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Recycler Ring TSP2IP Design Review

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Overview

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Purpose of the Conversion from Titanium Sublimation Pumps to Ion Pumps

The Recycler titanium sublimation pumps and bake out systems are both failing and need to be rebuilt. The Recycler TSP's and bake out systems are all locally controlled from the tunnel and require access time to manipulate.

The Recycler is no longer a storage machine for anti-protons, so the requirement for maintaining it as a ultra-high vacuum system has been relaxed. A high vacuum system similar to the Main Injector has been specified by the machine scientists for the new proton science program, which can be achieved using only ion pumps. The spacing of the ion pumps should be close enough to initially achieve low 10-8 Torr.

Current Status of Recycler Titanium Sublimation Pumps

The Recycler TSP filaments are very near depleted. The TSP controller considers end of life filament resistance to be 105mΩ. This data is consistent with data from Brookhaven National Lab. A measurement taken ring wide, during the 2013 ANU shutdown reflects that many TSP filaments are near extinction, high resistance. Also found were many open filaments.

This data was taken from a presentation in March of 2013 by David Capista.

Current Status of the Recycler Vacuum System

The vacuum system design of the Recycler has been changing with the science program, and several areas have successfully been converted to ion pump only operation. The NOvA/ANU upgrade in 2013 converted portions of RR10, 30, 40, and 60 to operate without TSP's. The 2014 muon beam transfer installation also converted RR52. To date, approximately one third of the Recycler has been modified in this manner. To separate the ultra-high vacuum system from the high vacuum systems, differential ion pump sections were installed on each end. The current ion pump spacing around the UHV portion of the machine is one ion pump for every three TSP cans, approximately every 50 ft. The plan is to add an ion pump at every TSP can, which would result in ion pump spacing similar to that of the Main Injector.

Vacuum System Analysis

The TSP spacing is stated to be one TSP can every five meters. In reality, they are anywhere from 4 to 10 meters, and most are between 4 to 7 meter spacing. The TSP spacing is being verified and checked to determine suitability for ion pump installation. The conductance from the ion pump to the beam tube and the center pressure between ion pumps is being checked. We have seen based upon calculations that there are some areas where the spacing is less than optimal. This work continues. Discussion is also ongoing about the use of noble diode pumps versus conventional pumps.

Vacuum System Analysis

The outgassing rate chosen for any method of analysis has a significant effect. The Recycler tube has been degassed, but it will not be baked. Conservative calculations are using 1e-10, but it is expected to actually be in the e-11 range.

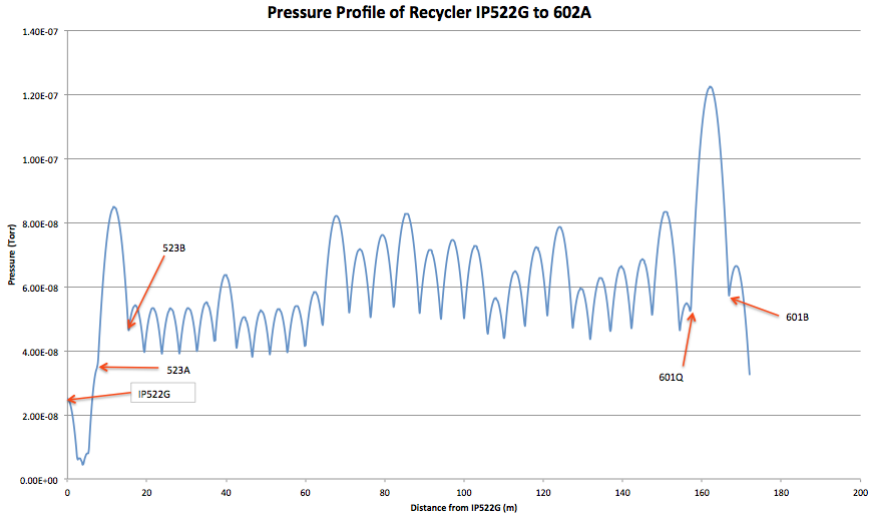
Table 1. Out-gassing Rates (Torr-L/s-cm^2) of Various Materials

Material	Totals (Torr-L/s-cm^2)	H_2	CH_4 Methane	H_2O	CO / N_2	C_2H_6 Ethane	Ethyl Alcohol	O_2	Ar	C_3H_6 Cyclo - propane	CO_2
Stainless Steel (unbaked, no degas)	1.0E-10	5.0E-11	2.0E-13	5.0E-11	1.0E-12	5.1E-14		3.0E-16		1.0E-14	1.0E-13
Stainless Steel (baked, no degas, based on Small Test Chamber)	5.1E-11	5.0E-11	2.0E-13	8.0E-14	2.0E-13	5.1E-14		3.0E-16		1.0E-14	8.0E-14
Stainless Steel (baked & degassed, based on Recycler)	6.7E-13	6.2E-13	1.0E-14	1.3E-14	1.3E-14	5.4E-15		1.7E-16	4.8E-16		5.7E-15

Outgassing rates presented by T. Anderson in “Accelerator Vacuum 101” document.

Vacuum System Analysis

VACCALC software was used to model a pressure profile for ion pumps placed with existing TSP spacing. The VACCALC method was confirmed by modeling an existing transfer line prior to the ANU installation, and it correlates to ACNET values for both the existing and newly installed regions. To be conservative, the outgassing rate for SS was taken to be unbaked and not degassed. Files are available for review.

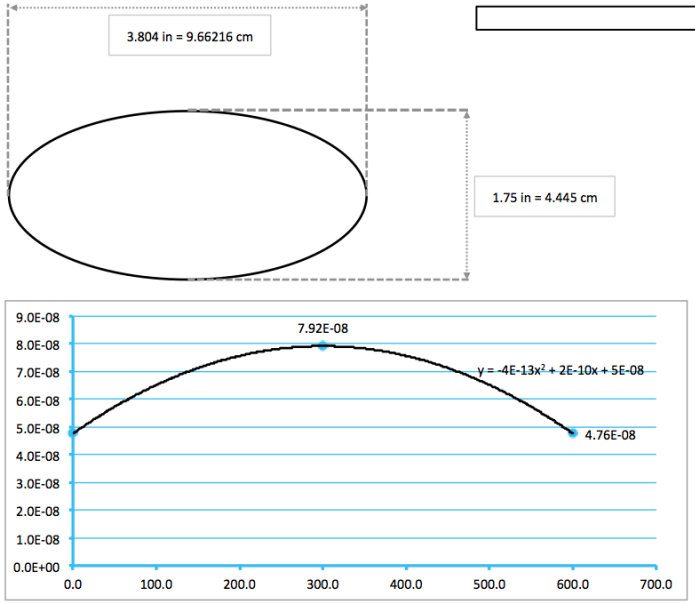


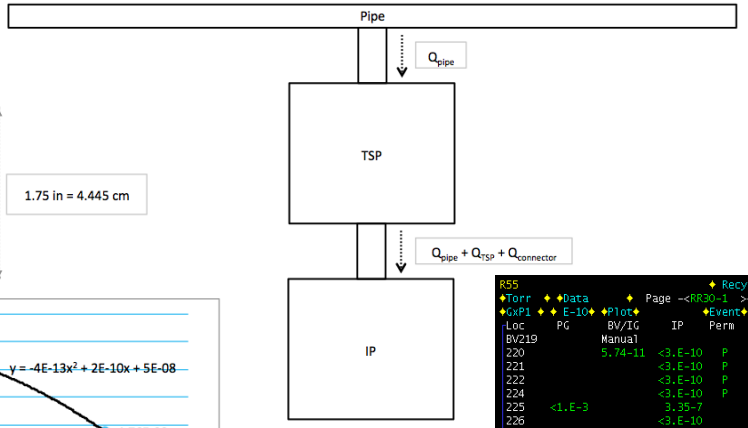
Profile plot from VACCALC prepared by B. Verdant.

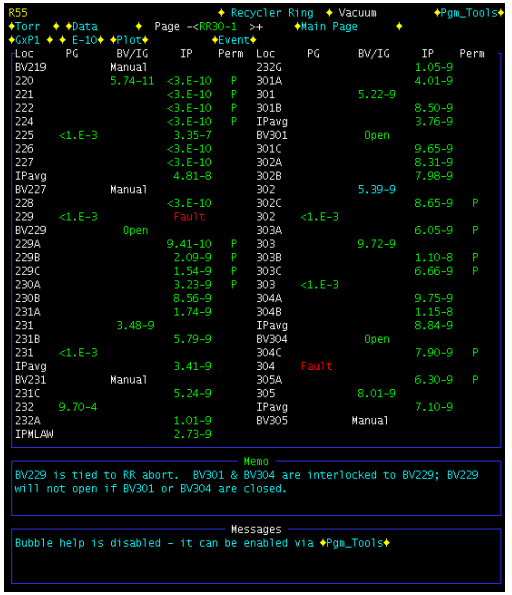
Vacuum System Analysis

Geometry	L_{pipe} (cm)	600.0
	$L_{majoraxis}$ (cm)	9.66216
	$L_{minoraxis}$ (cm)	4.445
	Ω_{pipe} (cm)	22.92
	A_{pipe} (cm^2)	13752.0
	$A_{pipecross}$ (cm^2)	33.7
	L_{TSP} (cm)	20.0
	D_{TSP} (cm)	15.0
	Ω_{TSP} (cm)	47.12
	A_{TSP} (cm^2)	1295.9
Outgassing Rates	q_{pipe} (Torr·L/s·cm^2)	1.00E-10
	Q_{pipe} (Torr·L/s)	1.38E-06
	q_{TSP} (Torr·L/s·cm^2)	0.00E+00
	Q_{TSP} (Torr·L/s)	0.00E+00
	$Q_{connector}$ (Torr·L/s)	0.00E+00
Flow Considerations	$C_{pipe\text{-}to\text{-}TSP}$ (L/s)	1000000.0
	$C_{TSP\text{-}to\text{-}IP}$ (L/s)	165.0
	α_{pipe} (-)	2.79E-02
	C_{pipe} (L/s)	10.9
	S (L/s)	35.0
	S_{eff} (L/s)	28.9
Pressures	P_{TSP} (Torr)	4.76E-08
	P_{pipe} (Torr)	4.76E-08
	ΔP (Torr)	3.16E-08
	P_{mid} (Torr)	7.92E-08
Graph	0.0	4.76E-08
	300.0	7.92E-08
	600.0	4.76E-08

White Cells Require User Input
Grey Cells Are Automatically Computed







Changing outgassing rate has significant effect. Assuming conservative 1e-10, but system is much cleaner and should be better.
Input values simulate ion pump attached directly to beam tube, no TSP. This is to compare to ACNET values of pumps already installed in RR. Does NOT take into account the RF slots.

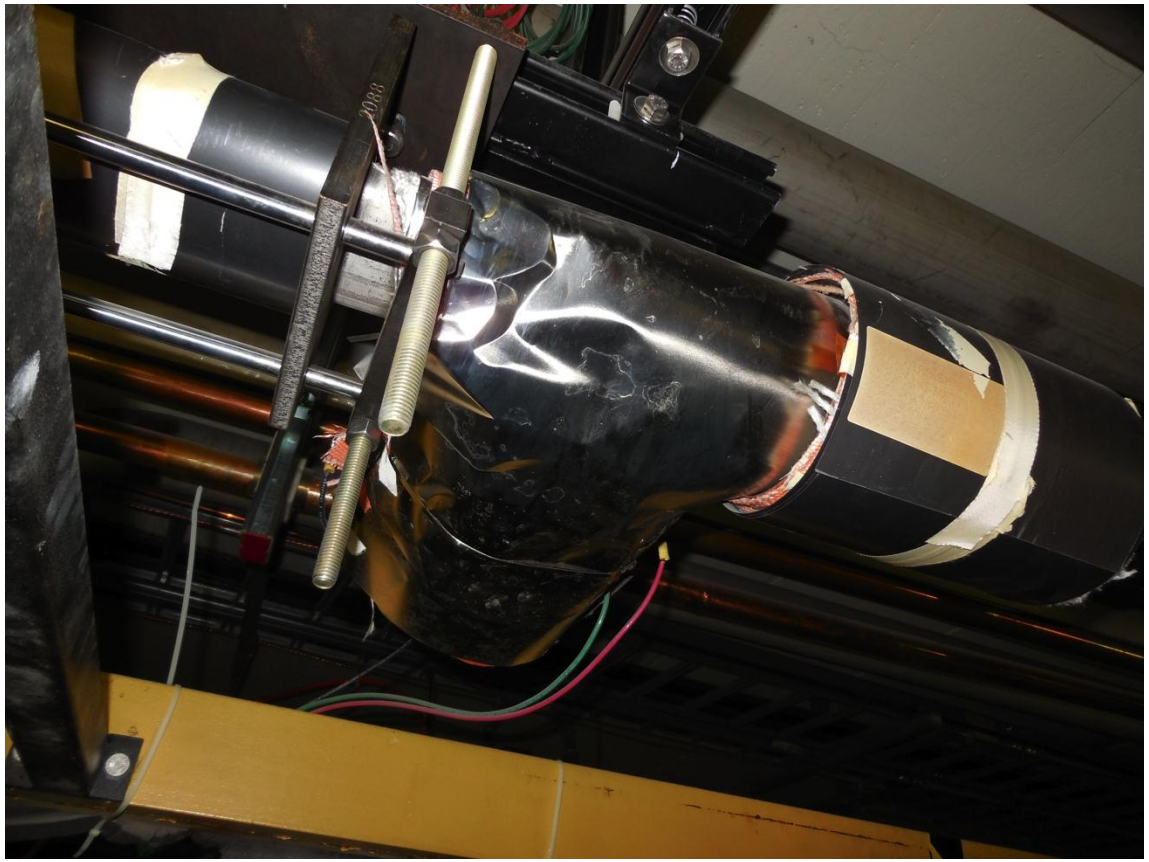
Vacuum pressure calculator developed by K.A. Anderson.

An example of more calculations in progress.

The ACNET screen shows an area of the RR already using ion pumps, and the calculation spreadsheet correlates well. This will be used to quickly predict effects of input variances.

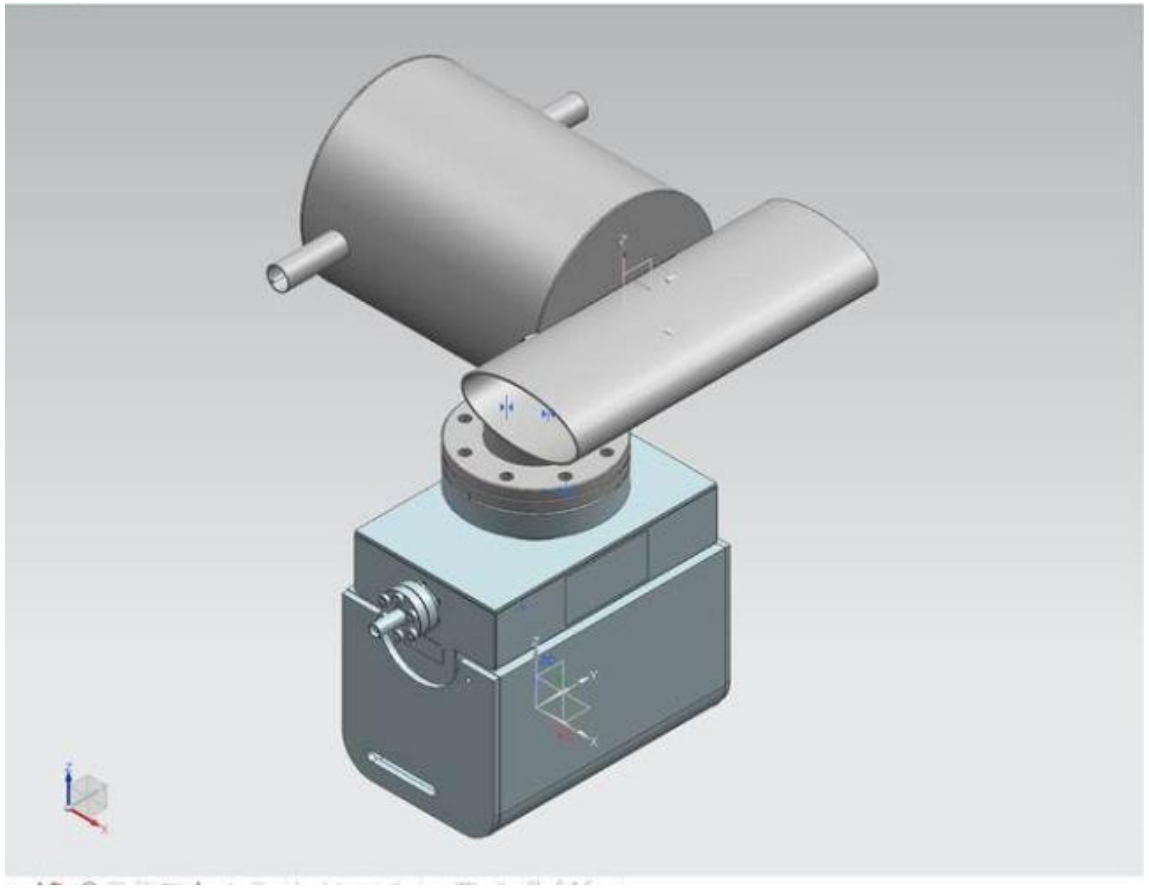
The Plan to Complete the Conversion to Ion Pumps
Initial condition

This is a typical view of a Recycler TSP can. Many of these have the connector end towards the radial outside of the machine. Some have the connector end towards the aisle. A few locations are close to other tunnel components that will require a custom design to avoid interference. Most TSP cans are readily accessible.



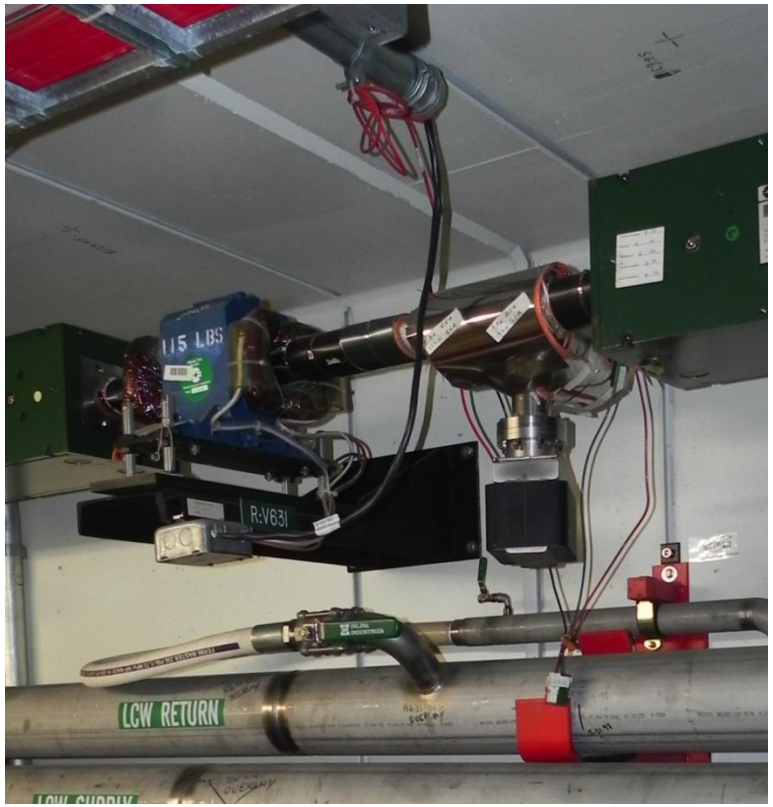
The Plan to Complete the Conversion to Ion Pumps
Ion Pump Installation on the TSP Can

Conceptual model of the ion pump on the TSP can. This is the same configuration as the original installation of the Recycler.



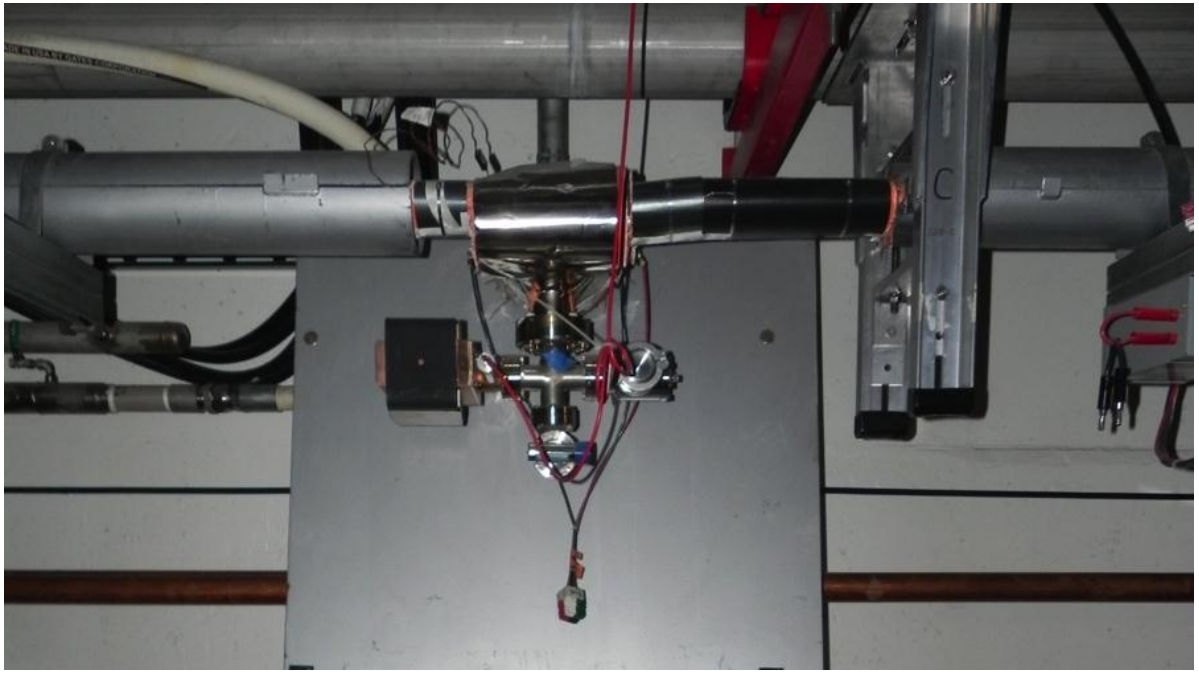
The Plan to Complete the Conversion to Ion Pumps
Ion Pump Installation on the TSP Can

Actual installation of an ion pump on a TSP can as part of the original installation of the Recycler. Ion pump shown is a 30 l/s diode ion pump.



The Plan to Complete the Conversion to Ion Pumps
Ion Pump Installation on the TSP Can

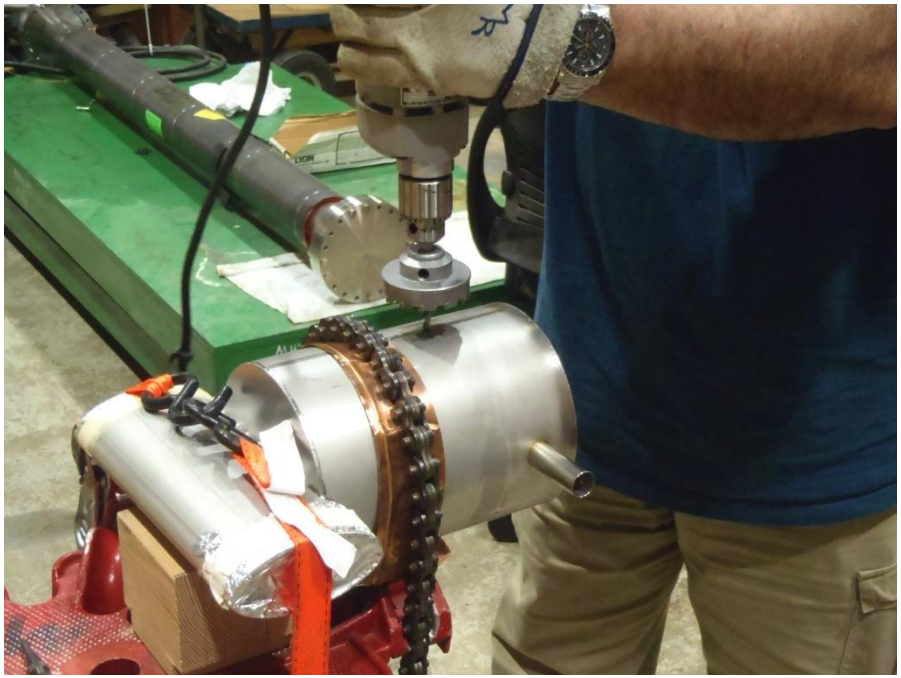
Example of existing VA2 vacuum instrumentation assembly on the TSP can. The 1.5” manifold will be replaced with 2.5” manifold in this vacuum system upgrade. Ion pump shown is a 20 l/s noble ion pump.



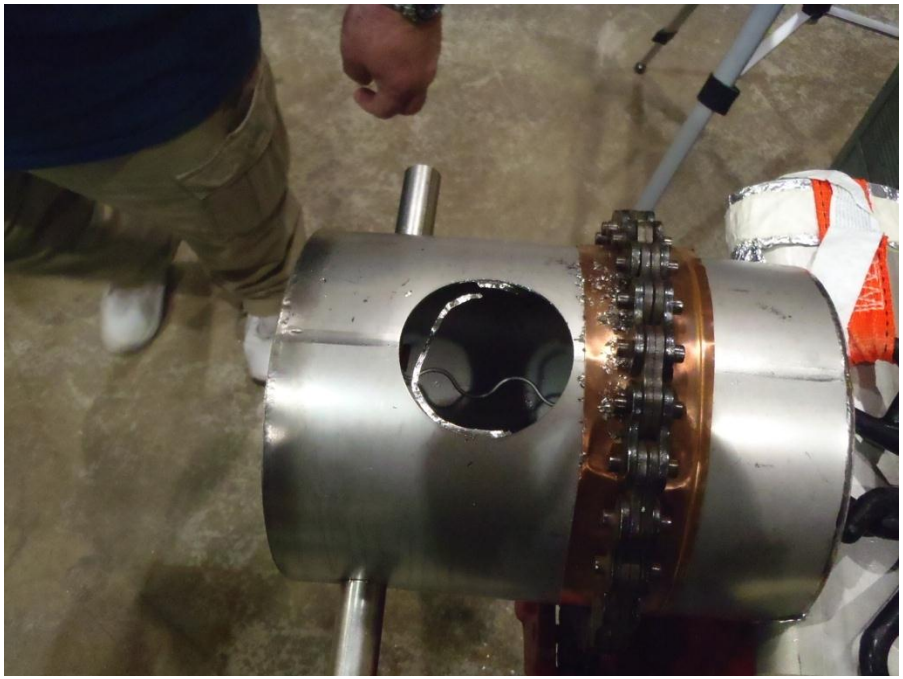
The Plan to Complete the Conversion to Ion Pumps
Ion Pump Installation Interferences

Some TSP cans are near other components that will impede the installation of an ion pump. A unique ion pump installation plan will be developed, such as moving the port to the side of the TSP can.

The Plan to Complete the Conversion to Ion Pumps
Custom Hole Drilling in the TSP



Drilling a 2.5 inch hole in a TSP Can by hand. This proves the ability to create a port by hand if the standard configuration cannot be used in a tight location.



Finished hole before de-burring.

The Plan to Complete the Conversion to Ion Pumps Ion Pump Installation on the TSP Can

A pipe drill is on loan to test the method to drill the holes in the TSP can. The Pipe drill is mounted to a TSP can. This drill weighs the same as a 30 l/s ion pump. Some modification to the base is necessary. This work is ongoing by Kevin Duel and Matthew Sawtell.

The Plan to Complete the Conversion to Ion Pumps Ion Pump Installation on the TSP Can

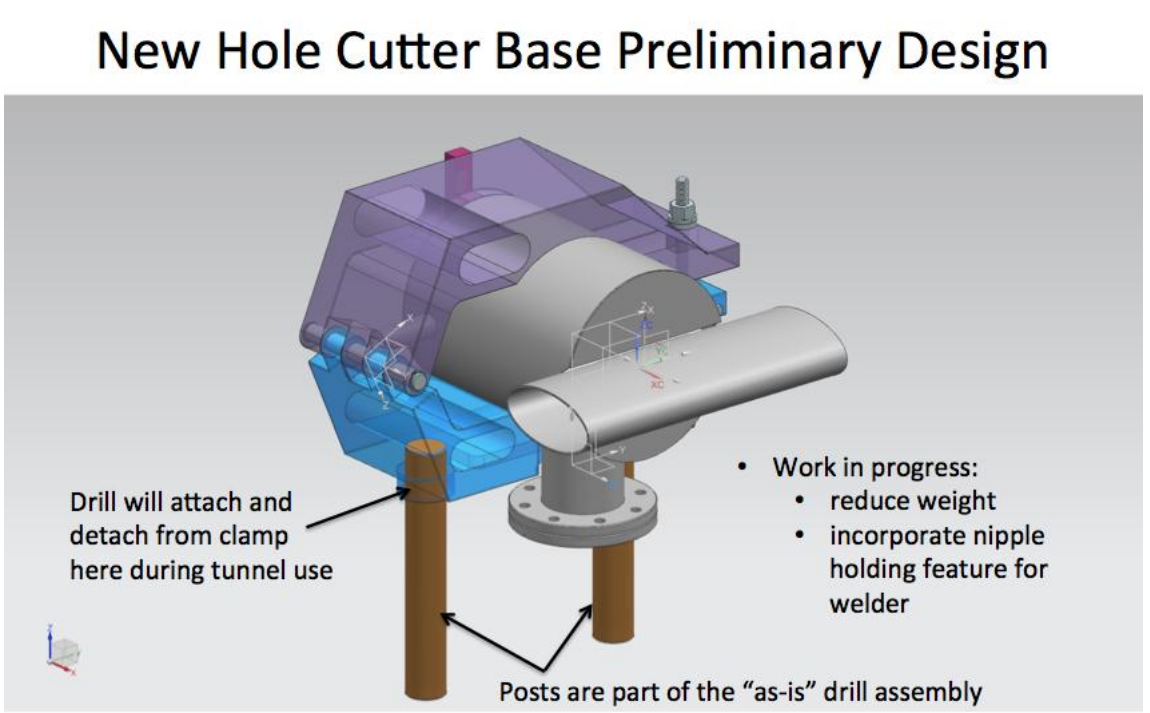
Approximately $1,500 for one tool assembly.

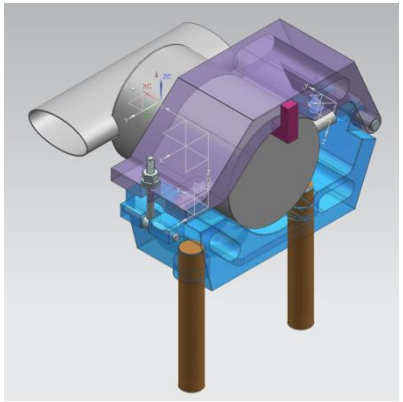
Tool is here on site on loan for now.

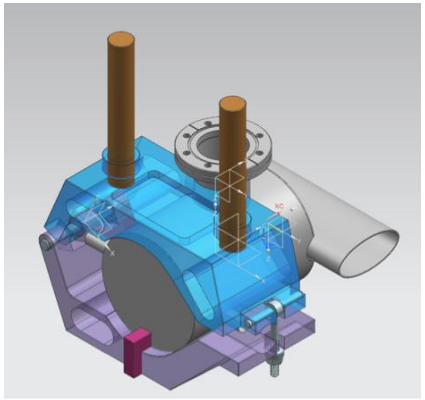
Drafter is currently measuring and modeling the hole saw assembly.

New base design started but needs refinement.

Status update from K. Duel. Initial design by B. Verdant.







The Plan to Complete the Conversion to Ion Pumps Drilling Hole

Drilled a 2.5 inch hole with the pipe drill in a 6 inch od tube to mimic drilling a hole in a TSP can. Positive proof was needed to demonstrate the ability for the drill.

The Plan to Complete the Conversion to Ion Pumps Drilling Hole

This is a photo of the hole after the drill was removed. The installation will require cleaning out the chips and de-burring the hole.

Additional Supports for the Ion Pumps

The addition of an ion pump or an ion pump instrumentation tree, i.e. a VA1,VA2, VB, or VC assembly, will add additional weight to the TSP can and beam tube. The highest weight will be 65 lbs. The work area from BV523 to BV100 has been reviewed by video. There looks to be a need for eighteen additional supports. Some of these will need a tunnel inspection to verify. Supports will need to be fabricated but will be based on previous designs. The need for supports in the remainder of the ring has not been determined yet.

Service Building Modifications for Controls and Ion Pump Power

The service building electrical modifications are underway. Preparing for new relay racks and electrical feed for these racks is in progress.

The ion pumps will need CIA crates to operate. These CIA crates will be removed from the Tevatron and be modified to work in the Main Injector.

The ion pump power supplies for this coming shutdown will be removed from the Tevatron. The balance will need to be built for the remaining sections of the Recycler.

Task Analysis and Schedule

The work in the tunnel has been analyzed for each TSP can in the area of BV523 to BV100. Each TSP location has been verified by drawing and by video documentation taken in the Main Injector tunnel over the last year. This video recording is used to verify the location of the TSP can, a view of the current installation, and determination if a local inspection is needed due to interferences.

The combination of mechanical drawings and tunnel videos has lead to the creation of a step by step installation schedule specific to each location. This schedule is used to predict time on the task and resources needed to complete the task within the duration of the advertised shutdown.

Full schedule is available for review.

Multi-year Plan

Due to the life of the TSP filaments and the beam tube wall gas desorbtion from intense proton beam, the Main Injector department requested the Recycler conversion to ion pumps in the next three years. The schedule is tentatively planned as follows:

BV523 to BV100 in 2015

BV105 to BV229 in 2016

BV308 to BV341 and BV401 to BV519 in 2017

Cost

Vacuum Sections	Cost Est Total	Cost Est Mech. Hdw	Cost Est Elec. Hdw	Electricians Labor	Contract Techs
	$2,454,799.80	$1,420,672.10	$608,177.70	$110,950.00	$315,000.00
RRBV105 to RRBV229	$609,894.45	$414,086.70	$195,807.75	$0.00	
RRBV308 to RRBV341	$364,924.35	$241,316.60	$123,607.75	$0.00	
RRBV401 to RRBV519	$489,739.75	$362,232.00	$127,507.75	$0.00	
RRBV523 to RRBV607	$325,045.95	$132,288.10	$56,957.85	$30,800.00	$105,000.00
RRBV608 to RRBV100	$665,195.30	$270,748.70	$104,296.60	$80,150.00	$210,000.00

This is the cost as it is understood at this time. The first area, BV523 to BV100 is well understood. The balance of the machine is being estimated. Accelerator Division management is directing the funding to complete the project. A specific task structure has been created to compile and fund charges for each remaining section of the machine.

Credits

The following personnel have contributed to the project.

Kevin Duel, Robert Reilly, Bradly Verdant, Kris A. Anderson, James Ranson, Cons Gattuso, Dave Capista,

George Krafczyk, Ken Sievert, John Brown, Michael Rauchmiller, Fernando Juarez, Brad Tennis, James Williams, Bill Dymond, Ann Nestander, Tom Zuchnik, Paul Kasley

Back Up Slides

3.2.1. Geometry Overview

In the Main Injector there are 6 ion pumps per cell and the length of vacuum sectors is approximately 500' (150 m). In the Recycler there will be one ion pump per cell, for a total of 104 ion pumps. Between the ion pumps there will be 5 titanium sublimation pumps (TSPs) per cell to achieve an average of pressure of approximately 1×10^{-10} Torr. The benefit of TSPs are lower cost and lower ultimate pressures. Since the length of normal cells is 34 m and the length of dispersion cells is 26 m, the longest vacuum sector possible if the isolation valves are spaced every 8 cells apart is 270 m. Therefore, the total number of sector valves is $104 \div 8 = 26$. Figures 3.2.1 through 3.2.3 contain sketches of the vacuum system in normal arc cells, straight section cells, and dispersion suppression arc cells.

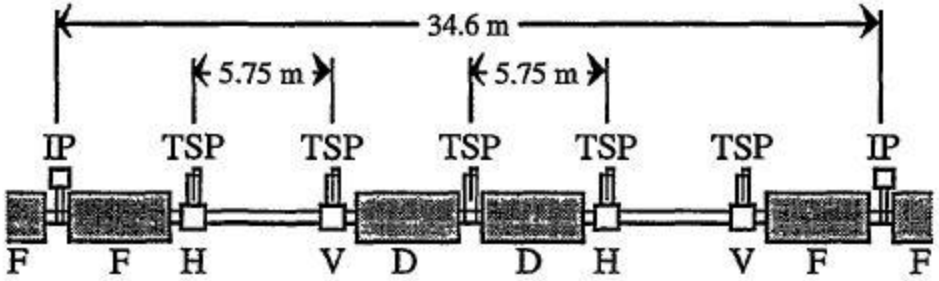


Figure 3.2.1: Sketch of the vacuum system in a normal arc cell. The horizontal (H) and vertical (V) beam position monitors have attached to them titanium sublimation pumps (TSP) in order to maintain a low average pressure and to minimize the number of welds in the tunnel.

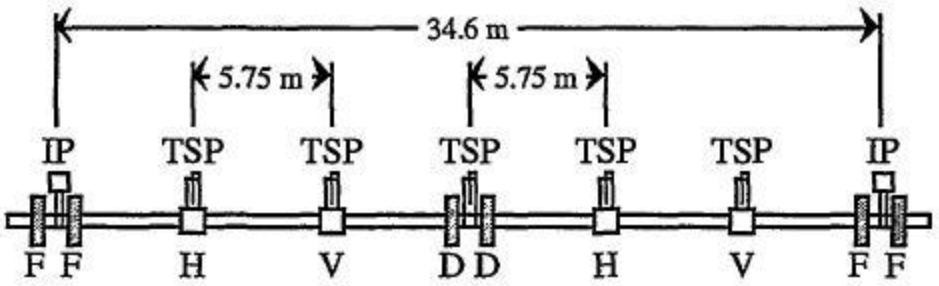


Figure 3.2.2: Sketch of the vacuum system in a normal straight section cell. Except for the fact that the quadrupoles are much shorter than the gradient magnets in the normal arc cell, nothing is different with respect to figure 3.2.1.

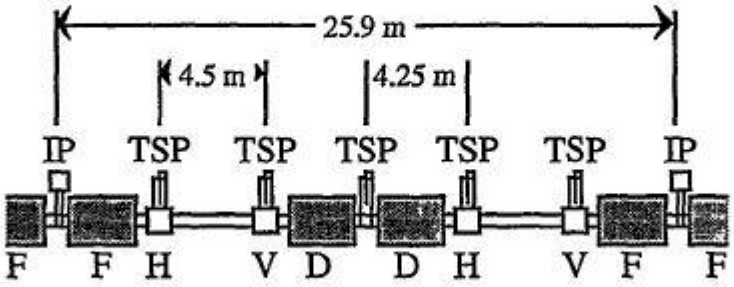


Figure 3.2.3: Sketch of the vacuum system in a dispersion suppresser cell.

The pumps

The majority of pumping in the Recycler is performed by TSPs. The TSPs are spaced at 5 m as shown in Fig. 1. The original design called for a small 30-L/s diode ion pump to be installed every 30 meters (Fig. 1, top). It was later decided to upgrade the pumping system by doubling the number of ion pumps (Fig. 1, bottom).

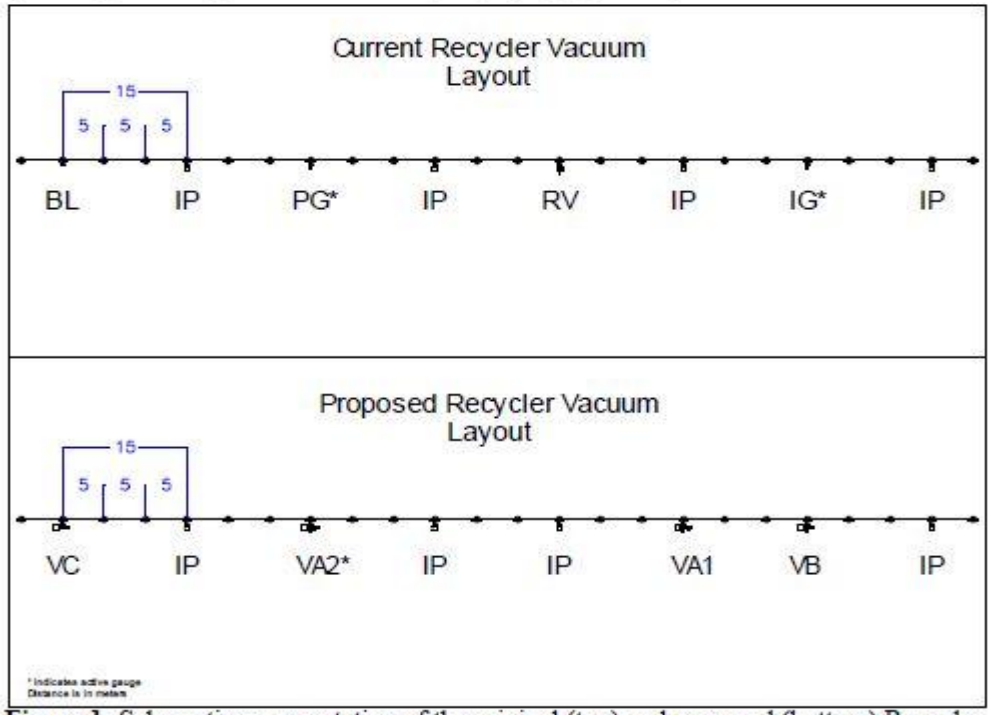
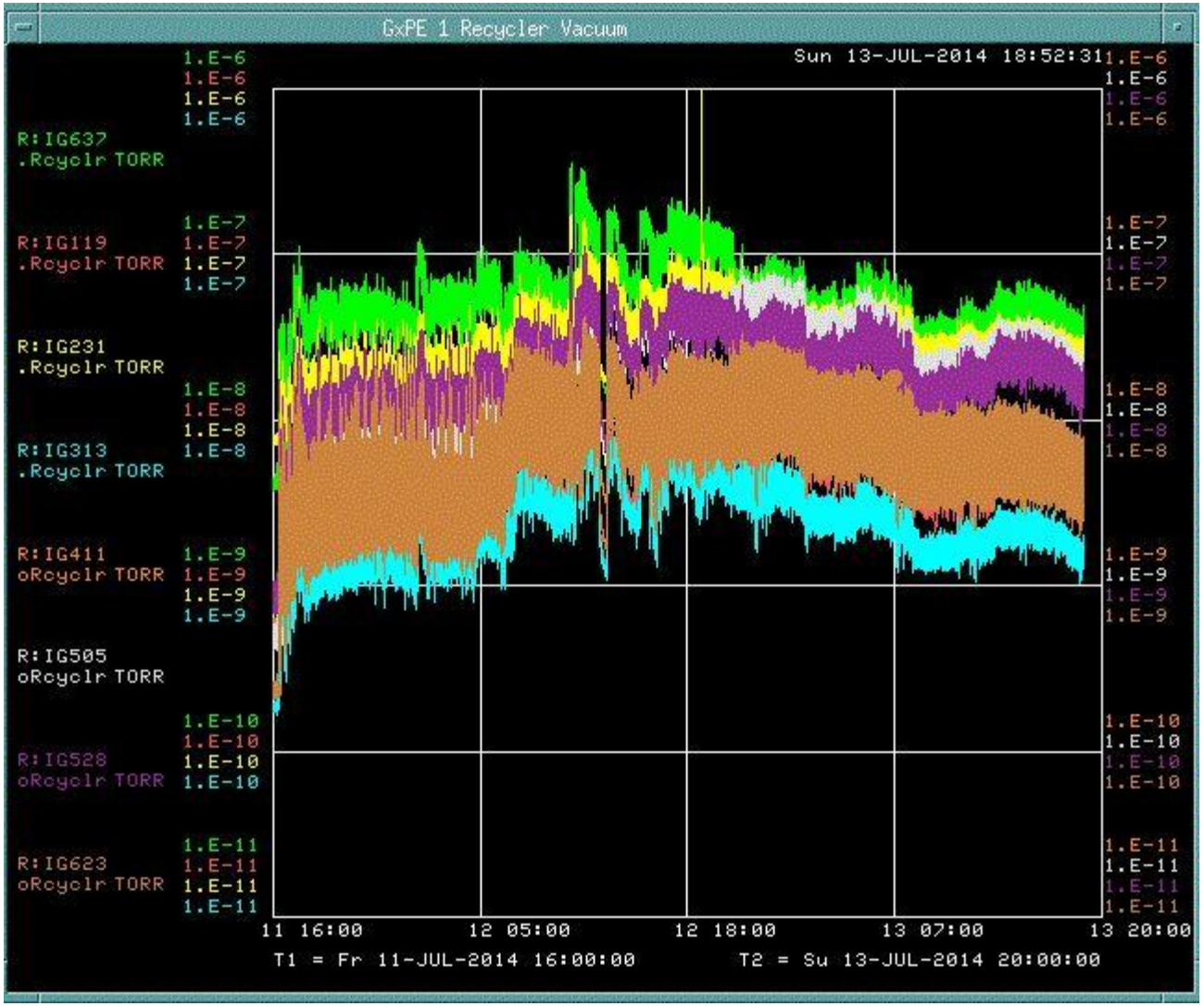


Figure 1: Schematic representation of the original (top) and proposed (bottom) Recycler vacuum layouts. Shown are TSPs (every 5 meters), ion pumps (IP), ion gauges (IG), Pirani gauges (PG), roughing valves (RV), blank-offs (BL), and newly added crosses with ion pumps (VA, VB, VC). Scale is in meters.

About 120 of 20-L/s ion pumps, capable of pumping argon, were procured from BNL. It is unknown to me if these pumps were new or used. Close to 90 of these pumps were

Recycler Vacuum with High Intensity Beam Pulses 13 July 2014

Recycler vacuum ion gauge plot for the UHV section ion gauges. This was taken while running proton beam and prior to the ring wide sublimation. The vacuum pressure due to desorbed beam tube gas depletes TSP's rapidly.



Recycler Vacuum with High Intensity Beam Pulses 1June 2014 to 12 Jan 2015

Recycler vacuum ion gauge plot for the UHV sections over a 6 month period. The plot period is just prior to ring wide sublimation in July 2014 to January 2015. Note the TSP lifetime is starting to expire with running proton beam in the Recycler