Recycler Ring Vacuum System Cost/Schedule Overview

November 12, 1996
Huddle

G. Jackson

<u>Summary of Presentation</u>

- Vacuum System Scope
- Installation Plan
- Commissioning Plan
- Cost Estimate Overview
- Obligation, Cost, Labor, and EDIA Profiles

RECYCLER COST ESTIMATE 28-OCT-96

Monies in FY96 Dollars

WBS	Description	Total M&S	Total Labor	Total	L3 Total	% of Total
	MAGNETS	D. Harding			4,666,636	40.5%
3.1.1.1.	Magnets - Ring	2,986,166	452,809	3,438,975		
3.1.1.8.	Magnets - Abort Line	42,812	8,482	51,294		
3.1.1.10.	Magnets - Tooling	0	5,396	5,396		
3.1.1.12.	Magnets - MI/R Trf Lines	179,427	34,708	214,135		
3.1.1.14.	Magnets - EDIA	0	486,121	486,121		
3.1.1.15.	Magnets - Installation	324,000	146,715	470,715		
	VACUUM	G. Jackson			1,135,242	9.9%
3.1.2.1.	Vacuum - Ring (A+B)	778,217	64,667	842,884		
3.1.2.12.	Vacuum - Xfer Lines (A+B)	51,139	5,205	56,344		
3.1.2.14.	Vacuum - EDIA	0	86,172	86,172		
3.1.2.15.	Vacuum - Installation (A+B)	0	149,842	149,842		
	POWER SUPPLIES	G. Krafczyk			53,471	0.5%
3.1.3.15.	Power Supplies - Installation	18,340	35,131	53,471		
	RF SYSTEMS	J. Reid			872,382	7.6%
3.1.4.1.	RF Systems - Ring	570,000	167,759	737,759		
3.1.4.14.	RF Systems - EDIA	0	117,515	117,515		
3.1.4.15.	RF Systems - Installation	0	17,108	17,108		
	KICKERS	G. Krafczyk			1,089,378	9.5%
3.1.6.1.	Kickers - Magnets	225,000	103,818	328,818		
3.1.6.2.	Kickers - Power Supplies	165,000	178,134	343,134		
3.1.6.14.	Kickers - EDIA	0	317,928	317,928		
3.1.6.15.	Kickers - Installation	39,000	60,498	99,498		
	STOCHASTIC COOLING	R. Pasquinelli			1,343,041	11.7%
3.1.7.1.	Stochastic Cooling -Ring	1,116,000	0	1,116,000		
3.1.7.14.	Stochastic Cooling - EDIA	0	218,368	218,368		
3.1.7.15.	Stochastic Cooling - Installation	0	8,673	8,673		
	INSTRUMENTATION	E. Barsotti Jr.			1,080,812	9.4%
3.1.8.1.	Instrumentation - Ring (A+B+C+D)	853,809	87,473	941,282		
3.1.8.14.	Instrumentation - EDIA	0	111,785	111,785		
3.1.8.15.	Instrumentation - Installation	0	27,745	27,745		
	CONTROLS	A. Mason			271,868	2.4%
3.1.9.1.	Controls - Ring (A+B)	113,371	0	113,371		
3.1.9.14.	Controls- EDIA	0	144,445	144,445		
3.1.9.15.	Controls - Installation	0	14,052	14,052		
	SAFETY SYSTEM	J. Anderson			38,626	0.3%
3.1.10.1.	Safety System - Ring	28,041	1,802	29,843		
3.1.10.14.	Safety System - EDIA	0	4,564	4,564		
3.1.10.15.	Safety System - Installation	1,336	2,883	4,219		
	UTILITIES	M. Ball			73,659	0.6%
3.1.12.1.	Utilities - Ring	16,078	0	16,078		
3.1.12.14.	Utilities - EDIA	0	17,844	17,844		
3.1.12.15.	Utilities - Installation	0	39,737	39,737		
	CIVIL	D. Bogert			370,043	3.2%
3.2.3.1.	Civil - Stch Cooling Light Links	324,000	0	324,000		
3.2.14.1	Civil - EDIA	0	46,043	46,043		
	PROJECT MANAGEMENT	S. Holmes			524,371	4.6%
3.3.1.	PM - Project Management	0	237,725	237,725		
3.3.2.	PM - Accelerator Physics	0	206,570	206,570		
3.3.3.	PM - General & Administrative	0	80,076	80,076		

Total EDIA:	1,550,785	13.5%			
Total Installation (M&S+L):	885,060	7.7%	**Grand Total:**	11,519,529	FY96$
Total Labor:	3,687,793	32.0%			
Total M&S:	7,831,736	68.0%	GT x 1.057	12,176,142	FY98$

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Vacuum System Scope

Summary of Section

- Vacuum System Specifications
- Cell Structure
- Beam Position Monitors
- Ion Pumps
- Titanium Sublimation Pumps
- 150°C Bakeout System
- Magnetic Shielding
- Bellows
- Beam Pipe Stands
- Valves, Ports, & Gauges

Vacuum System Specifications

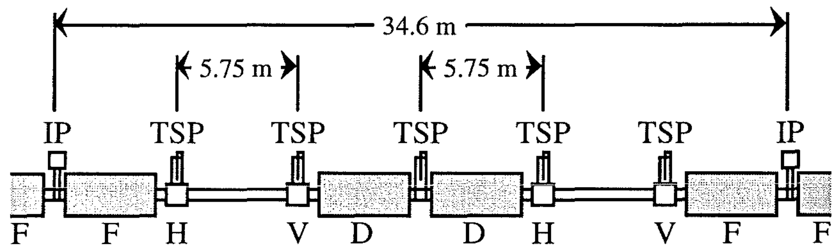
The performance of the vacuum system is determined by the pressure requirements for beam lifetime, scattering induced emittance growth, and ion trapping. In addition, the clearing of trapped ions also imposes requirements on the system.

The average pressure is specified to be $\leq 1\text{x}10^{-10}$ Torr. This pressure is acquired after first performing a 150°C in-situ bake of the vacuum chamber while pumping with portable turbomolecular pumps. This stainless steel chamber has already been hydrogen degassed before installation. During the in-situ bake the titantium sublimation pump (TSP) filaments are degassed using a portable 50 A power supply running at approximately 40 A. After the pipe has cooled, ion pumps started with portable power supplies bring the pressure down to approximately $1\text{x}10^{-8}$ Torr. At this point the current through the TSP filaments is increased to 50 A to sublimate the titanium on to the pump walls. At this point the average pressure should drop to the required level.

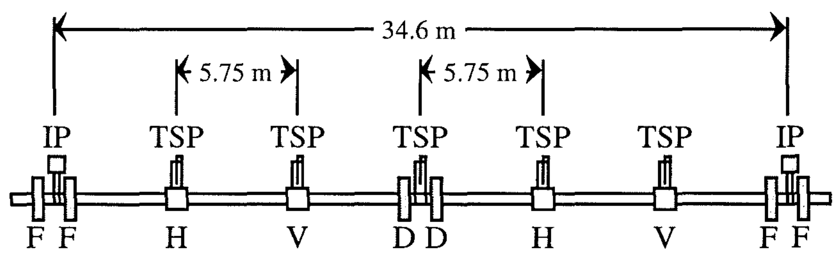
Ion trapping concerns require that clearling electrodes be installed in the vacuum system. By chosing capacitive beam position monitor (BPM) electrodes and feedthoughs capable of standing off approximately 700 V, the BPM system can double as the clearing electrodes.

Cell Structure

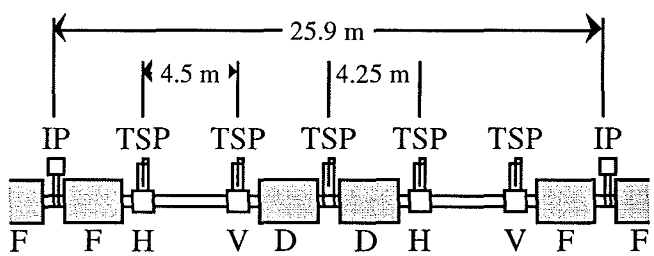
There are 3 types of standard lattice cells around the Recycler ring. In the normal arcs the cells are 34.6 m long and contain gradient magnets which are each 4.5 m long. The straight section cells are also 34.6 m long, but contain quadrupoles which are each 0.5 m long. The dispersion suppresser cells are 25.9 m long with 3.0 m long gradient magnets. Below are sketches of all 3 cell types.



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.

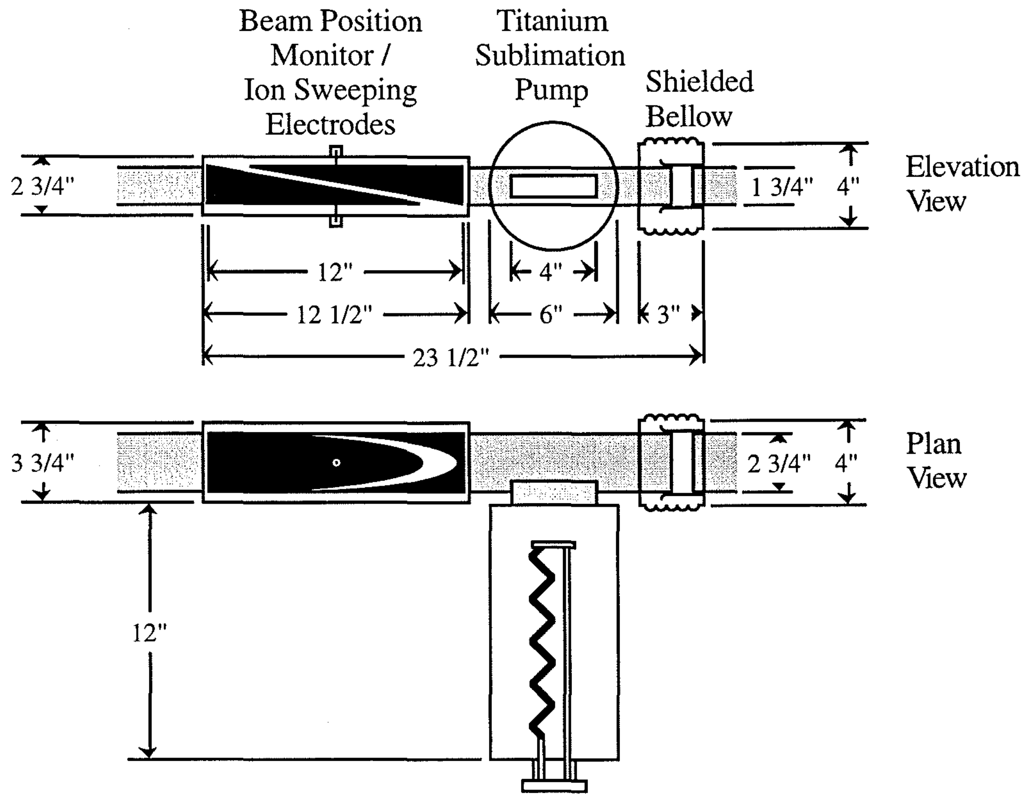


Sketch of the vacuum system in a normal straight section cell. It is the same as a normal arc cell except for the fact that the quadrupoles are much shorter than the gradient magnets.



Sketch of the vacuum system in a dispersion suppresser cell.

Beam Position Monitors



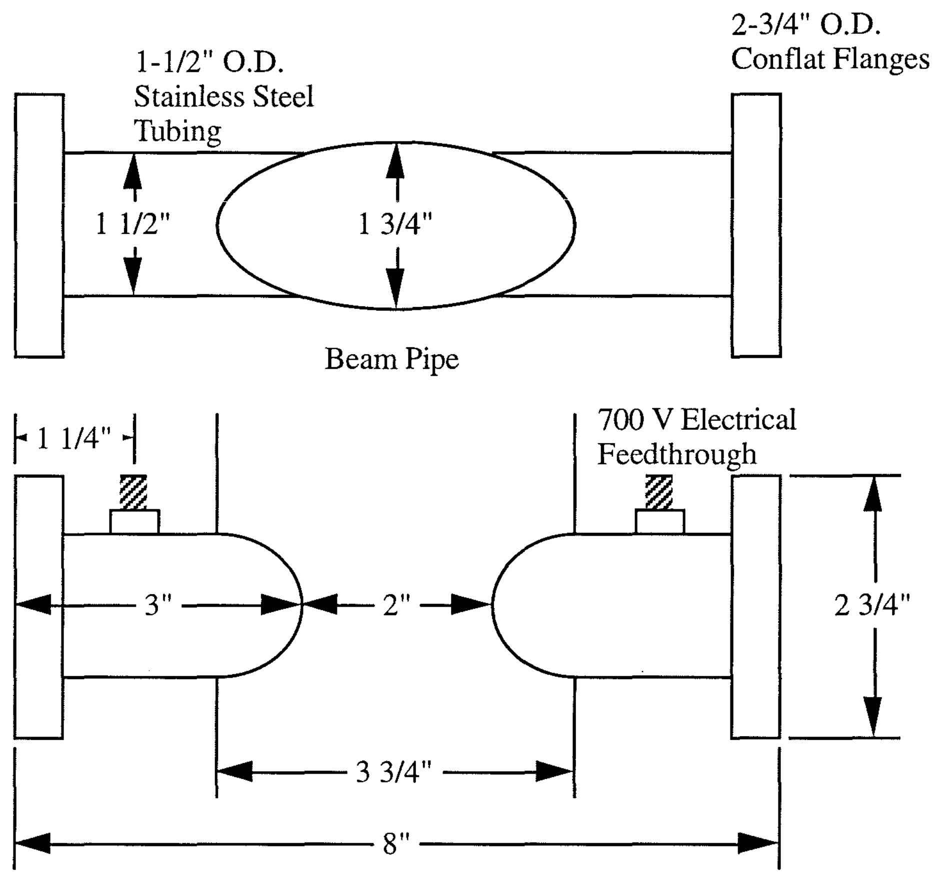
Elevation and plan views of the BPM assemblies which each include a titanium sublimation pump (12" long) and shielded bellows. A vertical BPM is shown, which is on the downstream side of each half cell. The horizontal BPM, which is placed on the upstream side of each half cell, has a horizontally sensitive electrode and the entire assembly is rotated left for right.

The beam position monitor (BPM) detectors are prefabricated structures which are leak checked before installation in the tunnel. For each half cell the section of bare vacuum chamber and the BPM detectors on either side are welded together and installed as one rigid unit. The bellows associated with each detector assembly are always on the side near the magnets, away from the bare vacuum chamber.

The beam vacuum chamber has a profile matched to the beam pipe shape and also composed of stainless steel. The detector electrodes have the same shape as the beam pipe, but are composed of titanium. The use of titanium reduces the amount of secondary ion emission due to clearing electrode induced ion kinetic energy gain. The feedthoughs should stand off at least 700 V and need only transmit frequencies up to 10 MHz.

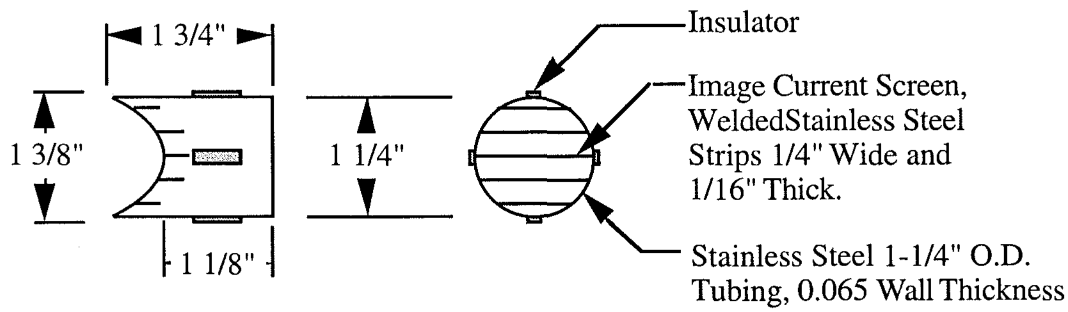
Ion Pumps

Ion pumps are required to 1) bridge the gap between pressures accessible with the turbomolecular pumps and the operational pressure provided by the titanium sublimation pumps (TSPs), and 2) to pump on those gas species for which TSPs are ineffective. Therefore, at one location in each cell a port for an ion pump must be added to the Recycler vacuum system. Below is a drawing of such a connection.



In fact, one of these port assemblies are to be added to each half cell between the magnets. In those locations where an ion pump is not called for, a TSP is attached instead. The other port is provided for turbomolecular pump ports, Pirani (thermocouple) gauges, and ion gauges. In most cases this port is simply blanked off.

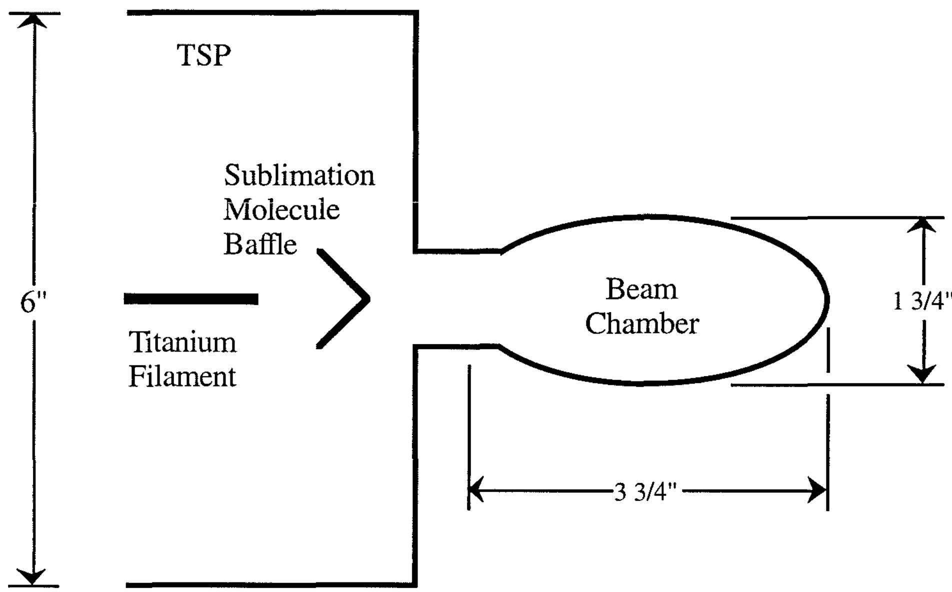
The shapes of the cut-outs from both the beam pipe and the 1.5" O.D. tubing are cut via wire EDM techniques. Each 1.5" O.D. tube has an inexpensive, low precision, and low frequency electrical feedthrough capable of standing off at least 700 V. These feedthroughs are connected to ion clearing electrodes. The shape of these electrodes are described on the next page.



The above figure shows the stainless steel tube which is inserted into the 1-1/2" O.D. tubing on both sides of the port assembly and welded to the center pin of each electrical feedthrough. The shaped end within which conductor strips are welded is placed so as to be flush with the beam tube itself. The welded strips serve 2 functions: 1) Provide path for beam image currents to reduce the machine impedance, and 2) shape the ion clearing field applied to the feedthroughs.

Titanium Sublimation Pumps

Titanium sublimation pumps (TSPs) are used to bring the average pressure down to $\leq 1 \times 10^{-10}$ Torr. While the filaments and the 2-3/4" O.D. conflat flange mounted filament connection are commercial products, the pump containment vessel is constructed separately. The design envisioned for the Recycler is shown in the sketch below and in the beam position monitor sketch two pages earlier.



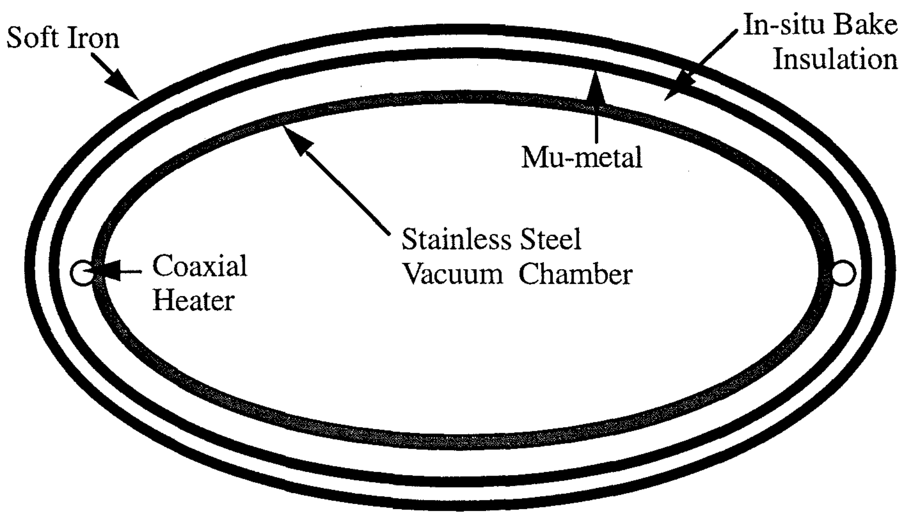
The connection between the TSP and the beam chamber is 1" high by 4" long, and is rectangular in cross-section. Both the slot in the beam chamber and the matching conic section removed from the connection to match the vacuum chamber shape are both wire EDM cut. All pieces are composed of stainless steel.

In order to prevent sublimated titanium molecules from entering the beam chamber and depositing flaky films onto the wall next to the beam, a stainless steel baffle plate is welded to the inside of the TSP housing before final assembly. The baffle is shaped so as to not impose an excessive vacuum conductance limitation.

The interval of time between TSP filament sublimations is determined by the pump surface area and the rate at which the pump is collecting gas molecules. For the outgassing rate expected for hydrogen degassed stainless steel beam pipe, a remote & distributed heater system is not required. Instead, filament heater supplies will be transported on carts, similar to turbomolecular pumps.

150°C Bakeout System

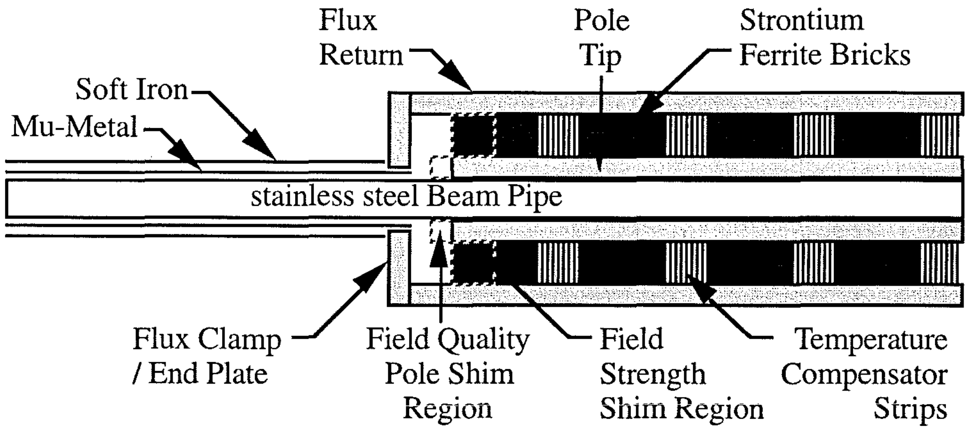
In order to reach the low vacuum pressures called for by the vacuum specifications, an in-situ bake of the vacuum system is required. The bake temperature required is 150°C. In order to achieve this temperature, a heater element is connected to both sides of the beam pipe, which together are wrapped in layers of thermal insulator (and magnetic shielding material outside of the magnets).



The heater element is simply an epoxy coated coaxial pair of stainless steel tubing. The coaxial nature of the heater arrangement is necessary in order to prevent the heater current stray fields from inducing a remnant field change in the magnet iron. The heater elements are also placed around the BPM and TSP chambers, but not around the bellow sections.

The thermal insulation is a woven cloth composed of ceramic fibers. A great deal of experience has been accumulated in tests with this material. Inside magnets the cloth is bound to the beam pipe using a very loose winding of high temperature tape. This thermal insulation is also placed around the BPM assemblies.

Magnetic Shielding

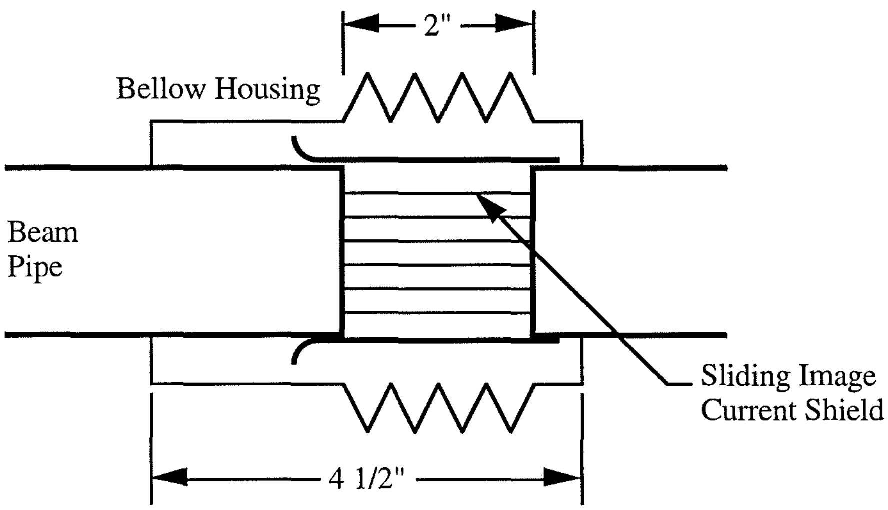


Side view of magnet, showing transition from magnetic shielding of naked beam pipe to magnet flux return. Also indicated are the regions at the ends of the pole tips devoted to shimming the field shape, and the ends of the ferrite bricks which are used to trim the strength of the magnet by adjusting the total amount of magnetic material.

The magnetic shielding is composed of a layer of mu-metal surrounded by a layer of soft iron. The soft iron suppresses the relatively high magnetic fields which would saturate the mu-metal, which isolates the beam aperature from stray magnetic fields down to a level of ≤10 milliGauss. The magnetic shielding encircles all beam line elements not inside magnets, such as ion pump ports, bellows, BPMs, and TSPs. The soft iron and mu-metal are separated by an additional layer of thermal insulation.

Bellows

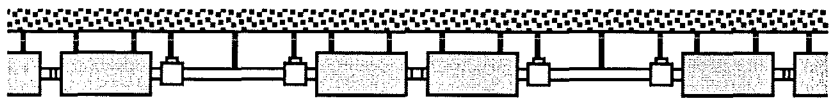
The bellows are patterned after the design in the Main Injector. Each bellow must be able to absorb the increase in beam pipe length which occurs during the 150°C in-situ bakes. These welded-convolution bellows are two inches long, absorbing one inch of length change each during the bakes. The bellows are shielded from the beam image currents by a liner which resides on the outside surface of the bellows.



The nature of this sliding image current sheet in the present design is a beryllium-copper sleave which is slotted for vacuum pumping. Another alternative is to use the nominal stainless steel vacuum chamber, cut 3" - 4" long slots into it around the circumference, and then forming a 1/16" flare in the slotted section so that it slides over unmodified chamber. This approach could be cheaper and more resistant to mechanical failure.

Beam Pipe Stands

It is necessary to build stands specifically for the vacuum system due to the long distances between the magnets. The magnets themselves act as vacuum chamber stands. In the center of the long sections between magnets the vacuum chamber stand holds the pipe in a fixed position. During bakes the vacuum chamber lengthens toward the bellows near the beam position monitors. The stands connected to these monitors have sliding joints which allow this expansion. Similarly, the pipe can slide within the magnets, but is held fixed at the end of the magnets at the 1 m short straights between the magnets. The figure below contains a sketch of this geometry.



The stands are composed of a stainless steel plate welded to a stainless steel post to which a beam pipe clamp can be attached. The steel plate is attached to the tunnel ceiling using the imbedded unistrut anchors.

Valves, Ports, & Gauges

There are 26 vacuum sectors around the Recycler ring, which corresponds to one sector valve every 8 half cells. In each sector there needs to be one turbomolecular pump port with an all metal valve, one Pirani gauge, and one ion gauge. Since there are 4 available ports per sector, that leaves 1 spare port per sector which is blanked off.

Installation Plan

This plan assumes that the Recycler installation is complete on April 1, 1998. At an installation rate of 1 half cell per day, 208 working days are required. Since the installation interval would include the Christmas season, it is assumed that 11 full calender months are required, starting on May 1, 1997. Assuming a project start date of April 1, 1996, this schedule calls for the delivery and assembly of components starting within a month.

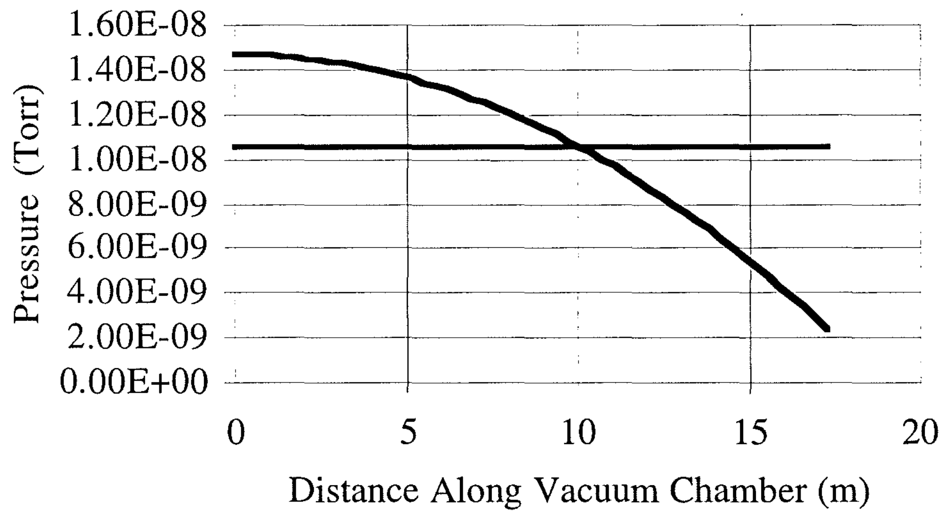
The critical path item which will determine out ability to meet this schedule are the beam position monitor/titanium sublimation pump assemblies. A pre-production program with an external machine shop for which an option exists to begin building all assemblies for the entire ring would make this schedule possible. An order of 12 BPM assemblies starting in the beginning of January 1997 and delivered by April 1997 would constitute a reasonable pro-production run.

The portion of the vacuum system inside and between the magnets will be installed (on average) at the same rate that the magnets are installed. On the other hand, the sections containing the BPM assemblies can be installed around the ring as soon as built and leak checked.

Commissioning Plan

There are 26 vacuum sectors in the Recycler ring. As each sector is completed, the first step is to use a turbomolecular pump port to pull a vacuum and leak check that sector.

The next step is to turn on the 4 ion pumps in the vacuum sector. Because the initial vacuum pressure is in the 10^{-5} Torr range, the initial current drawn by the ion pumps will exceed the capacity of the control system operated remote power supplies. Therefore, a power supply capable of delivering 200 mA and transported around the ring on the turbomolecular pump cart is used to start each ion pump before attaching them to the remote supplies. At this point the pressure in the sector should quickly drop into the 10^{-8} Torr range.



Vacuum profile assuming an surface outgassing rate of 1×10^{-12} Torr-liter/cm^2-sec, a pumping speed of 30 liter/sec, and an ion pump spacing of 34 m.

Once the entire vacuum system is complete, beam opertions can begin with protons. The intention is to run only protons until all beam control and dynamics issues in the Recycler are complete, all components have been installed, and antiproton operations is imminent. At this point a 150°C in-situ bake is needed.

Each vacuum sector is baked individually, with a turbomolecular pump again attached. While the vacuum chamber heaters are maintaining the 150°C temperature and vacuum pressure begins dropping (indicating the water in the chamber has been purged, usually after 24 hours), the TSP filaments are again degassed to 40 Amps. At this point the heat is turned off and the ion pumps are again turned on after the system has cooled.

One by one, the TSP filaments are turned up to 50 Amps for 15 minutes to sublimate titanium. A water jacket is place on the TSP chamber to keep it cool, which improves the TSP performance and prevents vacuum pressure increases. The water jacket is part of a small closed loop water circulation system which will be developed before the project begins. It will take approximately 1 hours per pump.

At this point the system should have an average pressure $\leq 10^{-10}$ Torr.

Cost Estimate Overview

Summary of Section

- System Counts and Lengths
- Vacuum Chamber
- BPM/TSP Assembly
- Ion Pumps
- 150°C Bakeout System
- Magnetic Shielding
- Bellows
- Beam Pipe Stands
- Valves, Ports, & Gauges

System Counts and Lengths

The number of cells is 104. The number of half cells is 208. The total circumference of the Recycler is 3319.4 m. The counts and lengths associated with these half cells are:

Half Cell Parameter	Normal Arc	Straight Section	Dispersion Suppresser
Number	108	36	64
Total Length (m)	17.288	17.288	12.967
Magnet Length (m)	8.890	1.000	5.927
NonMagnet Length (m)	8.398	16.288	7.040
BPM/TSP/IP (m)	1.321	1.321	1.321
Beam Tube Length (m)	7.077	14.967	5.719

Vacuum Chamber

There are two ways to calculate how much beam tube needs to be purchased. One is the total length of the machine minus the length of the BPM/TSP and IP assemblies. The other is to estimate via the number of pipes needed per half cell, taking the penalty for excess pieces. The table below uses the latter method.

Half Cell Parameter	Normal Arc	Straight Section	Dispersion Suppresser	Total
Number	108	36	64	108
20' Pipe Lengths	3	3	2	
SubTotal Pieces	324	108	128	560
SubTotal Lengths (ft.)	6480	2160	2560	11,200

Excess pieces from when the tubes are cut to exact lengths will be used to create the BPM/TSP assemblies and the IP port sections. Because of the unknown extent to which this may be beneficial cost wise, we do not take credits for it in this estimate.

The labor associated with the preparation of the vacuum chamber is costed per standard 20' length of round pipe delivered from industry. The two dominant operations are pipe cleaning & degassing and pipe crushing. In both cases pipes are handled in batches, generating some economy by scale. The hydrogen degassing operation labor is dominated by (un)loading the 6 pipe sections into the oven (at Lab B) once per day (for a rate of 2 half cells per day).

The pipe boundaries have been chosen to minimize the number of welds required in the tunnel. At most 4 welds per half cell are needed. Using the experience with the test vacuum system in MP8, the allotted time for welding is more than enough even when the welding is occurring 1 ft. from the tunnel ceiling.

BPM/TSP Assembly

The cost of the BPM portion of the assembly is in the instrumentation estimate. The addition of the TSP and the bellows are also costed separately, but in this vacuum system estimate. Even though each of the three sub-components of the BPM/TSP assembly are costed individually, it is anticipated that the entire assembly will be designed and constructed as one integrated unit.

The cost of the TSP is broken into two portions. The titanium filaments mounted onto a holder are provided by industry. The holder is attached to a 2.75" O.D. conflat flange through which the connectors transmit the heater current necessary to fire the filaments and sublimate titanium.

The TSP housing is a stainless steel 6" O.D. tube section. On one side a 1" x 4" rectangular port mounted to a round flat plate is welded. On the other side a flat plate through which a 2.75" O.D. matching conflat flange is welded for connection with the filament holder.

Ion Pumps

The ion pumps are 30 liter/sec diodes identical to the Main Injector. The cost basis for Recycler pumps is the Main Injector order, where the Varian sales representative has verbally assured us that a Recycler order would be treated as an option type extension to the present order.

The ion pump power supplies are more standard low current models. Unlike the Main Injector design, which chose unusually high current capacity supplies to overcome leaks, Recycler operations would never survive this level of leak. Therefore, power supplies delivering a maximum current as low as 1 mA are acceptable (and a lot cheaper). The estimate was based on discussions with three ion pump power supply vendors. In all cases the present control system interface scheme (on, off, reset) was specified.

150°C Bakeout System

The 150°C bakeout system consists of heater elements and thermal insulation around the entire circumference of the Recycler ring. The system is not in the transfer lines. Therefore, the lengths associated with each of these components in the cost estimate are equal to the machine circumference.

The thermal insulation is a standard ceramic fiber woven cloth with which we have considerable purchase and R&D experience. There may be cheaper alternatives, such as an aluminized high-temperature mylar material used extensively in Japan. These alternatives are not reflected in the cost estimate.

The heater element is a coaxial pair of conductors on each side of the vacuum chamber. They are on the side so as to not use up valuable magnet aperture. There is one on each side since unbalanced heating can result in bending of the pipe (differential thermal expansion) which may bend stands. The heater element is coaxial since it has been observed that a common mode current through the magnet can result in significant field quality change (50 Amps DC current changed the field across the aperture by 1×10^{-3}. It is anticipated that this element can be trivially generated by placing two stainless steel tubes through one another after insulating the exterior of each tube with high temperature epoxy or varnish or paint.

The heater power supply is basically a portable variac mounted to a turbomolecular pump cart connected to the welding outlets. Each vacuum sector is heated individually with these already existing supplies.

Magnetic Shielding

Because of the ramping of Main Injector elements, a hermetic magnetic shield is required around the Recycler. This shielding is integrated with the thermal insulation of the 150°C in-situ bakeout system. The idea is to shield the large magnitude fields with an outside layer of low-mu soft iron, and shield the residual low magnitude fields by a large factor with hi-mu mu-metal. An extra layer of thermal insulation is placed between the two shields to prevent flux shorting.

The magnetic shielding is only in those places not already occupied by magnets, which already have a flux return which also serves as magnetic shielding.

Bellows

The bellows are a copy of the Main Injector design and cost. Not much additional design work has gone into these for the Recycler version. The design of a cheaper and more mechanically robust version of the bellows will be a priority in the next few months.

Beam Pipe Stands

Pipe stands have already been produced for the MP8 vacuum test section. Though the Recycler stands will be modified, the general spirit of simplicity will be maintained. Basically, they are steel plates with two slotted holes machined into them. Welded to the plates are stainless steel tubing which extend down the beam pipe and are terminated with a clamp with holds the pipe.

Between the BPMs the clamp is rigid and shaped to the beam pipe shape. This maintains a reference point to limit motion from heating expansion and also requires the pipe to be oriented on the correct XY axis.

At the beam position monitors a sliding holder is used to let the BPMs move longitudinally when the 150°C bake is occuring.

Valves, Ports, & Gauges

There are 26 vacuum sectors in the Recycler ring. Dividing 208 half cells by 26, this means that there are 8 half cells per sector. Each sector has a manual operated gate valve (round 4" I.D.) associated with it. Ancilliary hardware are 54 blank 6" O.D. rotatable flanges which must have the elliptical vacuum chamber shape (1.75" high by 3.75" wide, inside) cut out before welding to the beam pipes on either side of the valve. In addition, the copper gasket and the nuts/bolts must also be costed.

At each half cell boundary there is a pull-out section with a 1.5" O.D. port (2.75" O.D. conflat flange) for possible ion pump, turbomolecular pump, or vacuum gauge connection. Every other port is occupied by an ion pump for a total of 4.

In each vacuum sector an all-metal valve is required for the turbomolecular pump required for roughing down the sector vacuum.

In each vacuum sector one Pirani gauge (rough vacuum) and one ion gauge (high vacuum) is needed. The one remaining port is simply blanked off.

Associated with each of these connections are the copper gaskets and nuts/bolts needed to seal the ports. These ports have a 2.75" O.D. conflat flange associated with them, so there are 208 sets of gaskets and nuts/bolts.

Obligation, Cost, Labor, and EDIA Profiles

The cost and schedule of the Recycler ring vacuum system has a number of assumptions buried in it which affect the distribution and total of resources required to complete it.

1) It is assumed that the project officially begins on April 1, 1996. Before that time any design work or prototype production is not included in the project cost.

2) The construction of the vacuum system components roughly follows the magnet schedule, i.e. 5 half cells per week for a production period of 40 weeks.

3) Since no long lead time (greater than 6 months) components are anticipated, the cost and obligation profiles are fairly similar.

4) The labor estimate presumes that the installation work is **NOT** Davis-Bacon. The argument is that ultra-high vacuum system welding and handling requires a level of expertise and attention to detail not reliably found in contractors.

5) The installation of the magnets and the vacuum system are completely independent.

WORK PACKAGE COST ESTIMATE DETAIL SHEET
SYSTEM: RECYCLER

WORK PACKAGE WBS CODE (LEVEL 4): 3.1.2.1.
COMPONENT or WBS DESCRIPTION: Vacuum - Ring (Sheet A)
OVERALL MULTIPLIER: 1

NAME: Gerry Jackson
PHONE & MAIL STOP: x2317 MS 306
ESTIMATE DATE: 28-Oct-96

ITEM WBS (LEVEL 4 or 5)	ITEM DESCRIPTION	MATERIAL & SUPPLIES							LABOR						
		RESOURCE NAME	COST BASIS	UNIT MEASURE	NO. UNITS	Ayy $ /UNIT	FY96 $ /UNIT	TOTAL MAT $	RESOURCE NAME	NO. UNITS	LABOR TYPE	HOURS /UNIT	TOTAL HOURS	$/HOUR	TOTAL LABOR $
3.1.2.1.1	Four Inch Gate Valve	Valve	CP	Each	26		1,750	45,500					0		0
3.1.2.1.1.	Six Inch Rotatable Flange Blank	Blank	CP	Each	52		75	3,900					0		0
3.1.2.1.1.	Six Inch Copper Gasket	Gasket	CP	Each	52		3.50	182					0		0
3.1.2.1.1.	Bolts, Washers, and Plate Nuts	BNW	CP	Each	52		25	1,300					0		0
3.1.2.1.1.	Cutout Ellipse from Blank - 52 Pieces Total							0	Shop	1	S1	104	104	38.91	4,047
3.1.2.1.1.	Blank-to-Elliptical Pipe Welds - 52 Places Total							0	Welder	1	T3	26	26	25.94	674
3.1.2.1.1.	Beam Pipe - Round (20 Foot Lengths)	Beam Pipe	VQ	Foot	11,800		6.50	76,700					0		0
3.1.2.1.1.	Beam Pipe Cleaning & Degassing - Quantity 560 x 20 Foot Lengths								Mech Tech	1	T2	280	280	22.52	6,306
3.1.2.1.1.	Beam Pipe Crushing - Quantity 560 x 20 Foot Lengths								Mech Tech	1	T2	280	280	22.52	6,306
3.1.2.1.1.	Bellows	Bellows	EE	Each	416		300	124,800					0		0
3.1.2.1.1.	Mu-Metal Magnetic Shielding	MM Shielding	A95	Lin Foot	6,378	1.70	1.77	11,309					0		0
3.1.2.1.1.	Soft-Iron Magnetic Shielding	SI Shielding	A95	Lin Foot	6,378	3.72	3.88	24,746					0		0
3.1.2.1.1.	Coaxial Beam Pipe Heater - Parts and Fabrication @ 0.5 Hour/10 Feet	CHeater	EE	Lin Foot	10,891		2.00	21,782	Tech	1	T2	545	545	22.52	12,263
3.1.2.1.1.	Thermal Insulator	Insulator	A95	Lin Foot	10,891	1.25	1.30	14,199					0		0
3.1.2.1.1.	Beam Tube Stands with Hiltis - End Supports by BPMs, 2 per Half Cell	Stands	EE	Each	416		100	41,600					0		0
3.1.2.1.2.	Ion Pumps - Fitted for SHV Connector	Ion Pump	A96	Each	104		750	78,000					0		0
3.1.2.1.2.	Ion Pump Power Supplies	Ion Pump PS	EE	Each	104		400	41,600					0		0
3.1.2.1.3.	Turbo Port 1.5 Inch All-Metal Valves	Valve	CP	Each	26		375	9,750					0		0
3.1.2.1.2.	2.75 Inch Blank - One per Sector	Blank	CP	Each	26		14	364					0		0
3.1.2.1.2.	Bolts, Washers, and Plate Nuts	BNW	CP	Each	208		13	2,704					0		0
3.1.2.1.2.	2.75 Inch Copper Gasket	Gasket	CP	Each	208		1.70	354					0		0
TOTALS								498,790							29,596

TOTAL MATERIAL & SUPPLIES AND LABOR COST:	528,386	**TOTAL M & S AND TOTAL LABOR COSTS x OVERALL MULTIPLIER:**	528,386

TECHNICAL DESCRIPTION:

ESTIMATE ASSUMPTIONS:

WORK PACKAGE COST ESTIMATE DETAIL SHEET
SYSTEM: RECYCLER

WORK PACKAGE WBS CODE (LEVEL 4): 3.1.2.1.

COMPONENT or WBS DESCRIPTION: Vacuum - Ring (Sheet B)

OVERALL MULTIPLIER: 1

NAME: Gerry Jackson

PHONE & MAIL STOP: x2317 MS 306

ESTIMATE DATE: 28-Oct-96

ITEM WBS (LEVEL 4 or 5)	ITEM DESCRIPTION	MATERIAL & SUPPLIES RESOURCE NAME	COST BASIS	UNIT MEASURE	NO. UNITS	Ayy $ /UNIT	FY96 $ /UNIT	TOTAL MAT $	LABOR RESOURCE NAME	NO. UNITS	LABOR TYPE	HOURS /UNIT	TOTAL HOURS	$/HOUR	TOTAL LABOR $
3.1.2.1.3.	Turbo Port Ion Gauge	Gauge	CP	Each	26		425	11,050					0		0
3.1.2.1.3.	Turbo Port Pirani Gauge	Gauge	CP	Each	26		122	3,172					0		0
3.1.2.1.3.	Ion Pump High Voltage Cable - Red RG58C/U (1170-0360)	Cable	CP	Foot	69,600		0.10	6,960					0		0
3.1.2.1.3.	Gauge Cable - Green RG58C/U (1170-0340)	Cable	CP	Foot	15,600		0.10	1,560					0		0
3.1.2.1.3.	Gauge Cable - 22 AWG 6 Conductor (1170-0600)	Cable	CP	Foot	15,600		0.11	1,716					0		0
3.1.2.1.3.	Ion Pump High Voltage SHV Connector for RG58C/U (1435-2110)	Connector	CP	Each	104		4.19	436					0		0
3.1.2.1.3.	Ion Pump BNC Connectors for RG58C/U (1435-2850)	Connector	CP	Each	104		2.28	237					0		0
3.1.2.1.3.	Ion Gauge BNC Connectors for RG58C/U (1435-2850)	Connector	CP	Each	26		2.28	59					0		0
3.1.2.1.3.	Pirani Gauge Connector at Gauge	Connector	EE	Each	26		2.00	52					0		0
3.1.2.1.3.	Pirani Gauge Connector at CIA Crate - 8 Pos Trim Trio (1430-3000)	Connector	CP	Each	26		18.20	473					0		0
3.1.2.1.2.	Machine Slotted Pump Hole - Quantity 208							0	Shop	1	S1	624	624	38.91	24,280
3.1.2.1.2.	Weld 1.5 Inch Pullout for Pump - Quantity 208							0	Welder	1	T3	416	416	25.94	10,791
3.1.2.1.2.	Pump Port Flange	Flange	CP	Each	208		14	2,912					0		0
3.1.2.1.1.	Titanium Windows	Window	EE	Each	4		1,000	4,000					0		0
3.1.2.1.1.	Lambertson Flanges	Flange	EE	Each	8		200	1,600					0		0
3.1.2.1.1.	Six Inch Rotatable Kicker Flanges	Flange	CP	Each	4		75	300					0		0
3.1.2.1.1.	Round to Elliptical Transition Pieces	Adapter	EE	Each	10		50	500					0		0
3.1.2.1.1.	Titanium Sublimation Pump Filaments	TS Pumps	CP	Each	624		175	109,200					0		0
3.1.2.1.1.	Beam Tube Support with Hiltis - Mid Section Support, 1 per Half Cell	Stands	EE	Each	208		50	10,400					0		0
3.1.2.1.1.	Titanium Sublimation Pumps	Port	EE	Each	624		200	124,800					0		0
TOTALS								279,427							35,071

TOTAL MATERIAL & SUPPLIES AND LABOR COST:	314,498	**TOTAL M & S AND TOTAL LABOR COSTS x OVERALL MULTIPLIER:**	314,498

TECHNICAL DESCRIPTION:

ESTIMATE ASSUMPTIONS:

WORK PACKAGE COST ESTIMATE DETAIL SHEET
SYSTEM: RECYCLER

WORK PACKAGE WBS CODE (LEVEL 4): 3.1.2.12.

COMPONENT or WBS DESCRIPTION: Vacuum - Transfer Lines (Sheet A)

OVERALL MULTIPLIER: 1

NAME: Gerry Jackson

PHONE & MAIL STOP: x2317 MS 306

ESTIMATE DATE: 28-Oct-96

ITEM WBS (LEVEL 4 or 5)	ITEM DESCRIPTION	MATERIAL & SUPPLIES: RESOURCE NAME	COST BASIS	UNIT MEASURE	NO. UNITS	Ayy $ /UNIT	FY96 $ /UNIT	TOTAL MAT $	LABOR: RESOURCE NAME	NO. UNITS	LABOR TYPE	HOURS /UNIT	TOTAL HOURS	$/HOUR	TOTAL LABOR $
3.1.2.12.3.	Four Inch Gate Valve	Valve	CP	Each	6		1,750	10,500					0		0
3.1.2.12.1.	Six Inch Rotatable Flange Blank	Blank	CP	Each	12		75	900					0		0
3.1.2.12.1.	Six Inch Copper Gasket	Gasket	CP	Each	12		3.50	42					0		0
3.1.2.12.1.	Bolts, Washers, and Plate Nuts	BNW	CP	Each	12		25	300					0		0
3.1.2.12.1.	Cutout Ellipse from Blank - 12 Pieces Total							0	Shop	1	S1	24	24	38.91	934
3.1.2.12.1.	Blank-to-Elliptical Pipe Welds - 12 Places Total							0	Welder	1	T3	6	6	25.94	156
3.1.2.12.1.	Beam Pipe - Round (20 Foot Lengths)	Beam Pipe	VQ	Foot	900		6.50	5,850					0		0
3.1.2.12.1.	Beam Pipe Cleaning & Degassing - Quantity 45 x 20 Foot Lengths							0	Mech Tech	1	T2	24	24	22.52	540
3.1.2.12.1.	Beam Pipe Crushing - Quantity 45 x 20 Foot Lengths								Mech Tech	1	T2	24	24	22.52	540
3.1.2.12.1.	Bellows	Bellows	EE	Each	45		300	13,500					0		0
3.1.2.12.1.	Mu-Metal Magnetic Shielding	MM Shielding	A95	Lin Foot	650	1.70	1.77	1,153					0		0
3.1.2.12.1.	Soft-Iron Magnetic Shielding	SI Shielding	A95	Lin Foot	650	3.72	3.88	2,522					0		0
3.1.2.12.1.	Thermal Insulator	Insulator	A95	Lin Foot	900	1.25	1.30	1,173					0		0
3.1.2.12.1.	Beam Tube Stands with Hiltis - End Supports, 2 per Section	Stands	EE	Each	36		100	3,600					0		0
3.1.2.12.2.	Ion Pumps - Fitted for SHV Connector	Ion Pump	A96	Each	6		750	4,500					0		0
3.1.2.12.2.	Ion Pum Power Supply	Ion Pump PS	EE	Each	6		400	2,400					0		0
3.1.2.12.3.	Turbo Port 1.5 Inch All-Metal Valves	Valve	CP	Each	3		375	1,125					0		0
3.1.2.12.2.	2.75 Inch Blank	Blank	CP	Each	3		14	42					0		0
3.1.2.12.2.	Bolts, Washers, and Plate Nuts	BNW	CP	Each	18		13	234					0		0
3.1.2.12.2.	2.75 Inch Copper Gasket	Gasket	CP	Each	18		1.70	31					0		0
TOTALS								47,871							2,170

TOTAL MATERIAL & SUPPLIES AND LABOR COST: 50,042

TOTAL M & S AND TOTAL LABOR COSTS x OVERALL MULTIPLIER: 50,042

TECHNICAL DESCRIPTION:

ESTIMATE ASSUMPTIONS:

WORK PACKAGE COST ESTIMATE DETAIL SHEET
SYSTEM: RECYCLER

WORK PACKAGE WBS CODE (LEVEL 4):	3.1.2.12.	**NAME:**	Gerry Jackson
COMPONENT or WBS DESCRIPTION:	Vacuum - Transfer Lines (Sheet B)	**PHONE & MAIL STOP:**	x2317 MS 306
OVERALL MULTIPLIER:	1	**ESTIMATE DATE:**	28-Oct-96

ITEM WBS (LEVEL 4 or 5)	ITEM DESCRIPTION	MATERIAL & SUPPLIES RESOURCE NAME	COST BASIS	UNIT MEASURE	NO. UNITS	Ayy $ /UNIT	FY96 $ /UNIT	TOTAL MAT $	LABOR RESOURCE NAME	NO. UNITS	LABOR TYPE	HOURS /UNIT	TOTAL HOURS	$/HOUR	TOTAL LABOR $
3.1.2.12.3.	Turbo Port Ion Gauge	Gauge	CP	Each	3		425	1,275					0		0
3.1.2.12.3.	Turbo Port Pirani Gauge	Gauge	CP	Each	3		122	366					0		0
3.1.2.12.3.	Ion Pump High Voltage Cable - Red RG58C/U (1170-0360)	Cable	CP	Foot	1,800		0.10	180					0		0
3.1.2.12.3.	Gauge Cable - Green RG58C/U (1170-0340)	Cable	CP	Foot	900		0.10	90					0		0
3.1.2.12.3.	Gauge Cable - 22 AWG 6 Conductor	Cable	CP	Foot	900		0.11	99					0		0
3.1.2.12.3.	Ion Pump High Voltage SHV Connector for RG58C/U (1435-2110)	Connector	CP	Each	6		4.19	25					0		0
3.1.2.12.3.	Ion Pump BNC Connectors for RG58C/U (1435-2850)	Connector	CP	Each	6		2.28	14					0		0
3.1.2.12.3.	Ion Gauge BNC Connectors for RG58C/U (1435-2850)	Connector	CP	Each	3		2.28	7					0		0
3.1.2.12.3.	Pirani Gauge Connector at Gauge	Connector	EE	Each	3		2.00	6					0		0
3.1.2.12.3.	Pirani Gauge Connector at CIA Crate - 8 Pos Trim Trio (1430-3000)	Connector	CP	Each	3		18.20	55					0		0
3.1.2.1.2.	Machine Slotted Pump Hole - Quantity 18							0	Shop	1	S1	54	54	38.91	2,101
3.1.2.1.2.	Weld 1.5 Inch Pullout for Pump - Quantity 18							0	Welder	1	T3	36	36	25.94	934
3.1.2.1.2.	Pump Port Flange	Flange	CP	Each	18		14	252					0		0
3.1.2.1.2.	Beam Tube Stands with Hiltis - Mid Section Support, 1 per Section	Stands	EE	Each	18		50	900					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
	TOTALS							3,268							3,035

TOTAL MATERIAL & SUPPLIES AND LABOR COST:	6,303	**TOTAL M & S AND TOTAL LABOR COSTS x OVERALL MULTIPLIER:**	6,303

TECHNICAL DESCRIPTION:

ESTIMATE ASSUMPTIONS:

WORK PACKAGE COST ESTIMATE DETAIL SHEET
SYSTEM: RECYCLER

WORK PACKAGE WBS CODE (LEVEL 4): 3.1.2.14.
COMPONENT or WBS DESCRIPTION: Vacuum - EDIA
OVERALL MULTIPLIER: 1

NAME: Gerry Jackson
PHONE & MAIL STOP: x2317 MS 306
ESTIMATE DATE: 28-Oct-96

		MATERIAL & SUPPLIES							LABOR						
ITEM WBS (LEVEL 4 or 5)	ITEM DESCRIPTION	RESOURCE NAME	COST BASIS	UNIT MEASURE	NO. UNITS	Ayy $ /UNIT	FY96 $ /UNIT	TOTAL MAT $	RESOURCE NAME	NO. UNITS	LABOR TYPE	HOURS /UNIT	TOTAL HOURS	$/HOUR	TOTAL LABOR $
								0					0		0
								0					0		0
3.1.2.14.	Recycler Vacuum System EDIA							0	Jackson	1	PH	400	400	42.33	16,932
3.1.2.14.	Recycler Vacuum System Design Drafting							0	DDrafter	1	DC	600	600	37.33	22,398
3.1.2.14.	Vacuum System Installation - Supervision and Inspection							0	Tech	1	T2	2,080	2,080	22.52	46,842
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
TOTALS								0							86,172

TOTAL MATERIAL & SUPPLIES AND LABOR COST:	86,172	TOTAL M & S AND TOTAL LABOR COSTS x OVERALL MULTIPLIER:	86,172

TECHNICAL DESCRIPTION:

ESTIMATE ASSUMPTIONS:

WORK PACKAGE COST ESTIMATE DETAIL SHEET
SYSTEM: RECYCLER

WORK PACKAGE WBS CODE (LEVEL 4): 3.1.2.15.
COMPONENT or WBS DESCRIPTION: Vacuum - Installation (Ultra High Vacuum) (Sheet A)
OVERALL MULTIPLIER: 1

NAME: Gerry Jackson
PHONE & MAIL STOP: x2317 MS 306
ESTIMATE DATE: 28-Oct-96

		MATERIAL & SUPPLIES							LABOR						
ITEM WBS (LEVEL 4 or 5)	ITEM DESCRIPTION	RESOURCE NAME	COST BASIS	UNIT MEASURE	NO. UNITS	Ayy $ /UNIT	FY96 $ /UNIT	TOTAL MAT $	RESOURCE NAME	NO. UNITS	LABOR TYPE	HOURS /UNIT	TOTAL HOURS	$/HOUR	TOTAL LABOR $
3.1.2.15.	Install Ring Manual Gate Valves - 26 Places							0	Vac Tech	1	T2	26	26	22.52	586
3.1.2.15.	Install Transfer Line Gate Valves - 6 Places							0	Vac Tech	1	T2	6	6	22.52	135
3.1.2.15.	Weld Ring Bellows							0	Welder	1	IP	416	416	48.46	20,159
3.1.2.15.	Weld Transfer Line Bellows							0	Welder	1	IP	45	45	48.46	2,181
3.1.2.15.	Wrap Ring Beam Tube with Mu-Metal							0	Pipe Fitter	1	IP	208	208	48.46	10,080
3.1.2.15.	Wrap Transfer Line Beam Tube with Mu-Metal							0	Pipe Fitter	1	IP	18	18	48.46	872
3.1.2.15.	Wrap Ring Beam Tube with Thermal Insulator							0	Pipe Fitter	1	IP	208	208	48.46	10,080
3.1.2.15.	Wrap Transfer Line Beam Tube with Thermal Insulator							0	Pipe Fitter	1	IP	18	18	48.46	872
3.1.2.15.	Wrap Ring Beam Tube with Soft Iron							0	Pipe Fitter	1	IP	208	208	48.46	10,080
3.1.2.15.	Wrap Transfer Line Beam Tube with Soft Iron							0	Pipe Fitter	1	IP	18	18	48.46	872
3.1.2.15.	Survey Ring Beam Pipe Stand Locations							0	Surveyor	2	IA	208	416	36.67	15,255
3.1.2.15.	Survey Transfer Line Beam Pipe Stand Locations							0	Surveyor	2	IA	18	36	36.67	1,320
3.1.2.15.	Install Ring Beam Tube Stands - 3 per Half Cell							0	Laborer	3	IL	156	468	32.07	15,009
3.1.2.15.	Install Transfer Line Beam Tube Stands - 3 per Section							0	Laborer	3	IL	14	42	32.07	1,347
3.1.2.15.	Mount Ring Beam Tube and Coaxial Heater							0	Pipe Fitter	3	IP	104	312	48.46	15,120
3.1.2.15.	Mount Transfer Line Beam Tube							0	Pipe Fitter	3	IP	9	27	48.46	1,308
3.1.2.15.	Install Ring Ion Pumps - Quantity 104							0	Vac Tech	1	T2	52	52	22.52	1,171
3.1.2.15.	Install Transfer Line Ion Pumps - Quantity 6							0	Vac Tech	1	T2	3	3	22.52	68
3.1.2.15.	Install Ring Turbo Valves - Quantity 26							0	Vac Tech	1	T2	13	13	22.52	293
3.1.2.15.	Install Transfer Line Turbo Valves - Quantity 3							0	Vac Tech	1	T2	2	2	22.52	45
	TOTALS							0							106,851

TOTAL MATERIAL & SUPPLIES AND LABOR COST: 106,851

TOTAL M & S AND TOTAL LABOR COSTS x OVERALL MULTIPLIER: 106,851

TECHNICAL DESCRIPTION:

ESTIMATE ASSUMPTIONS:

Most of the labor on this sheet is temporally judged to be Davis-Bacon. Some of the activities assigned to IP may be assigned to IL, thereby affording a cost savings. A case may and should be made that Fermilab personnel should do some of this work because the vacuum system is a ultra-high vacuum system which contractors would not typically encounter.

WORK PACKAGE COST ESTIMATE DETAIL SHEET
SYSTEM: RECYCLER

WORK PACKAGE WBS CODE (LEVEL 4): 3.1.2.15.
COMPONENT or WBS DESCRIPTION: Vacuum - Installation (Ultra-High Vacuum) (Sheet B)
OVERALL MULTIPLIER: 1

NAME: Gerry Jackson
PHONE & MAIL STOP: x2317 MS 306
ESTIMATE DATE: 28-Oct-96

ITEM WBS (LEVEL 4 or 5)	ITEM DESCRIPTION	MATERIAL & SUPPLIES RESOURCE NAME	COST BASIS	UNIT MEASURE	NO. UNITS	Ayy $ /UNIT	FY96 $ /UNIT	TOTAL MAT $	LABOR RESOURCE NAME	NO. UNITS	LABOR TYPE	HOURS /UNIT	TOTAL HOURS	$/HOUR	TOTAL LABOR $
3.1.2.15.	Install Ring Ion Gauges - Quantity 26							0	Vac Tech	1	T2	13	13	22.52	293
3.1.2.15.	Install Transfer Line Ion Gauges - Quantity 3							0	Vac Tech	1	T2	2	2	22.52	45
3.1.2.15.	Install Ring Pirani Gauges - Quantity 26							0	Vac Tech	1	T2	13	13	22.52	293
3.1.2.15.	Install Transfer Line Pirani Gauges - Quantity 3							0	Vac Tech	1	T2	2	2	22.52	45
3.1.2.15.	Install Ring Blanks - Quantity 26							0	Vac Tech	1	T2	13	13	22.52	293
3.1.2.15.	Install Transfer Line Blanks - Quantity 3							0	Vac Tech	1	T2	2	2	22.52	45
3.1.2.15.	Install Ring Ion Pump Cables - Quantity 104							0	Electrician	2	IE	104	208	45.04	9,368
3.1.2.15.	Install Transfer Line Ion Pump Cables - Quantity 6							0	Electrician	2	IE	6	12	45.04	540
3.1.2.15.	Install Ring Ion Gauge Cables - Quantity 26							0	Electrician	2	IE	26	52	45.04	2,342
3.1.2.15.	Install Transfer Line Ion Gauge Cables - Quantity 3							0	Electrician	2	IE	3	6	45.04	270
3.1.2.15.	Install Ring Pirani Gauge Cables - Quantity 26							0	Electrician	2	IE	26	52	45.04	2,342
3.1.2.15.	Install Transfer Line Pirani Gauge Cables - Quantity 3							0	Electrician	2	IE	3	6	45.04	270
3.1.2.15.	Leak Check and Bakeout of Installed Ring Beam Pipe							0	Vac Tech	2	T2	416	832	22.52	18,737
3.1.2.15.	Leak Check and Bakeout of Installed Transfer Line Beam Pipe							0	Vac Tech	2	T2	24	48	22.52	1,081
3.1.2.15.	Install Ring Titanium Sublimation Pumps - Quanity 624							0	Vac Tech	1	T2	312	312	22.52	7,026
								0					0		0
								0					0		0
								0					0		0
								0					0		0
								0					0		0
	TOTALS							0							42,991

TOTAL MATERIAL & SUPPLIES AND LABOR COST: 42,991

TOTAL M & S AND TOTAL LABOR COSTS x OVERALL MULTIPLIER: 42,991

TECHNICAL DESCRIPTION:

ESTIMATE ASSUMPTIONS: