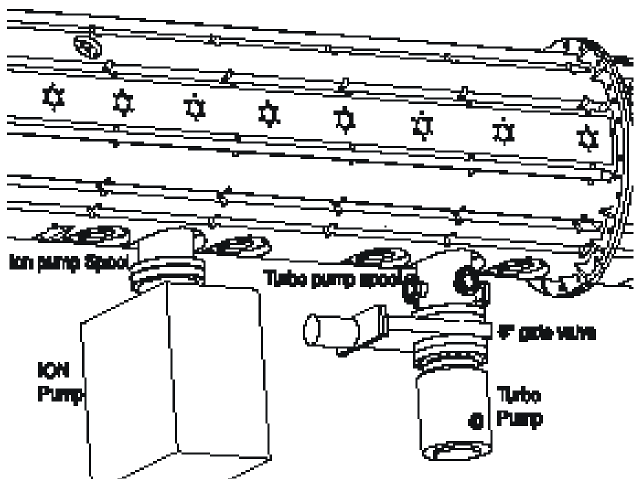
$C_{g1} = 211.763$ liters/sec

$C_{g2} = 255.131$ liters/sec

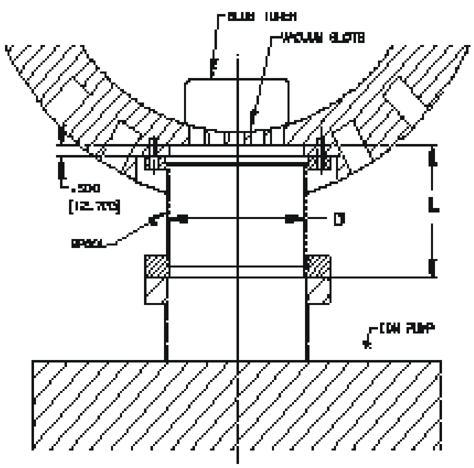
Total conductance for the 5 slotted grill is:

$C_g := 3\cdot C_{g1} + 2\cdot C_{g2}$

$C_g = 1145.55$ liters/sec




DTL Vacuum pump configuration




Section thru Ion pump station

Ion pump spool conductance calculation

$D = 14.478$ inside diameter of spool, cm

$L = 13.157$ length of spool, cm

Conductance of the spool in air is:

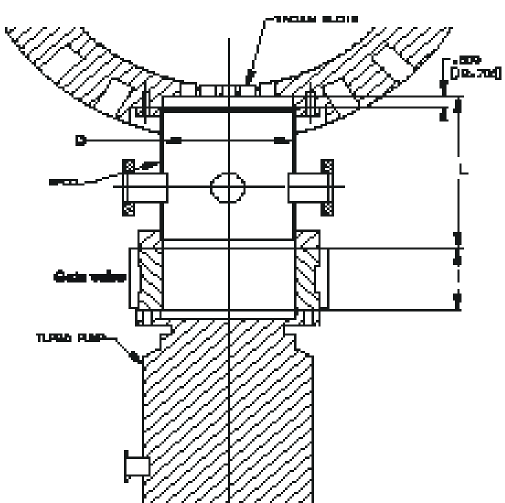
$$C_s = \frac{12.1 \cdot D^3}{L + (1.33 \cdot D)}$$

Ref: Roth, "Vacuum technology", Don Liska, "AT-4 tech note 92:04, Vacuum system design"

$C_s = 1132.91$ liters/sec

Total conductance for the ion pump station, including slots, is:

$$C_i = \frac{1}{\frac{1}{C_s} + \frac{1}{C_g}} \qquad C_i = 569.6 \quad \text{liters/sec}$$




Section thru Turbo pump station

Turbo pump spool conductance calculation

$D = 14.478$ inside diameter of spool, cm

$L = 19.69$ length of spool, cm

$l = 9$ Length of valve, cm

Conductance of the spool and valve in air is:

$$C_{ts} = \frac{12.1 \cdot D^3}{(L + l) + (1.33 \cdot D)}$$

$C_{ts} = 765.88$ liters/sec

Total conductance for the turbo pump station, including slots, is:

$$C_t = \frac{1}{\frac{1}{C_{ts}} + \frac{1}{C_g}} \qquad C_t = 459 \quad \text{liters/sec}$$

## 22.0 Appendix J - PLC Ladder Logic Example

```
 |P7 scroll pump
 1+--+ +-+--+/+---------+/+----------------------------------( )
 |00101 |00102         10003                                10004
 |start |stop          thermal overload                     P7 main contactor
 |scroll|scroll
 |pump  |pump
 |      |
 |      |
 |      |
2+--+ +-+
 |10004
 |P7 auxiliary contact seals in 00101
 |
 |
 |SV6 solenoid valve - turbo foreline
 3+--+ +-+--+/+----------+ +---------------------------------( )
 |00103 |00104          10004                               00002
 |open  |close          P7 must be running                  SV6 solenoid
 |SV6   |SV6
 |      |
 |      |
 |      |
 |      |
 |      |
4+--+ +-+
 |10014
 |SV6 Position indicator open position
 |seals in 00103
 |
 |
 |P8 turbo pump
 5+--+ +-+--+/+---------+ +--------+/+----------+ +----------( )
 |00105 |00106         10014      10035        10044        00045
 |start |stop          Position   foreline     turbo fault  P8 turbo running
 |turbo |turbo         indicator  pressure
 |      |              open       okay
 |      |
 |      |
 |      |
 |      |
6+--+ +-+
 |00045
 |turbo running
 |seals in 00105
 |
 |
 |GV7 main gate valve
 7+--+ +-+--+/+---------+ +--------+/+----------+ +----------( )
 |00109 |00110     |   00045      10059       | 10039        00013
 |open  |close     |   turbo      atmosphere  | turbo fault  GV7 solenoid
 |GV7   |GV7       |   start      or low vac  |
 |      |          |   mode       in vessel   |
 |      |          |                          |
 |      |          |---+ +--------+ +---------|
 |      |          |   10045      10067       |
8+--+ +-+          |   turbo      hi-vac      |
 |10069            |   full       in vessel   |
 |Position         |   speed                  |
 |indicator        +--------------------------+
 |open position
 |seals in 00109
 |
 |
 |P9 ion pump
 9+--+ +-+--+/+---------+ +--------+/+-----------------------( )
 |00161 |00162         10067      10008                       00004
 |start |stop          hi-vac     ion pump                    P9 ion pump
 |pump  |pump          in vessel  fault                       control
 |      |
 |      |
 |      |
 |      |
0+--+ +-+
 |10055
 |P9 ion pump running
 |seals in 00161
```

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