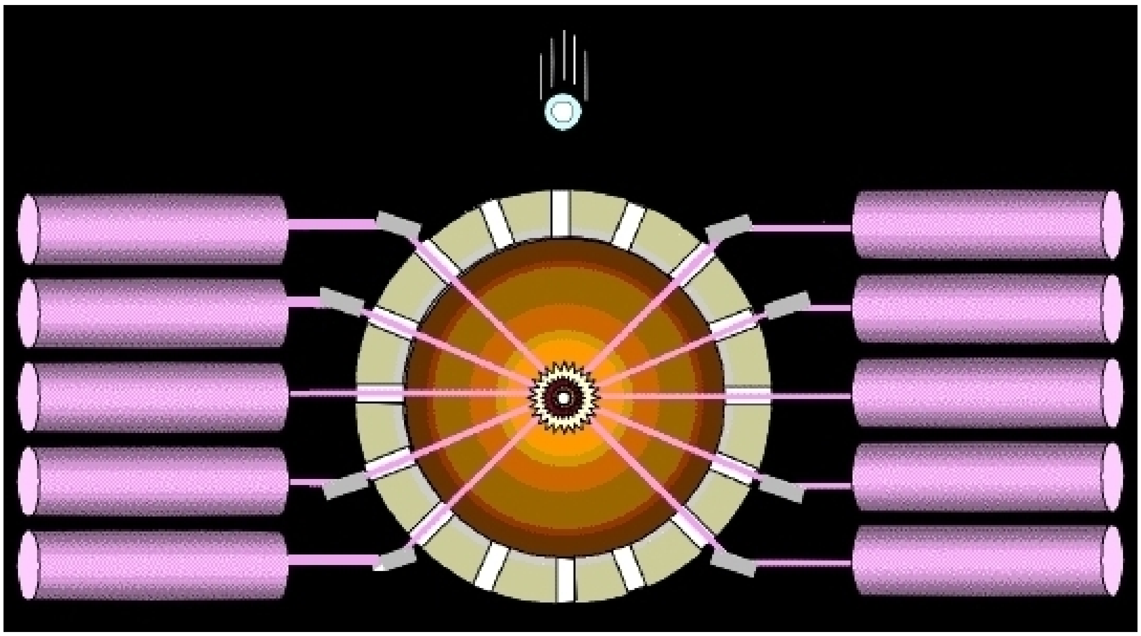
IFE CHAMBER VACUUM SYSTEM



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*** Please see "IFE Chamber Vacuum System" Poster**

Requirements

Requirement	Action
• Design pumping system to meet requirements of IFE target chamber in accordance with system specifications	• Proposed conceptual design employing conventional components indicate that system requirements can be achieved
• Provide a cost-effective/ economical system to meet requirements	• Employ pumps for multiple purposes (i.e. Kinney pumps also configured to rough down target chamber and beam ports) • Employ commercial off the shelf components with good operational history for system
• Provide a system for “eventual” D-T operations	• Proposed system will support tritium operations
• Design pumping system to operate in 1 k gauss magnetic field	• Employ shielding around target chamber TMP’s to provide a 50 gauss field which the TMP’s will operate in
• Manage debris in target chamber from target remnants	• Screens incorporated into the inlet of target chamber TMP’s
• Establish an accurate cost estimate for system components	• Vendor contacts established for component specifications and cost
• Design a reliable IFE target chamber pumping system	• Proposed conceptual design employs similar components successfully used on a large MFE (TFTR) vacuum vessel

Ref. Doc.: J. Sethian “Vacuum System for a Laser IFE Chamber”, January 23, 2005.

Conceptual Design

- Cryo pumping reviewed, but determined to be too costly.
- System employs commercial off the shelf (COTS) components to minimize costs.
- System employs high efficiency turbo molecular pumps backed by roughing pumps.
- System employs components which have good operational history in similar type environments.
- Cost estimate from vendors, online quotes, and telephone conversations with sales representatives.
- System designed to transition to tritium use with minimal modifications.

System Specifications

Target Chamber

Inner radius = 6.5 m
Outer radius = 7.3 m
Target chamber volume = 1,150,346 liters
Toroidal duct volume = 145,141 liters
Total volume (without beam ports) = 1,295,487 liters
First wall material = SiC

Target Chamber Pressures

Operational base pressure = 0.5 mtorr
Gas load = 141 torr-liters/sec
Total system in-leakage = $1x10^{-5}$ torr-liters/sec

Vacuum Pumping System – Target Chamber

TMP pumping ducts = 60
TMP's (Varian-V 6000) = 2/duct
TMPS's total =120
TMP backing pumps (Kinney KMBD-2000) = 1/6 TMP's
Backing pumps total = 20

Vacuum Pumping System – Beam Ports

TMP's (Varian-V 2000 HT) = 1/beam port
TMPS's total =60

Target Chamber TMP Magnetic Shielding

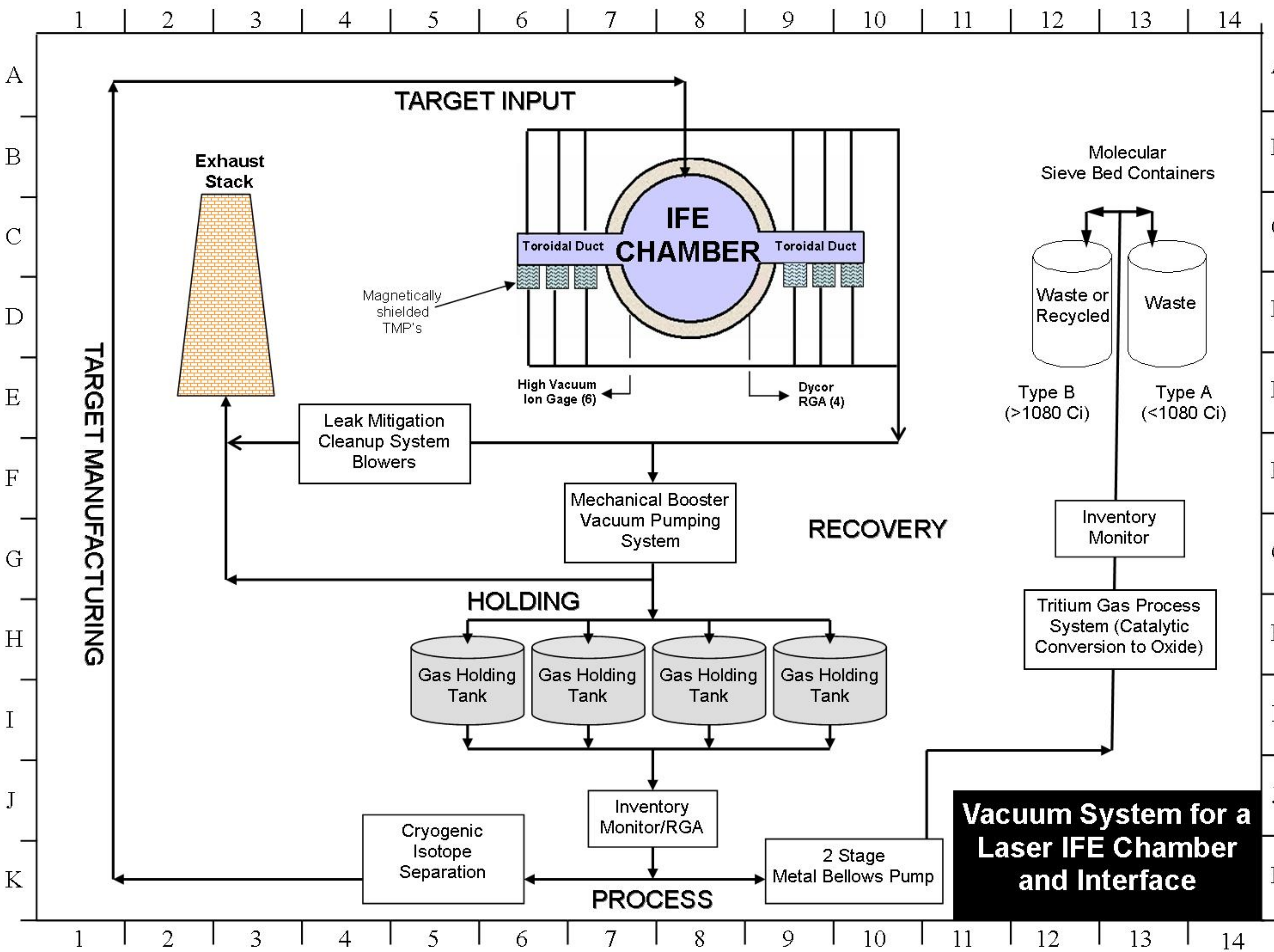
Magnetic shields = 1/target chamber TMP
Magnetic shields total = 120
Shield design for external 1 kgauss field
TMP shielded to less than 50 gauss

TMP Heat Loading

Gas load T 1000K – 4000K = no operational effects on TMP's

System Pumpdown

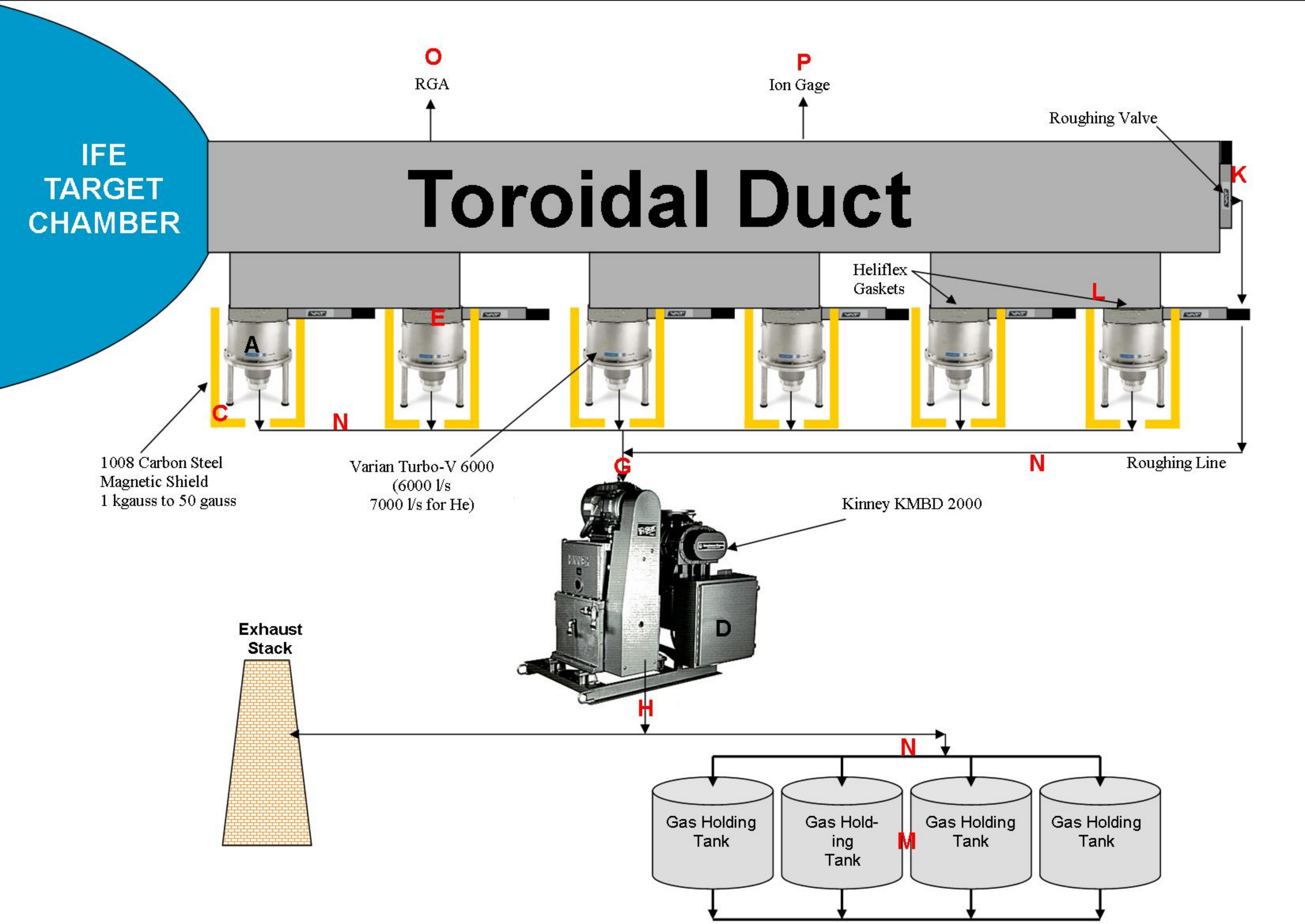
From 760 torr to 0.5 mtorr (initial conditions) = < 8 hrs



Vacuum System for a Laser IFE Chamber and Interface

IFE Vacuum System Components

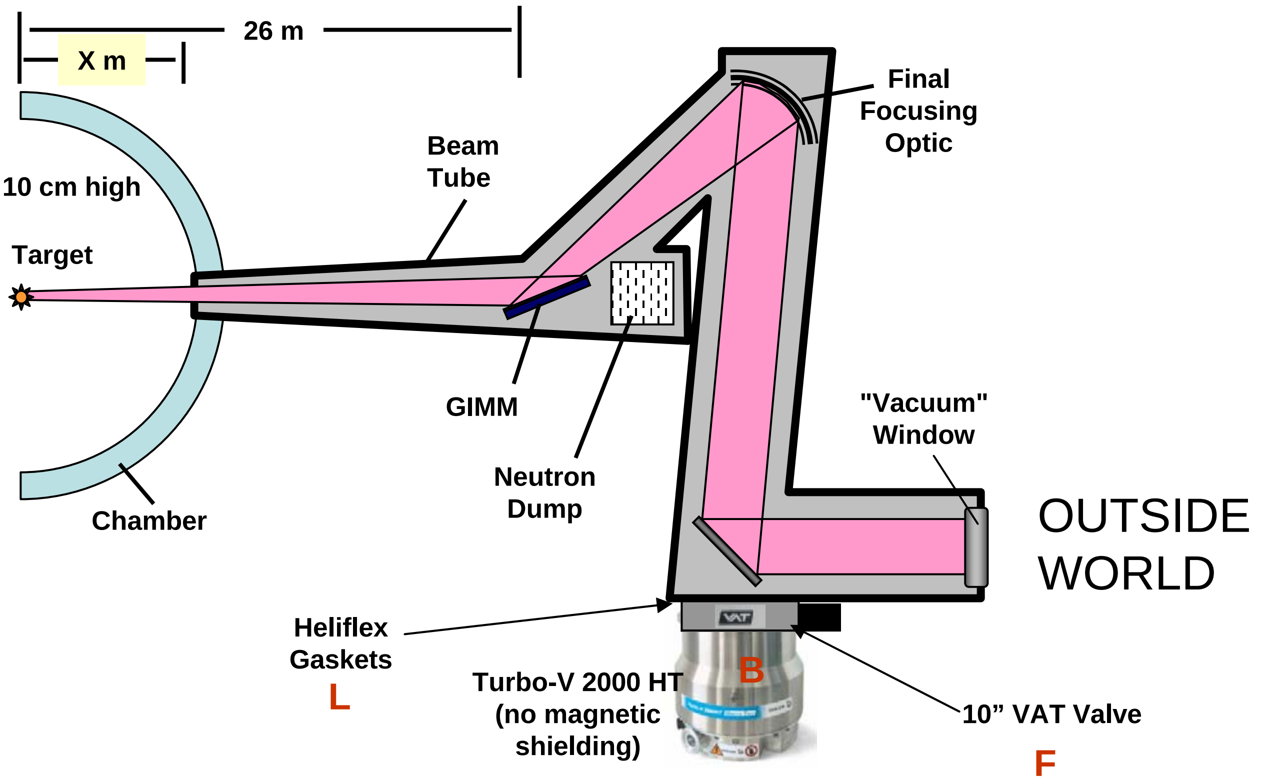
Key	Equipment Name
A	Varian Turbo-V 6000 (on target chamber)
B	Varian Turbo-V 2000 HT (on each beam tube)
C	Magnetic Shielding (only on Turbo-V 6000)
D	Kinney KMBD -2000 Backing Pumps
E	TMP/Target Chamber Isolation Valves (VAT valves, 20" throughput)
F	Beam Tube (TMP) Isolation Valves (VAT valves, 10" throughput)
G	Roughing Valves (between TMP exhaust/Kinney Inlet)
H	Gate Valves (after Kinney discharge)
I	Dycor RGA (0-200 AMU w/ pumping system)
J	Instrumentation and Control
K	Target Chamber Isolation Valves (for roughing pump interface-VAT valves, 8" throughput)
L	Heli-Flex Seals
M	Gas Holding Tanks (10 m^3)
N	Interfacing Piping
O	Residual Gas Analyzer
P	High Vacuum Ion Gage


IFE TARGET CHAMBER
Toroidal Duct
O
RGA
P
Ion Gage
Roughing Valve
K
Heliflex Gaskets
L
E
A
C
N
G
1008 Carbon Steel
Magnetic Shield
1 kgauss to 50 gauss
Varian Turbo-V 6000
(6000 l/s
7000 l/s for He)
N
Roughing Line
Kinney KMBD 2000
D
Exhaust Stack
H
N
Gas Holding Tank
Gas Hold-ing Tank
M
Gas Holding Tank
Gas Holding Tank

Beam Port

beam port aperture*: 125 cm wide x 10 cm high
Equivalent dia 40 cm
target to GIMM* 26 m
GIMM width 90 cm
GIMM length 10 m
f# of the system 200

* Closest point on GIMM to tgt



Prepared by: Bob Parsells

Scope

This analysis evaluates the pressure as a function of time in the 6.5 meter radius IFE chamber

References

1. John Sethian, "Vacuum System for a Laser IFE Chamber", Jan 23, 2005.
2. A. Roth, "Vacuum Technology", North -Holand, 1996.

Assumptions

1. IFE spherical chamber 6.5 meters radius.
2. IFE mid-plane toroidal duct 10 meter radius, 80 cm high

Pumping speed

$P_0 := 1 \cdot atm$

$P_0 = 760\,torr$

$S_{TMP} := 6000 \cdot \frac{liter}{sec}$

$S_{eff\_TMP} := \frac{1}{2} \cdot S_{TMP}$

$r_{sphere} := 6.5 \cdot m$

$V_{sphere} := \frac{4}{3} \cdot \pi \cdot r_{sphere}^3$

$S_{eff\_TMP\_sys} := 120 \cdot S_{eff\_TMP}$

$V_{sphere} = 1.15 \times 10^3\,m^3$

$V_{duct} := 145141 \cdot liter$

$S_{eff\_TMP\_sys} = 3.6 \times 10^5\,\frac{liter}{sec}$

$V := V_{sphere} + V_{duct}$

Half the system to rough and half the system to back TMPs

Half the system is 10 pumps

$S_{booster} := 2000 \cdot \frac{ft^3}{min}$

$S_{eff\_booster} := \frac{1}{2} \cdot S_{booster}$

$S_{eff\_booster} = 471.947\,\frac{liter}{sec}$

$S_{booster\_sys} := 10 \cdot S_{eff\_booster}$

$S_{booster\_sys} = 4.719 \times 10^3\,\frac{liter}{sec}$

$S_{mech\_pmp\_sys} := \frac{1}{10} \cdot S_{booster\_sys}$

PHASE I

Pump down time to turn on booster pump, from Atmosphere to 10 Torr

$T_{one} := \frac{V}{S_{mech\_pmp\_sys}} \cdot \ln\left(\frac{760 \cdot torr}{10 \cdot torr}\right)$

$T_{one} = 198.1\,min$

$P_o := 760 \cdot torr$

$N := 600$

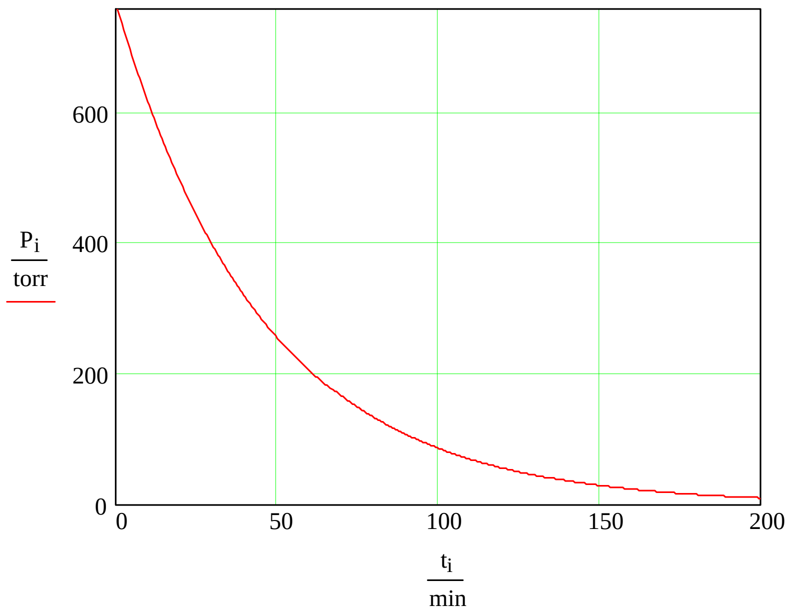
$i := 0..N$

$t_i := i \cdot \frac{300}{N} \cdot min$

$t_{150} = 75\,min$

$t_0 = 0\,s$

$P_i := P_o \cdot e^{\frac{-S_{mech\_pmp\_sys}}{V} \cdot t_i}$



$P_0 = 760\,torr$

$P_{100} = 254.784\,torr$

PHASE I PUMP DOWN
PHASE II

Pump down time from 10 torr to 20 mtorr when TMPs are opened to the Vacuum Vessel.

$T_{two} := \frac{V}{S_{booster\_sys}} \cdot \ln\left(\frac{10 \cdot torr}{.02 \cdot torr}\right)$

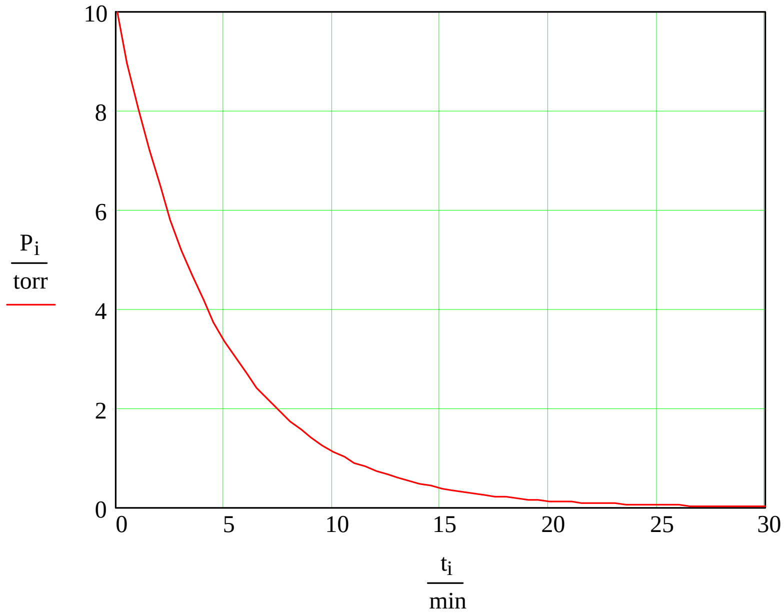
$T_{two} = 28.432\,min$

$P_o := 10 \cdot torr$

$t_0 = 0\,s$

$P_i := P_o \cdot e^{\frac{-S_{booster\_sys}}{V} \cdot t_i}$

$t_{60} = 30\,min$



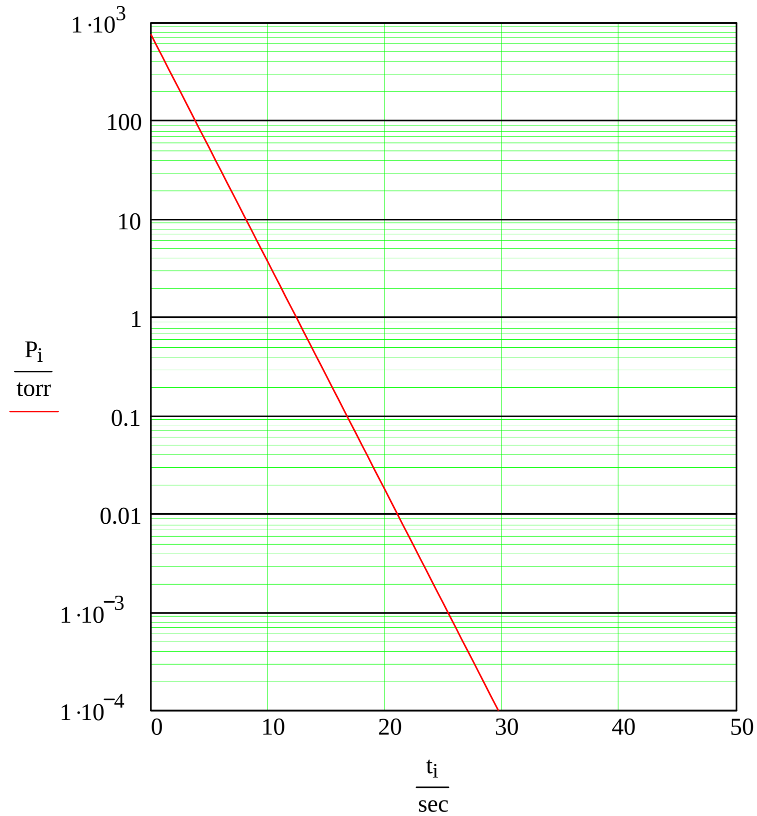
$P_0 = 10\,torr$

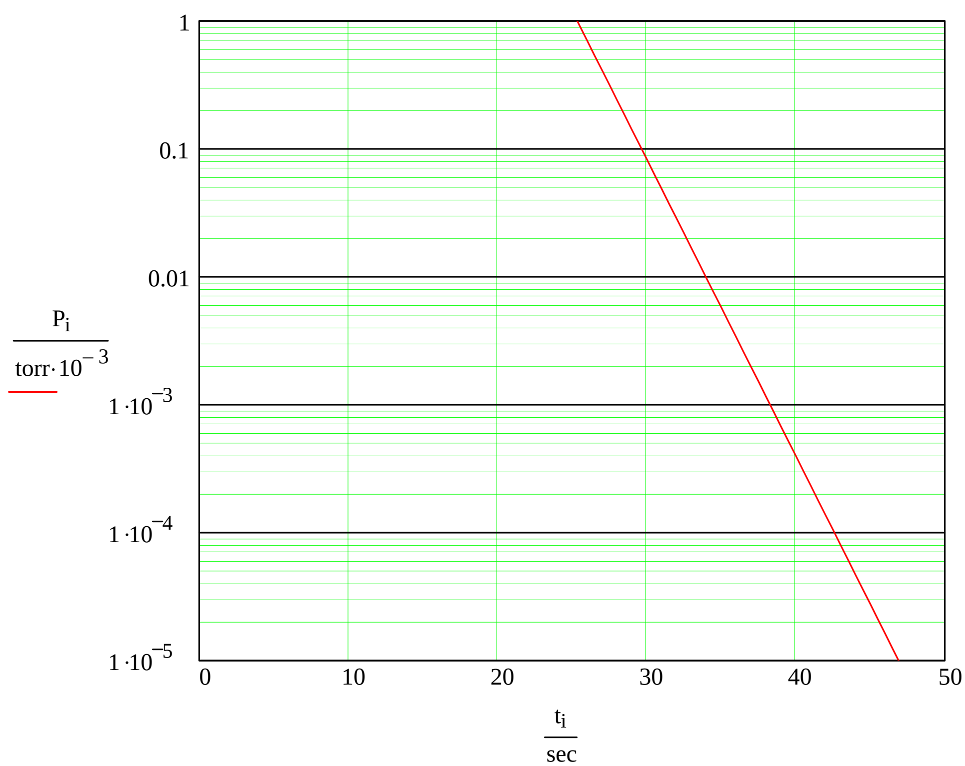
$P_{57} = 0.02\,torr$

PHASE II PUMP DOWN
PHASE III

Pump down time of TMP to base pressure. This depends on the bakeout system and surface conditions.

Vacuum System for a Laser IFE Chamber





Vacuum System for a Laser IFE Chamber

The same curve with a total outgassing rate Q becomes.

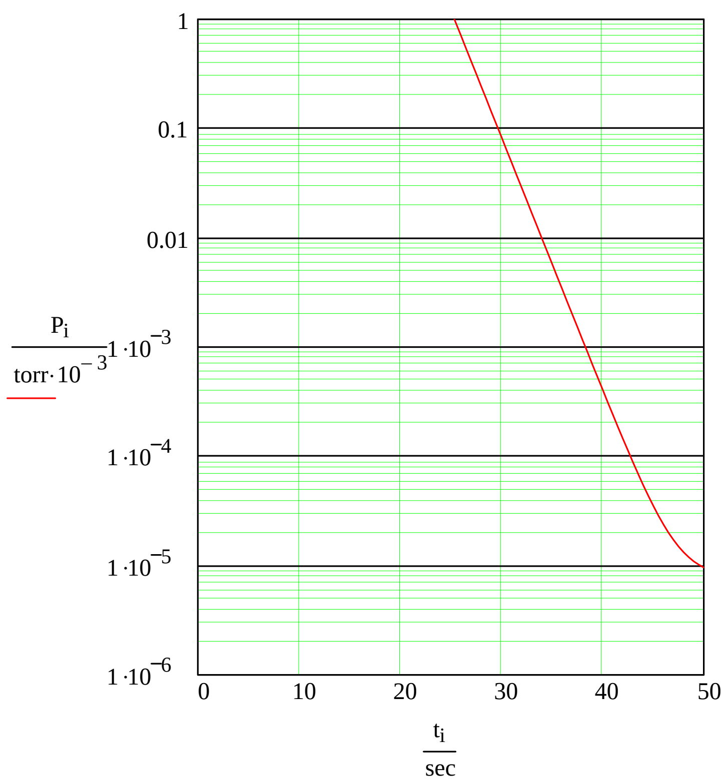
$$r := 6.5 \cdot m$$

$$q_{ss} := 10^{-9} \cdot \frac{\frac{torr \cdot liter}{sec}}{cm^2}$$

$$Q := q_{ss} \cdot 4 \cdot \pi \cdot r^2$$

$$Q = 5.309 \times 10^{-3} \frac{torr \cdot liter}{sec}$$

$$P_i := \frac{Q}{S} + \left(P_0 - \frac{Q}{S}\right) \cdot e^{\frac{-S}{V} \cdot t_i}$$



Vacuum System for a Laser IFE Chamber

Molecular density

$molecule := 1$

Avogradro's number $N_A := 6.023 \cdot 10^{23} \cdot \frac{molecule}{mole}$

The universal gas constant

$R_0 := 62.364 \cdot \frac{torr \cdot liter}{K \cdot mole}$ $R_0 = 6.236 \times 10^{4} \frac{torr \cdot cm^3}{K \cdot mole}$

For a gas sample of mass W, of a gas having a molecular weight M, the general gas law is written:

$PV = (W/M)R_oT$

Where W/M denote the number of moles and

$(W/M)(N_A/V) = n$

Where n in the number of molecules per unit volume.

From these two expressions,

$n = (N_A/R_o)(P/T)$

The case of P=760torr, T=273.16K, and Ro in torr-cm^3/K,

$n=2.687 \times 10^{19}$ molecule/cm^3

Known as *Loschmidt number*

The number of molecules per unit volume

$$n := \frac{N_A}{R_0} \cdot \left(\frac{P}{T}\right)$$

Molecular Loading:

$shot := 1$

$N_{molecule} := 10^{21} \cdot \frac{molecule}{shot}$ **ref. 1**

Vacuum System for a Laser IFE Chamber

$V_{sphere} = 1.15 \times 10^{9}\,cm^{3}$

$n_{shot} := \dfrac{N_{molecule}}{V_{sphere}}$ $\qquad n_{shot} = 8.693 \times 10^{11}\,cm^{-3}$

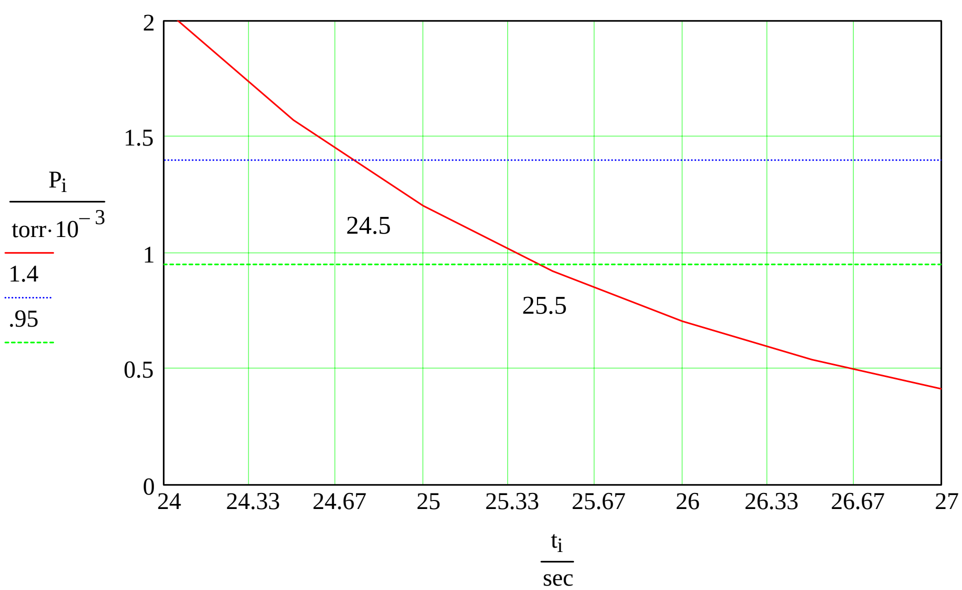
$P_{gas} := \dfrac{n_{shot} \cdot R_0 \cdot T_{gas}}{N_A}$ $\qquad T_{gas} := 1000 \cdot K$

$P_{gas} = 9.001 \times 10^{-5}\,torr$

$P_{base} := .5 \cdot 10^{-3} \cdot torr$

$P_{1sec} := 5P_{gas} + P_{base}$ $\qquad P_{2sec} := 10 \cdot P_{gas} + P_{base}$

$P_{1sec} = 0.95\,torr \cdot 10^{-3}$ $\qquad P_{2sec} = 1.4\,torr \cdot 10^{-3}$



Conclusion

The pressure will rise from .5 mtorr to 1.4 mtorr for 5Hz rep rate.

Prepared by: Bob Parsells & Craig Priniski
Scope
This analysis evaluates the pressure as a function of time in the 6.5 meter radius IFE chamber
References
1. John Sethian, "Vacuum System for a Laser IFE Chamber", Jan 23, 2005.
2. A. Roth, "Vacuum Technology", North -Holand, 1996.
Assumptions
1. IFE spherical chamber 6.5 meters radius.
2. IFE mid-plane toroidal duct 10 meter radius, 80 cm high
Pumping speed

$P_0 := 1 \cdot atm$

$P_0 = 760\, torr$

$S := 720000 \cdot \frac{liter}{sec}$

$S_{eff} := \frac{2}{3} \cdot S$

$r_{sphere} := 6.5 \cdot m$

$V_{sphere} := \frac{4}{3} \cdot \pi \cdot r_{sphere}^{3}$

$V_{sphere} = 1.15 \times 10^{3}\, m^{3}$

$V_{plenum} := 145141 \cdot liter$

$V := V_{sphere} + V_{plenum}$

$N := 600$

$i := 0 .. N$

$t_i := i \cdot \frac{200}{N} \cdot sec$

Molecular density

$molecule := 1$

Avogradro's number

$N_A := 6.023 \cdot 10^{23} \cdot \frac{molecule}{mole}$

The universal gas constant

$R_0 := 62.364 \cdot \frac{torr \cdot liter}{K \cdot mole}$

$R_0 = 6.236 \times 10^{4}\, \frac{torr \cdot cm^{3}}{K \cdot mole}$

The number of molecules per unit volume

$n := \frac{N_A}{R_0} \cdot \left(\frac{P}{T}\right)$

Molecular Loading:

$shot := 1$

$N_{molecule} := 10^{21} \cdot \frac{molecule}{shot}$

ref. 1

$V_{sphere} = 1.15 \times 10^{9}\, cm^{3}$

$$n_{shot} := \frac{N_{molecule}}{V_{sphere}}$$

$$n_{shot} = 8.693 \times 10^{11} cm^{-3}$$

$$T_{gas} := 1000 \cdot K$$

$$\lambda := 5 \cdot Hz$$

$$P_{gas} := \frac{n_{shot} \cdot R_0 \cdot T_{gas}}{N_A}$$

$$P_{gas} = 9.001 \times 10^{-5} torr$$

$$P_{base} := 5 \cdot 10^{-4} \cdot torr$$

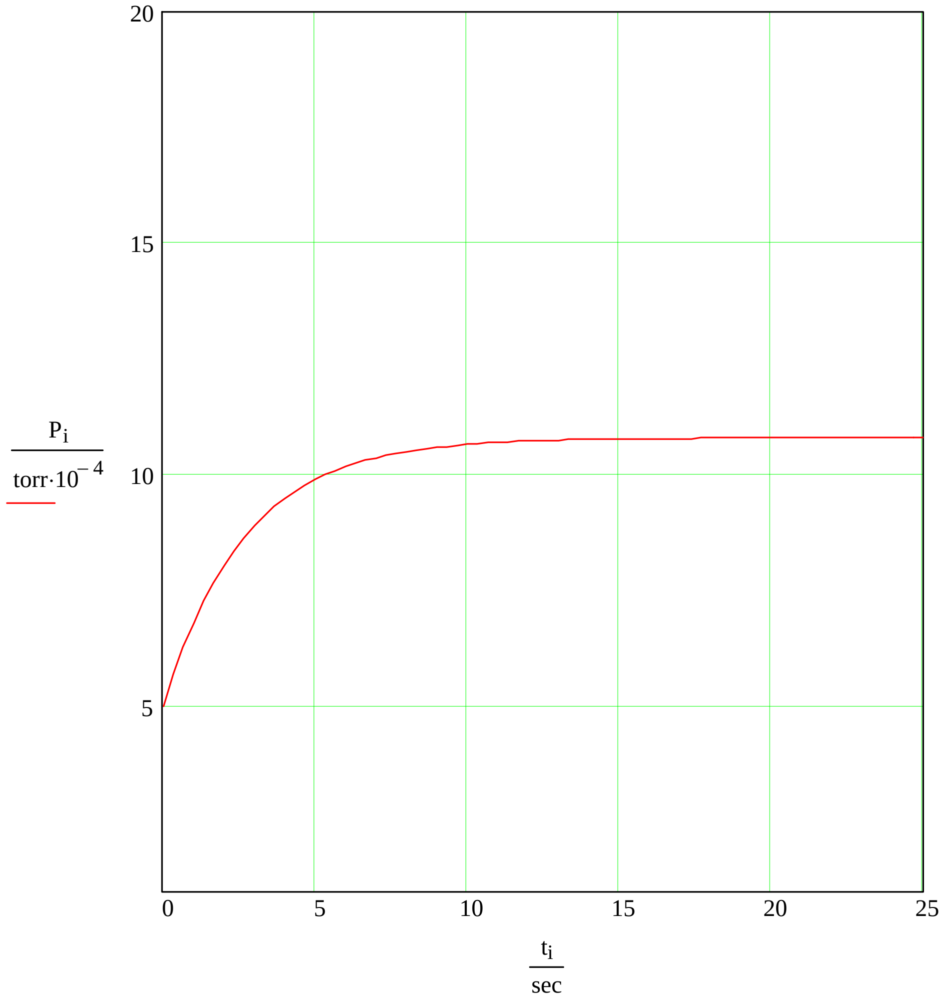
The pumpdown curve with a total 5 Hz shots produses an equivalent outgassing rate Q_2 becomes.

$$Q_2 := P_{gas} \cdot V_{sphere} \cdot \lambda$$

$$Q_2 = 517.7 \, torr \cdot \frac{liter}{sec}$$

$$P_0 := 5 \cdot 10^{-4} \cdot torr$$

$$P_i := \frac{Q_2}{S_{eff}} + \left(P_0 - \frac{Q_2}{S_{eff}}\right) \cdot e^{\frac{-S_{eff}}{V} \cdot t_i}$$



10.782

torr x 10 $^{-4}$

Operating Pressure

OPERATIONAL PRESSURE

Baseline .5 mtorr

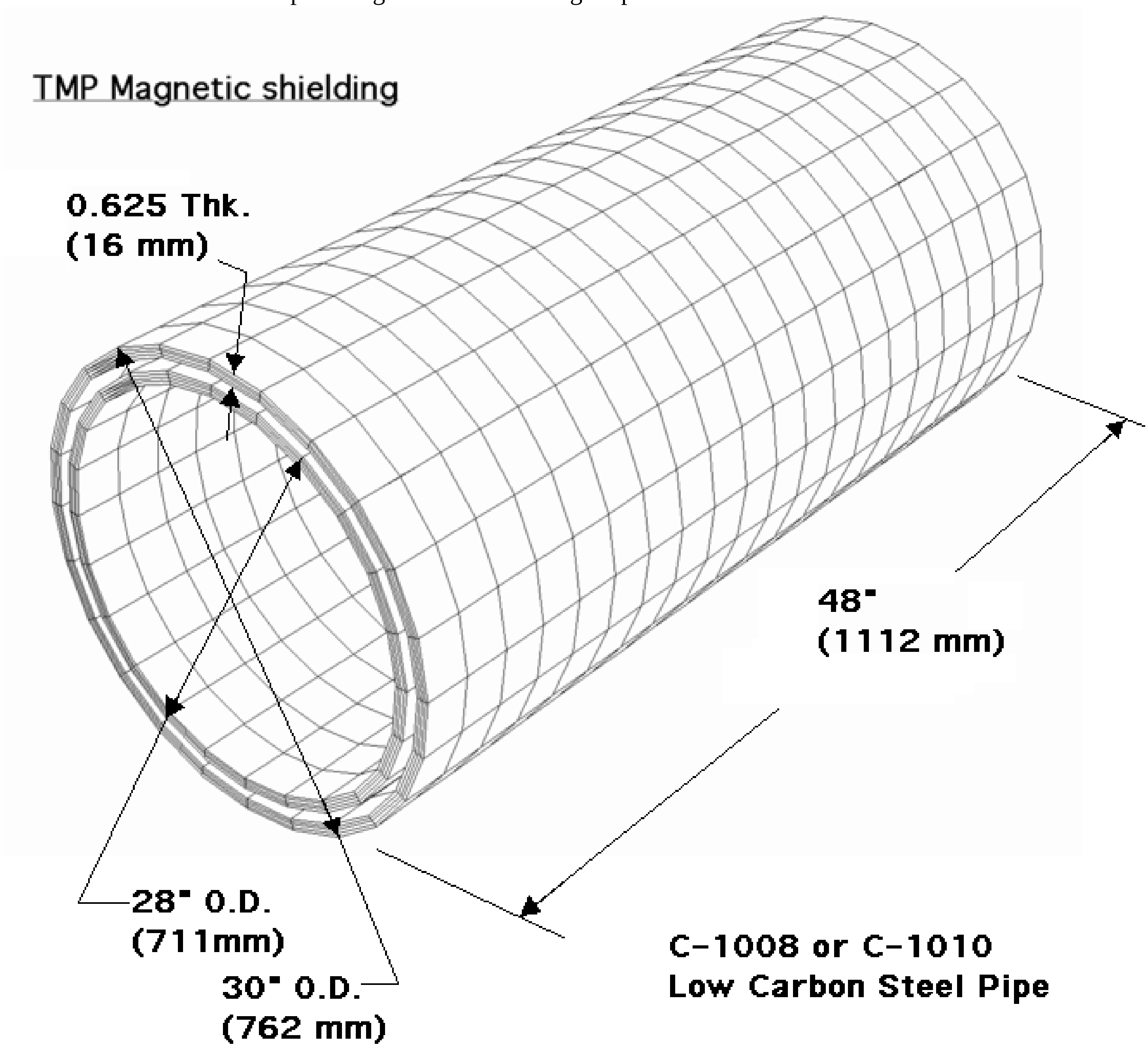
Rep Rate 5 Hz

Magnetic shielding components for Varian V-6000 TMP:
for a 1 KG field shielded down to < 50 gauss

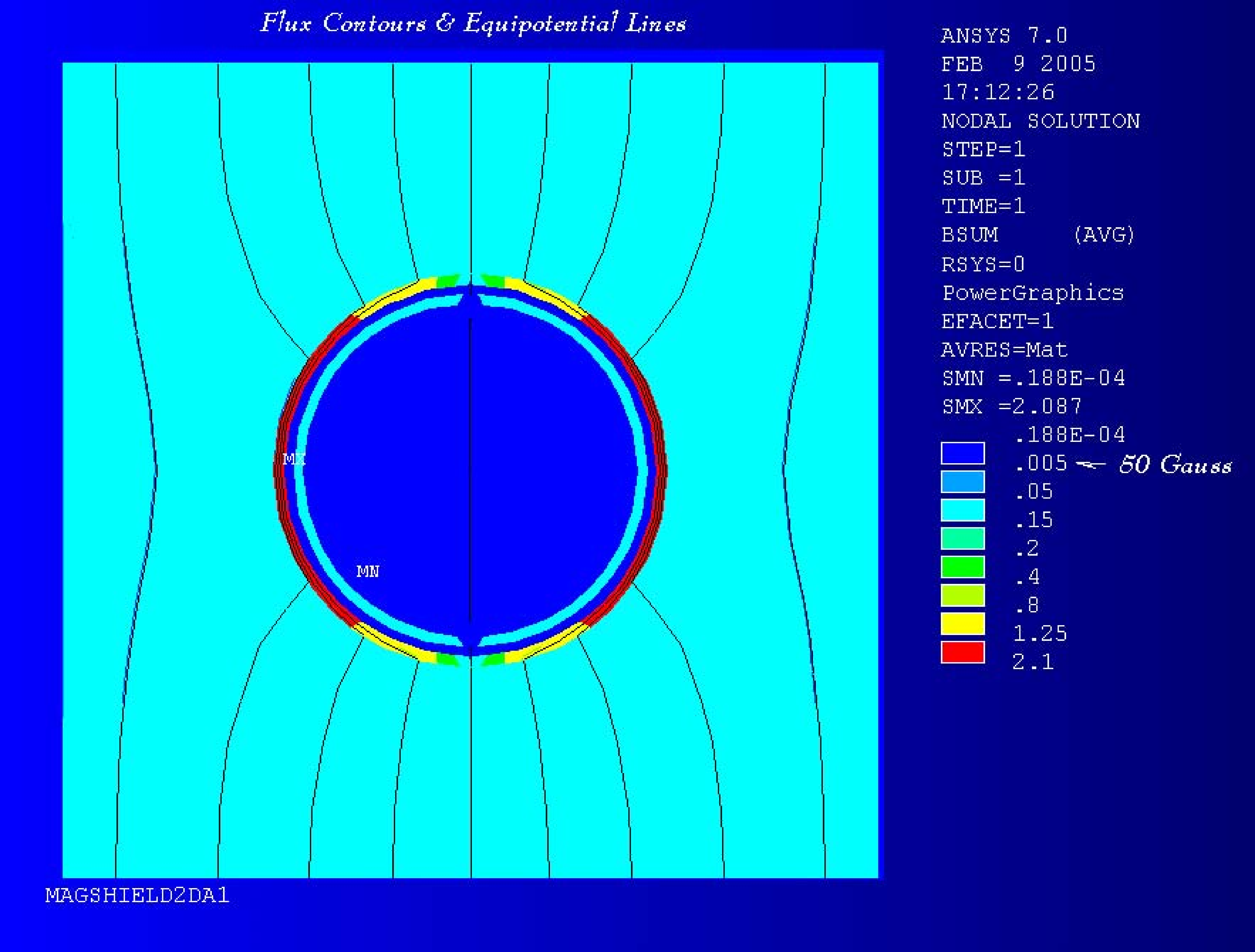
2-layer shield

30” O.D. x 0.675 Sched.30 pipe	*Low Carbon C-1010 500ft. @ $120.0/ft.	$60,000.00
28” O.D. x 0.625 Sched.30 pipe	*Low Carbon C-1010 500ft. @ $115.0/ft.	$57,500.00
Total material cost for 120 TMP magnetic shields		$117,500.00

* Estimate assumes employment of seamless line pipe in C-1010
Rolled & welded C-1008 plate might be somewhat higher price.



Weight per shield = ~ 1850 lbs. (includes mounts and stand-offs)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FEB 9 2005
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RSYS=0
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EFACET=1
AVRES=Mat
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SMX =2.087
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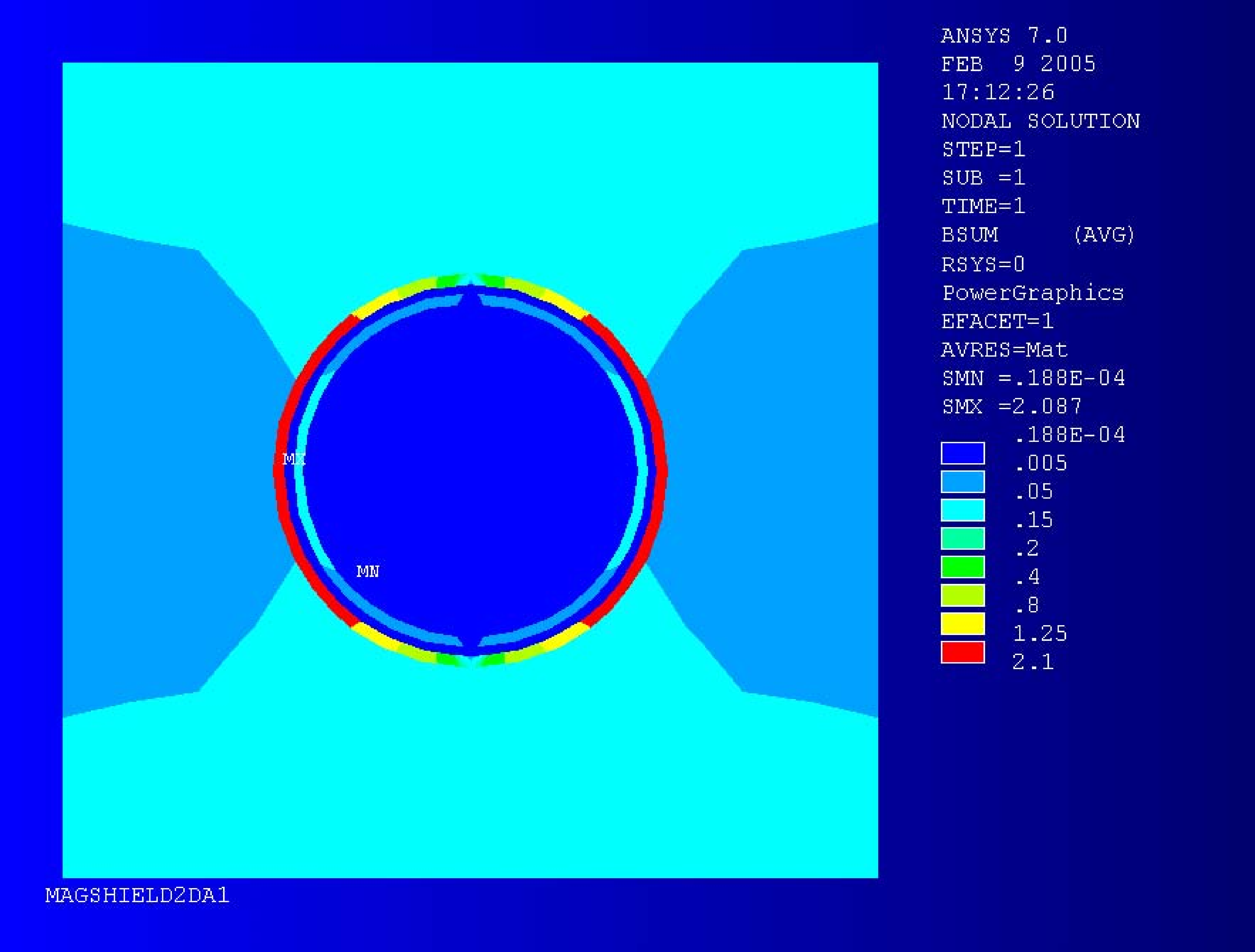
.05
.15
.2
.4
.8
1.25
2.1
MX
MN
MAGSHIELD2DA1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NODAL SOLUTION
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AVRES=Mat
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SMX =2.087
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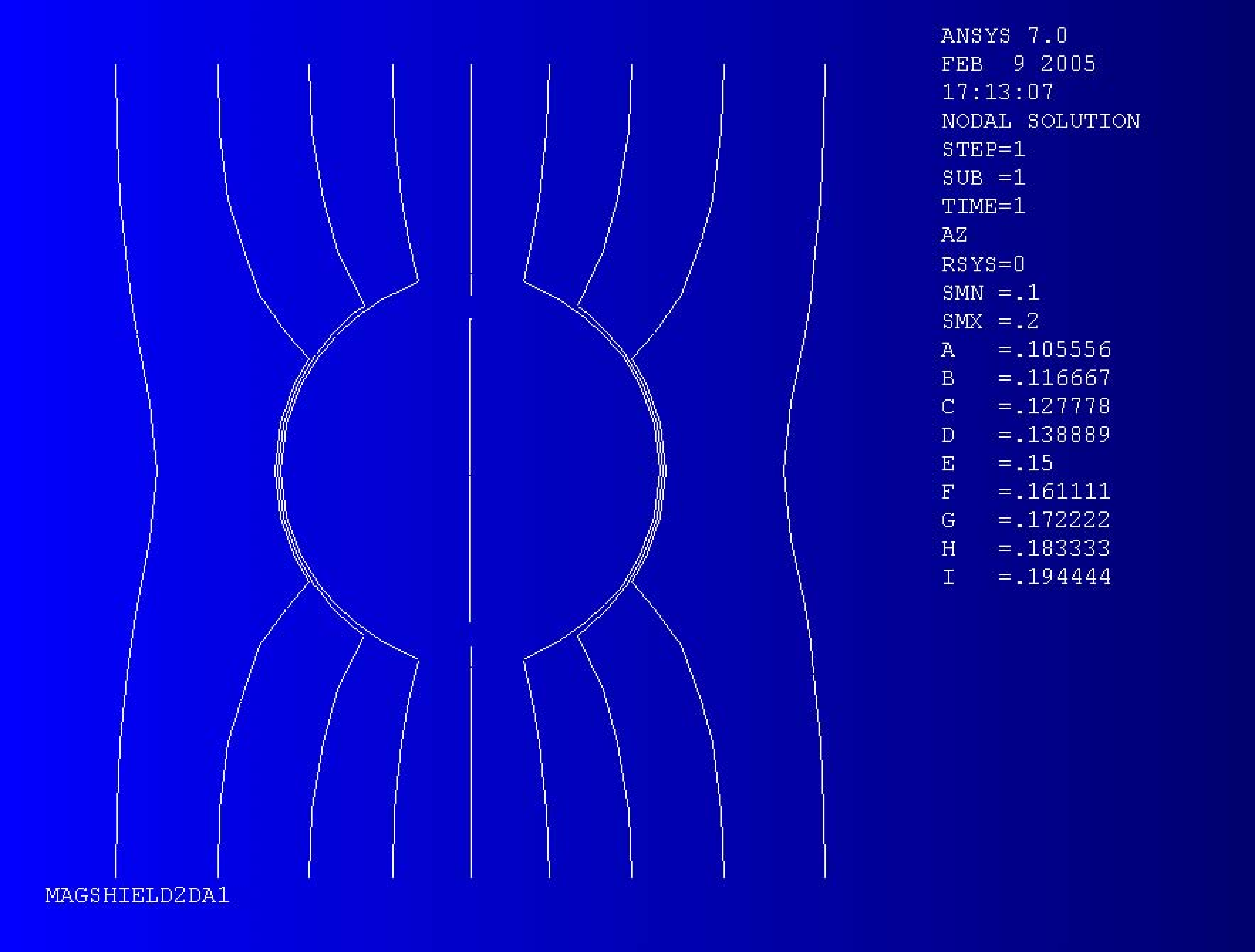
.8
1.25
2.1
MX
MN
MAGSHIELD2DA1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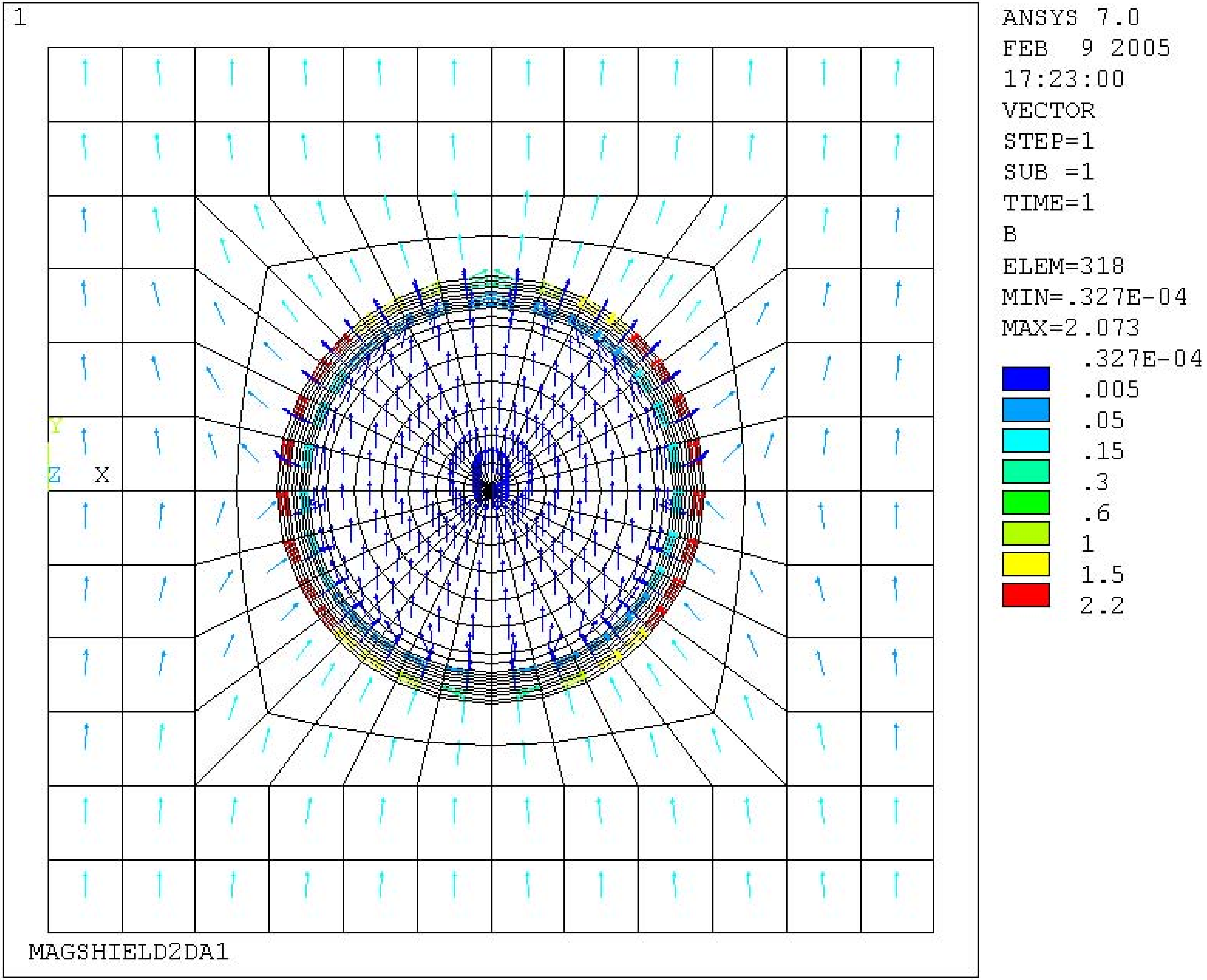

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.6
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1.5
2.2
Y
Z X
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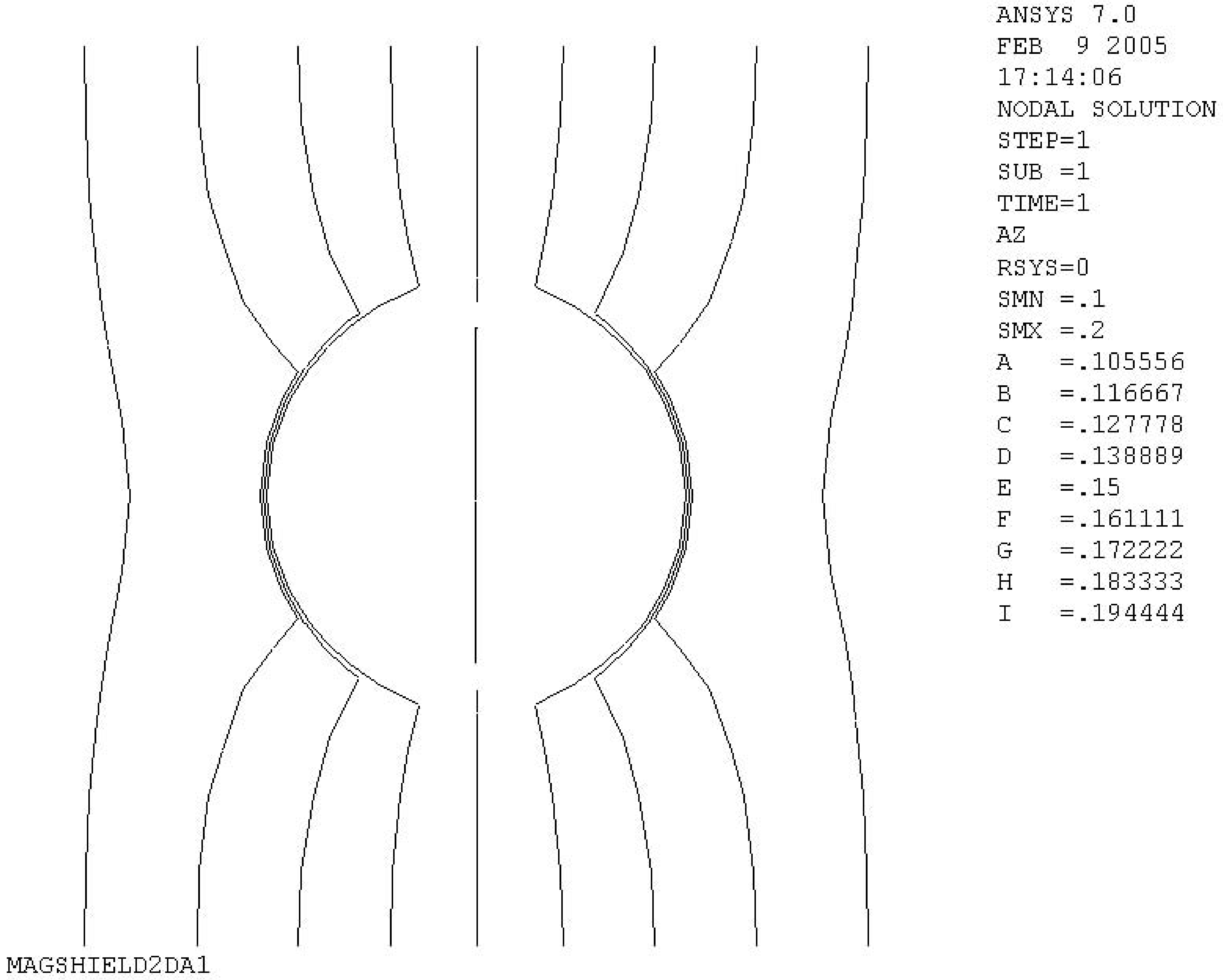
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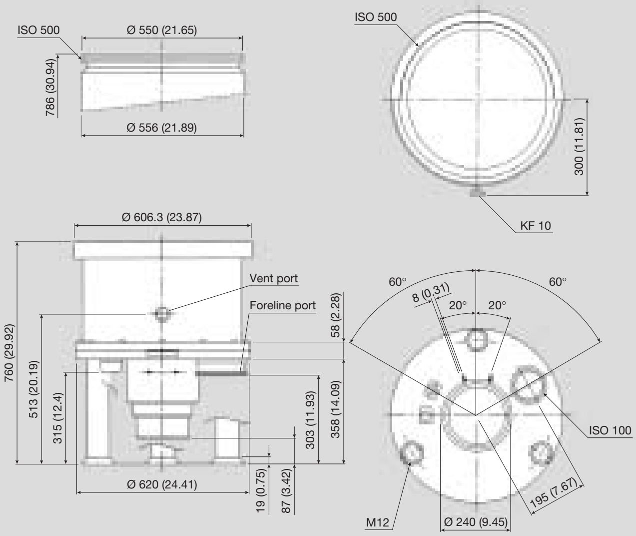
SUB =1
TIME=1
AZ
RSYS=0
SMN =.1
SMX =.2
A =.105556
B =.116667
C =.127778
D =.138889
E =.15
F =.161111
G =.172222
H =.183333
I =.194444
MAGSHIELD2DA1

Vacuum System for a Laser IFE Chamber Component Cost Estimate

Key	Equipment Name	Unit Cost	Qty	Total	Qty Discount	Discount Total	Total
A	Varian Turbo-V 6000 (on target chamber)	$ 70,000.00	120	$ 8,400,000.00	20%	$ 1,680,000.00	$ 6,720,000.00
B	Varian Turbo-V 2000 HT (on each beam tube)	$ 25,000.00	60	$ 1,500,000.00	20%	$ 300,000.00	$ 1,200,000.00
C	Magnetic Shielding (only on Turbo-V 6000)	$ 1,000.00	120	$ 120,000.00	0%	$ -	$ 120,000.00
D	Kinney KMBD -2000 Backing Pumps	$ 41,000.00	20	$ 820,000.00	20%	$ 164,000.00	$ 656,000.00
E	TMP/Target Chamber Isolation Valves (VAT valves, 20" throughput)	$ 20,000.00	120	$ 2,400,000.00	20%	$ 480,000.00	$ 1,920,000.00
F	Beam Tube (TMP) Isolation Valves (VAT valves, 10" throughput)	$ 12,000.00	60	$ 720,000.00	20%	$ 144,000.00	$ 576,000.00
G	Roughing Valves (between TMP exhaust/Kinney Inlet)	$ 8,000.00	20	$ 160,000.00	20%	$ 32,000.00	$ 128,000.00
H	Gate Valves (after Kinney discharge)	$ 8,000.00	20	$ 160,000.00	20%	$ 32,000.00	$ 128,000.00
I	Dycor RGA (0-200 AMU w/ pumping system)	$ 23,000.00	4	$ 92,000.00	5%	$ 4,600.00	$ 87,400.00
J	Instrumentation and Control	$ 200,000.00		$ 200,000.00	0%	$ -	$ 200,000.00
K	Target Chamber Isolation Valves (for roughing pump interface-VAT valves, 8" throughput)	$ 8,000.00	10	$ 80,000.00	10%	$ 8,000.00	$ 72,000.00
L	Heli-Flex Seals	$ 500.00	380	$ 190,000.00	5%	$ 9,500.00	$ 190,000.00
M	Gas Holding Tanks (10 m^3)	$ 150,000.00	4	$ 600,000.00	0%	$ -	$ 600,000.00
N	Interfacing Piping	$ 250,000.00		$ 250,000.00	0%	$ -	$ 250,000.00
O	High Vacuum Ion Gage	$ 5,000.00	6	$ 30,000.00	0%	$ -	$ 5,000.00
	Totals			**$ 15,722,000.00**		**$ 2,854,100.00**	**$ 12,852,400.00**

Turbo-V 6000

Outline Drawings

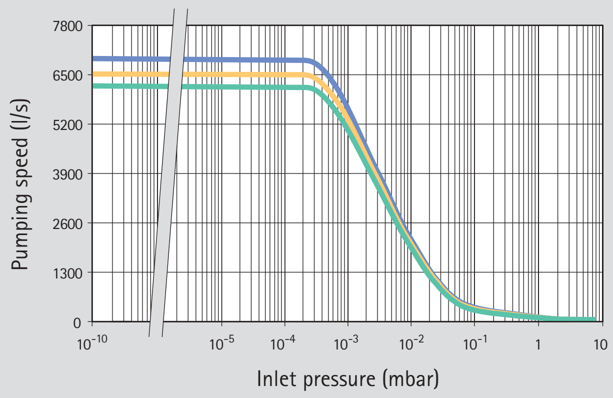


Dimensions: millimeters (inches)

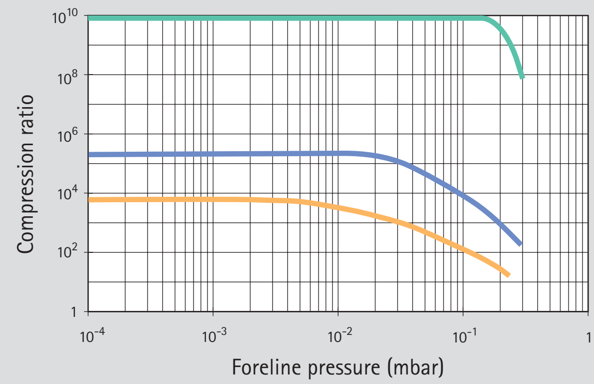
Technical Specifications

Pumping speed l/s	N_2: 6,000	He: 7,000	H_2: 6,500
Compression ratio	N_2: > 1 x 10^{10}	He: 2.3 x 10^5	H_2: 8 x 10^3
Base pressure with recommended mechanical pump:	< 1 x 10^{-10} mbar (< 1 x 10^{-10} Torr)		
Inlet flange	ISO 500		
Foreline flange	ISO 100		
Rotational speed	14,000 rpm		
Startup time	30 minutes		
Recommended forepump	Varian DS 1602		
Operating position	Vertical ±10°		
Cooling requirements	Water		
Bakeout temperature	80 °C at inlet flange (ISO version)		
Vibration level (displacement)	≤ 0.05 μm at inlet flange		
Weight kg (lbs)	250 (550)		
Lubricant	Varian T.A. oil (charge 1,000 cm^3)		

Pumping Speed vs Inlet Pressure (DN 500 only)



Compression Ratio vs Foreline Pressure

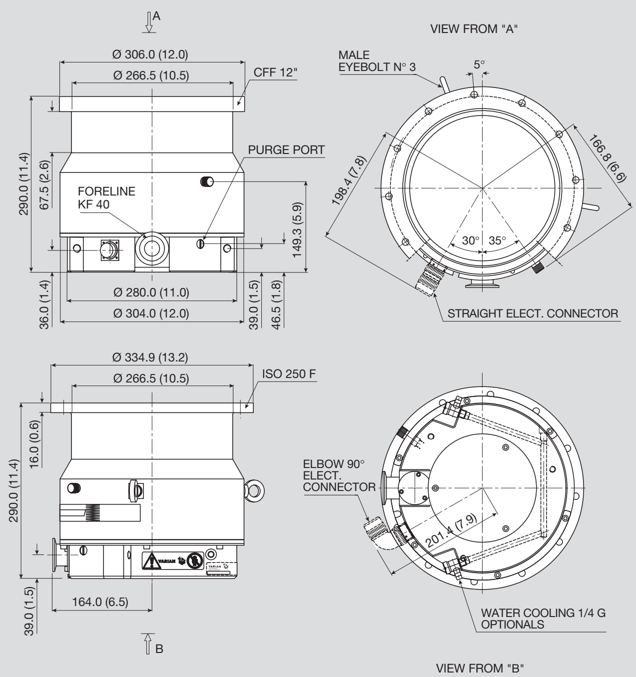


Ordering Information

Description	Weight kg (lbs)	Part Number
Pump		
Turbo-V 6000 pump with ISO 500 inlet flange	282.0 (620.0)	On request
Controllers		
Turbo-V 6000 controller, 120 V	50.0 (110.0)	9699591
Turbo-V 6000 controller, 220 V	50.0 (110.0)	9699491
Accessories		
Inlet screen, DN 500	10.0 (22.0)	9699308
Vent valve with fixed delay time	2.0 (4.0)	9699843
Vent device with adjustable delay time	2.2 (5.0)	9699831
Replacement Parts		
Varian T.A. oil, 100 cm^3	0.5 (1.0)	9699901
Varian T.A. oil, 1000 cm^3	1.4 (3.0)	9699902

Turbo-V 2000HT

Outline Drawings



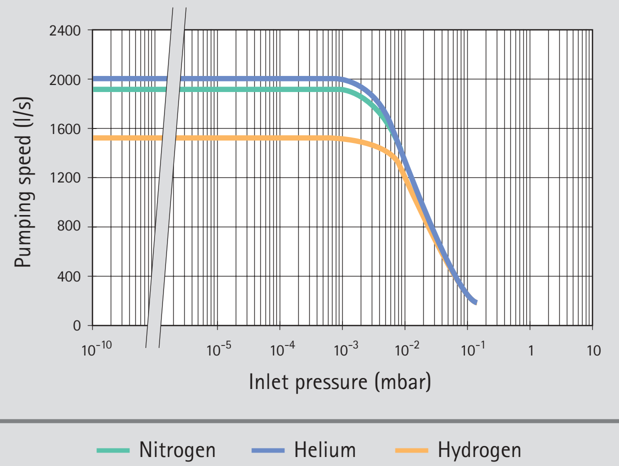
Dimensions: millimeters (inches)

Technical Specifications

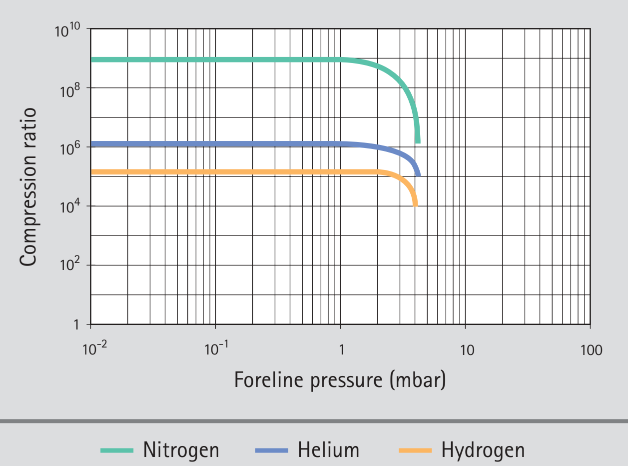
Pumping speed	N_2: 1,950 l/s	He: 2,000 l/s	H_2: 1,500 l/s
Compression ratio	N_2: >1 x 10^9	He: 2 x 10^6	H_2: 2 x 10^5
Base pressure* (minimum with recommended mechanical forepump)	1 x 10^{-10} mbar (7.5 x 10^{-11} Torr)		
Inlet flange	CF 12"	ISO 250-F bolted	
Foreline flange	KF 40		
Rotational speed	33,000 rpm		
Startup time	10 minutes		
Recommended forepump	Mechanical: Varian DS 602 Dry scroll: Varian TS600		
Operating position	Any		
Cooling requirements	Water		
Bakeout temperature	120 °C max. at inlet flange (CF flange) 80 °C max. at inlet flange (ISO flange)		
Vibration level (displacement)	<0.01 µm at inlet flange		
Weight kg (lbs)	ISO 250: 44 (96.8) CF 12": 55 (121.0)		

** According to standard DIN 28 428, the base pressure is measured in a leak-free test dome, 48 hours after completion of test dome bake-out, with a Turbopump fitted with a ConFlat flange and using the recommended backing pump.*

Pumping Speed vs Inlet Pressure (DN 250 only)



Compression Ratio vs Foreline Pressure



Ordering Information

Description	Weight kg (lbs)	Part Number
Pumps		
Turbo-V 2000HT, ISO 250-F bolted flange	44.0 (96.8)	9699059
Turbo-V 2000HT, 12" CF flange	55.0 (121.0)	9699084
Controllers		
Turbo-V 2000HT controller, 220 V	19.0 (42.0)	9699462
Turbo-V 2000HT controller, 120 V	19.0 (42.0)	9699562
Accessories		
Inlet screen, DN 250	1.0 (2.0)	9699350
Water cooling kit	0.5 (1.0)	9699338
Plastic water cooling kit	0.5 (1.0)	9699348
Vent flange, NW 10 KF / M8	0.5 (1.0)	9699108
Vent valve with fixed delay time	2.0 (4.0)	9699843
Vent device with adjustable delay time	2.2 (5.0)	9699831
Heavy duty vent valve	2.2 (5.0)	9699842
Purge valve 10 SCCM NW16KF – M12	0.2 (0.5)	9699239
Purge valve 10 SCCM 1/4 Swagelok – M12	0.2 (0.5)	9699240
Purge valve 20 SCCM NW16KF - M12	0.2 (0.5)	9699241
Purge valve 20 SCCM 1/4 Swagelok – M12	0.2 (0.5)	9699242
Purge valve 10 SCCM 1/4 Swagelok - 1/4 Swagelok	0.2 (0.5)	9699232
Purge valve 20 SCCM 1/4 Swagelok - 1/4 Swagelok	0.2 (0.5)	9699236