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The goal of the program was the demonstration of the feasibility of a compact hydrogen maser by use of a high temperature superconductor (HTS)-based cavity. The cavity was of the "lumped element" type, with dimensions about 1/4 those of the TE₀₁ cylindrical cavity normally used. A coating of HTS on the cavity electrodes was used to increase the Q from about 5,000 for copper to a value over 25,000 for which masing would occur. The maser was design and fabricated, overcoming a number of difficult problems, most of which were associated with operation at cryogenic temperatures. Limitations on resources prevented significant testing. However, given the difficulties discovered during the design and fabrication, it was determined that the commercial viability of the compact maser was doubtful, and no further effort toward development was anticipated. The program was very useful in enhancing the maser-related technology base at Physical Sciences Inc. (PSI). This technology has been directly applied to the development of a novel rubidium maser that is expected to have a strong commercial market.

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Final Report
COMPACT HYDROGEN MASER WITH A HIGH TEMPERATURE
SUPERCONDUCTOR-BASED CAVITY

Contract No. F49620-93-C-0060

SBIR PHASE II Program Plan

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February 1996

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Objectives

The objective of the program was to determine the feasibility of a hydrogen maser in which the cavity is dramatically smaller than the TE_{011} cavity normally used. This was to be accomplished using a loop-gap resonator. Such a resonator is satisfactory in all aspects except that the quality factor, Q , would be too low for the device to operate in the active mode, *i.e.*, as maser. This problem was to be avoided by coating the cavity electrodes with YBCO, a high temperature superconductor (HTS). The use of the HTS was expected to restore the cavity Q to about 30,000, a value at which the maser would self-oscillate.

The tasks to meet this objective were as follows:

Task 1. We will complete the final design of the resonator and cryostat. The basic design was completed in Phase I, with only the construction details to be resolved.

Task 2. Construction of the cryostat and copper maser resonator will be performed during this task. The temperate control circuits, and configuring the maser for passive mode measurement also will be included.

Task 3. The construction and characterization of the superconducting cavity will be performed simultaneously with Task 2. The copper resonator and the superconducting resonator will have identical geometries.

Task 4. We will use a vector impedance method for the passive measurement of the maser. This method offers greater accuracy of measurement and compensation for cavity pulling.

Task 5. The measurement and evaluation of the maser will include the maser stability measurements as well as characterization of the hydrogen interactions with the teflon.

Task 6. A commercially relevant design will be produced that reflects the maser requirements determined during the completion of the first five tasks.

Status

After one year of the contractual effort, Task 1 and a portion of Task 2 were accomplished. For Task 2, the (copper) cavity was constructed, and its resonant frequency and Q measured. The C field coil was fabricated, and the field profile measured. The maser, with the original cavity, was tested to insure operation of the electronics, including the hydrogen state selector. It operated acceptably, although there were indications that the magnetic shields required re-annealing. The annealing was redone. Finally, a number of difficult design issues were addressed, including the details of the tuning mechanism for the cavity. The year concluded with an essentially complete detailed mechanical design for the maser.

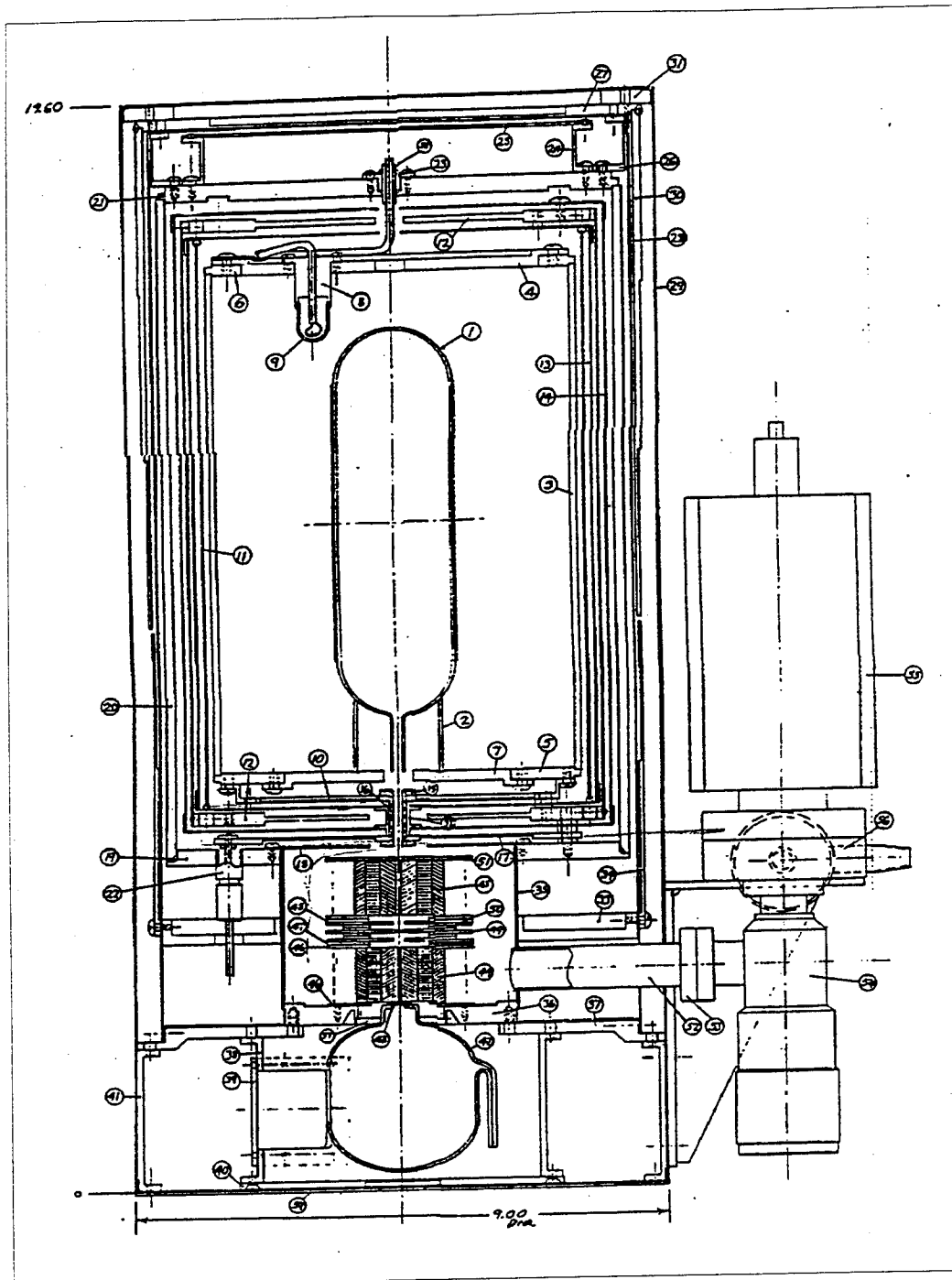


Figure 2. Schematic of the original Sigma Tau AF-1 maser used as the test vehicle for the program.

This significantly slowed the design process, and required more resources than anticipated. Issues of the design are discussed below in detail. For reference, the entire design of the physics package is shown in Figure 3. In summary, and from the center outward, the package consists of the hydrogen containment bulb, the cavity electrodes, the cavity shell (which is also a vacuum shell), the liquid nitrogen vessel, the high vacuum chamber (in common with the bulb vacuum), and the thermal isolation vacuum chamber. Included in the design are magnetic and thermal shields not shown in this drawing.

Results

Summary

All of the components have been designed. Most of the components for the maser have been fabricated, and sub-assemblies completed. The system has been checked for vacuum integrity. The cavity resonant frequency has been measured, in preparation for final machining and shimming.

Much of the effort during the second half of the program was directed toward the solution of numerous difficult problems encountered in realizing the maser within the significant constraints produced by cryogenic operation as well as those usually associated with masers used for precision time interval measurement. Most of these problems were solved, and their solutions are documented here.

Consideration was given of using superconducting magnetic shields. These shields were expected to be much more effective than conventional mu-metal ones. A paper documenting these shields is appended. However, after an initial investigation, it was decided that use of superconducting shields would entail an inordinate effort, and that conventional shields would be used.

Maser Design

Approach

The design of this maser was based on the previous work on developing compact hydrogen masers. The TE_{011} microwave cavity was the largest element in the maser and was the focus of the miniaturization effort. The microwave resonator developed in the cited work was the so-called loop-gap resonator, shown in Figure 1, 14. This resonator is a lumped element resonant structure tuned to the hydrogen hyperfine transition frequency and can be made much smaller than the wavelength dependent TE_{011} microwave cavity. An unfortunate result of using a compact resonator is a significant reduction in cavity Q , which is a measure of the resonant microwave energy storage. The maser resonator tested in this maser was a cryogenic superconducting maser that had a resonator Q that is significantly higher than its copper counterpart and was high enough to enable improved passive or active maser operation in a compact construction.

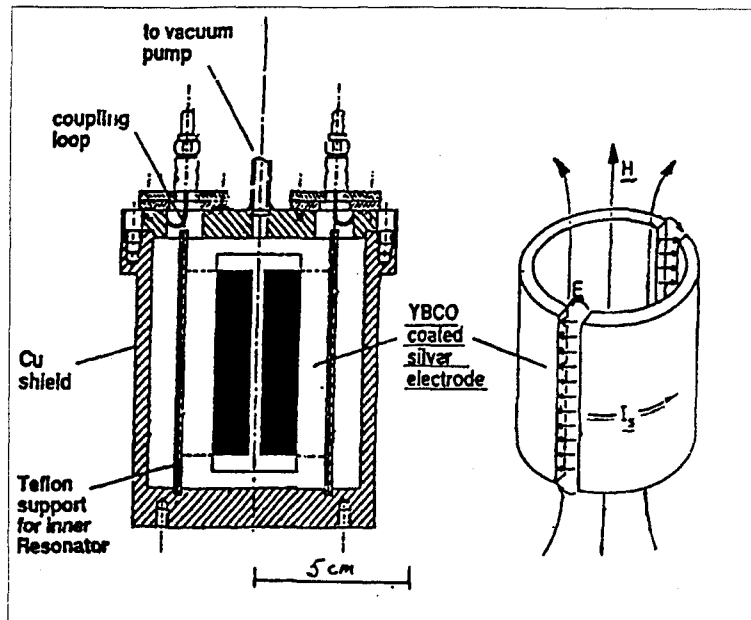


Figure 1. Schematic of the loop-gap resonator.

A complete maser consists of many elements other than the cavity, and to develop the entire system would be far beyond the scope of the Phase II. To avoid this difficulty, we used an existing hydrogen maser, the Sigma Tau AF-1. While this maser was constructed in 1981, it had not functioned well, and was therefore available for use as a test bed. This maser is shown in Figure 2. The intent was to replace the existing cavity and bulb with the loop gap resonator and an appropriate bulb, but retain almost all of the other elements, including the hydrogen source, state selector and optics, c-field coil supply, and the RF receiver. In this manner, we reduced the necessary engineering and design to a manageable level.

It is noted, however, that the use of the AF-1 imposed a significant constraint on the size of the new physics package. Although the AF-1 used a TE_{011} cavity, it had been made smaller than usual by loading it with dielectric. In other words, it was already a "compact" cavity. Early in the design phase, it became clear that fitting the PSI package, complete with cryogenics, into the available space was a challenge - one that required a number of carefully thought-out engineering solutions.

Issues

The issues involved in the design of the new physics package were the following:

Vacuum

- new electrical feedthroughs designed for cryogenic operation
- cryogenic liquid feedthroughs

Cryogenics

- LN₂ versus refrigeration
- mechanical supports and alignment
- RF cabling
- temperature control at several temperatures

Tuning of Superconducting Cavity

Magnetics

Solutions

Vacuum

- new electrical feedthroughs designed for cryogenic operation: The AF-1 maser was designed to operate in the active mode only. Thus, there was only one RF connection to the cavity. While, eventually, the new maser would also operate in the active mode, initial measurements could most easily be made in the passive mode. This required that there be two rf ports.

Feedthroughs for UHV at cryogenic temperatures are intrinsically more difficult than those at room temperature. Few connectors are designed to remain tight over a wide temperature range, particularly coaxial feedthroughs that were small enough to fit within the tight confines of the package. A solution was found in Microdot™ connectors, brazed into special flanges which were sealed to the cavity using indium "O" rings.

- cryogenic liquid feedthroughs: To feed liquid nitrogen into the system, a thin wall steel tube with a bellows for strain relief was used.

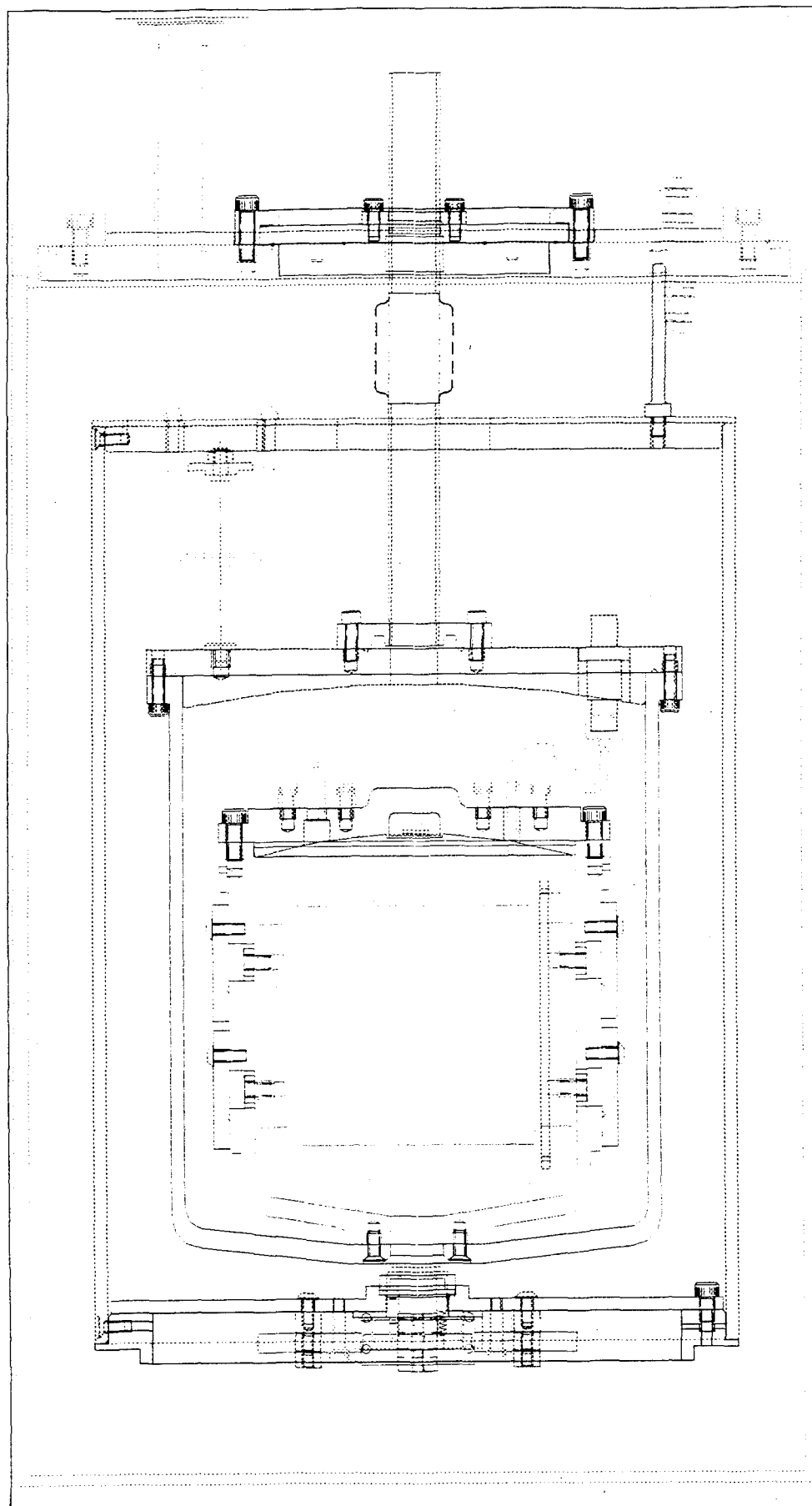


Figure 3. Drawing of the maser with the compact cavity.

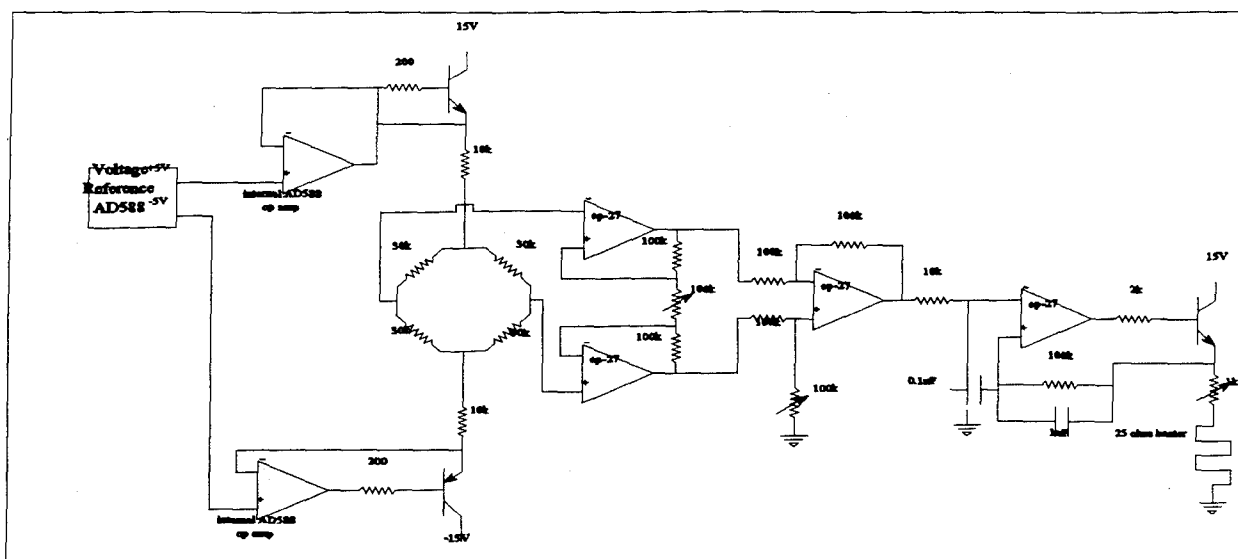


Figure 6. Schematic of the temperature control circuit.

In order to utilize the hydrogen source and state selector and its optics, the new cavity had to have the storage bulb aperture located in the same position as the original bulb. It was not necessary to maintain this bulb stem aperture at cryogenic temperatures. Nor would it be particularly easy to do so, since it was not possible to avoid the radiative heating of the section of the bulb and the resonator volume that is in line with the hydrogen source. Fortunately, the quartz bulb has a very low coefficient of thermal conductivity, and thus, if supported only by the neck at the aperture, would be very poorly coupled to the cavity. Any additional radiative heating was avoided with several heat shields.

Tuning of Superconducting Cavity

The maser resonator was intrinsically difficult to tune. Rough tuning of the resonant structure was performed by increasing the size of the capacitive gap between the electrode sections, as shown in Figure 7. However, once the maser is tuned at room temperature and then cooled to liquid nitrogen temperatures, the thermal contraction of the cavity will cause strong detuning of the resonant structure.

The frequency of the resonator decreases as the gap size is reduced. This phenomenon has been studied and documented. When the resonator is tested with copper electrodes, the outer shield-can contracts at the same rate as the electrodes. These effects partially cancel. However, stainless steel has a lower thermal expansion coefficient than copper.

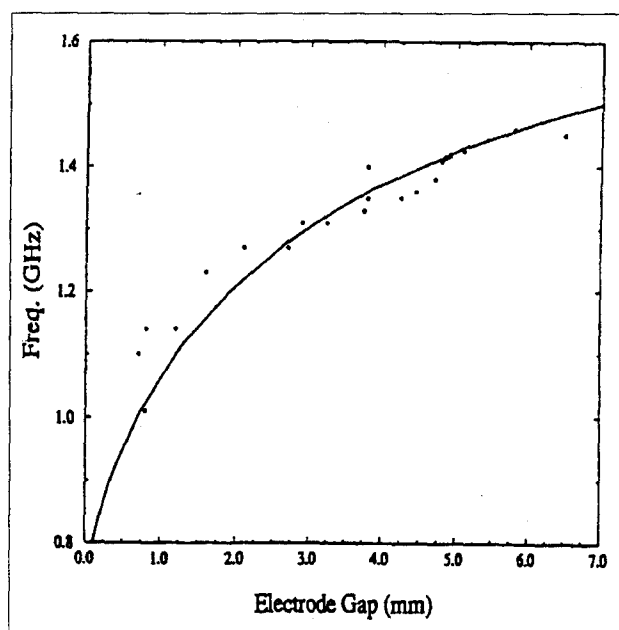


Figure 7. Resonant frequency as a function of the gap in the loop-gap resonator.

Cryogenics

- **LN₂ versus refrigeration:** The original intent was to operate the maser with either liquid nitrogen or mechanical cooling. After examining the design in detail, it was determined that the cryocooler would add too much to the complexity to warrant its inclusion in this experimental vehicle. Therefore, the design was limited to cooling with liquid nitrogen.

- **Mechanical supports and alignment:** The cryostat for the maser had to be thermally isolated, allowing liquid cryogen or closed cycle refrigerator operation, and provide adequate electrical and rf access to the resonator cavity. The challenge for thermal isolation is to simultaneously provide a short rigid mechanical support structure that also is thermally isolating. This was accomplished using zyarock spacers, countering the low yield strength under tension by compressionally preloading the zyarock. This arrangement, shown in Figure 4, was adequate to maintain the critical alignment of the storage bulb stem with the beam optics.

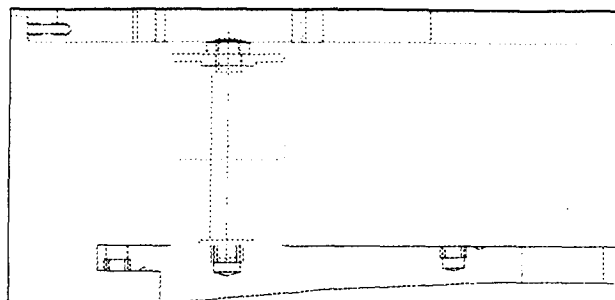


Figure 4. Detail of a zyaroc support.

- **RF cabling:** RF coaxial cables are typically good thermal conductors, and would result in unacceptably high LN₂ boil off and thermal gradients. The solution was to use cable with a stainless steel outer conductor, with the length chosen to balance the RF losses and the thermal conductivity.

- **Temperature control at several temperatures:** The YBCO-coated cavity had to be maintained at or below 77 K in order that it be superconducting. As discussed below, precise control of the temperature was required in order to stabilize the resonant frequency. This was made easier by the use of liquid nitrogen as the coolant, since it naturally remains at its boiling point. However, the boiling point varies with ambient pressure, as shown in Figure 5. With the 10 kHz/K frequency dependence of the cavity, discussed below, changes of 10% in the pressure will produce a frequency shift of $\Delta\nu/\nu_0 = 1.8 \cdot 10^{-10}$. This shift would significantly perturb the operation of the maser, and thus a thermal control circuit was required. A circuit previously used to control a quartz clock was used for this purpose. A schematic is shown in Figure 6. The heater for the controller was wound around the cryostat.

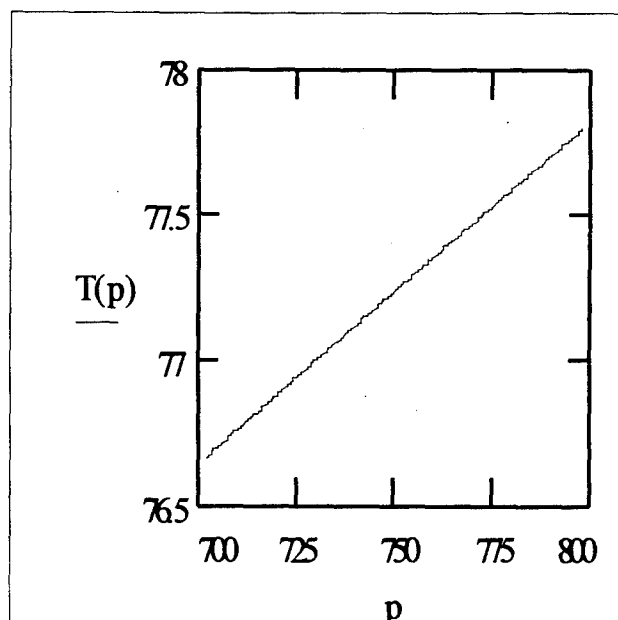


Figure 5. Temperature of the boiling point of liquid nitrogen as a function of the ambient pressure.

drive from Burleigh, and rough cavity tuning to within $\pm 5\text{kHz}$. Also, with this tuning system, maser performance could be measured over the complete temperature range. A varactor diode was used for fine tuning.

Magnetics

The maser is very sensitive to dc magnetic fields due to the Zeeman shift:

$$\frac{\Delta\nu}{\nu\Delta H} = 3.87 \times 10^{-9} (\text{Oe})^{-1}$$

over and great care must be taken to isolate the interaction region from ambient fields. The original maser had cylindrical magnetic shields, which appeared adequate for the new design. The shields were placed around the entire new physics package, at room temperature. The shield performance was modeled using a finite element code (Maxwell™ 2-D magnetostatic package.) The results of the modeling are shown in Figures 10 -12. Figure 10 shows a plot of the magnetic flux lines, while

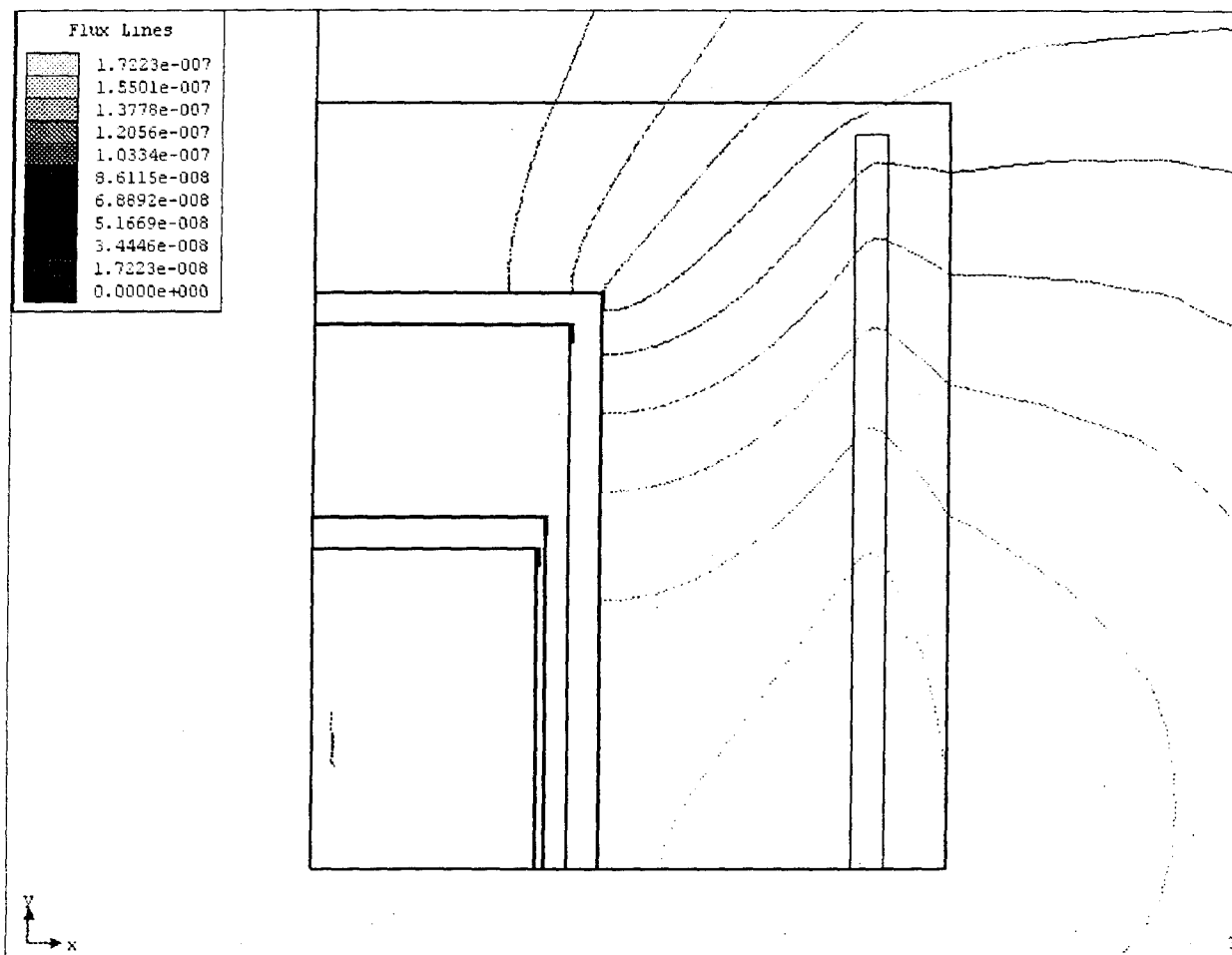


Figure 10. Plot of the magnetic field flux lines in the maser.

This results in a net reduction of the electrode gap, causing the frequency to decrease. Considering that all geometries are equal, resonators with copper, stainless steel, and superconducting electrodes will follow the same frequency vs. temperature curve. The range of the curve that is spanned will vary with the thermal expansion coefficients. For copper, the frequency dependence has been measured to be 10 kHz/K.

These thermal expansion effects require that the cavity is constructed with a mechanism for tuning the cavity as it is cooled from room temperature to 77° K. The easiest way to achieve the required range of tuning is to use a metallic or dielectric perturbation to the resonant fields. We considered each possibility and settled in dielectric tuning. This decision was made because of the optimal relative positions in the cavity of the dielectric or metallic perturbing volumes. The metallic perturbation is most effective when inserted into the magnetic fields of the resonator, which are along the longitudinal axis. This region of the cavity volume is occupied by the storage bulb. Conversely, a dielectric tuning paddle is most effective in the electric fields, which are concentrated in the electrode gap regions. Therefore, dielectric tuning could be performed without disturbing the storage bulb volume.

The Phase I results describe a sapphire paddle in the electric fields near the outer radius of the electrode gap. At that time we presumed that the paddle would pivot about in a longitudinal axis. We found that it would be very difficult to achieve this motion with feedthrough technology because of space limitations. The requirements for tuning the system were:

- move the sapphire within the cavity,
- locate or develop a means of mechanical feedthrough without increasing the cavity size,
- maintain the mechanical actuator at or near room temperature.

The solution was to fix the dielectric to the quartz bulb, attach a mechanical actuator to the warm stem of the quartz bulb, rotate the bulb along the longitudinal axis so that the paddle can be gradually moved into and out of the electric field regions. This solution, shown in Figures 8 and 9, permitted us to achieve mechanical tuning without adding any new feedthroughs, use an off-the-shelf inchworm

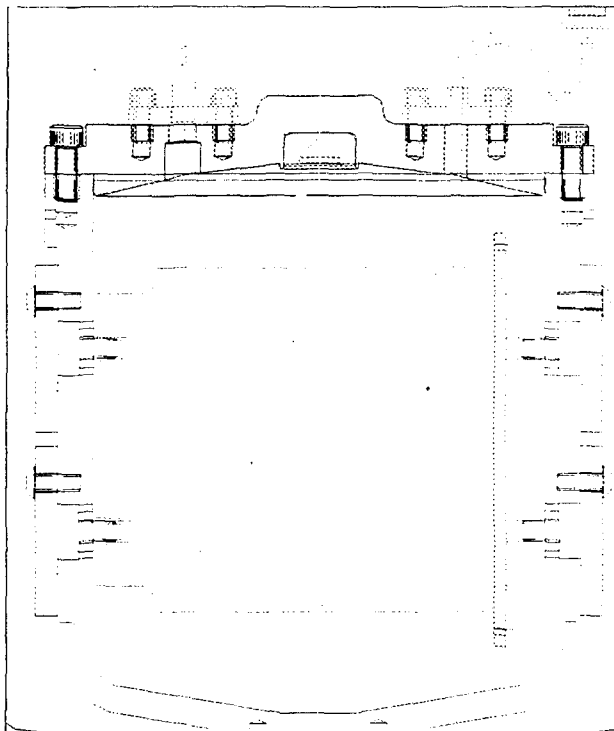


Figure 8. The quartz bulb with the tuning paddle. The cavity is of a diameter that fits between the bulb and the paddle, with the azimuthal alignment such that the paddle is roughly centered over the gap.

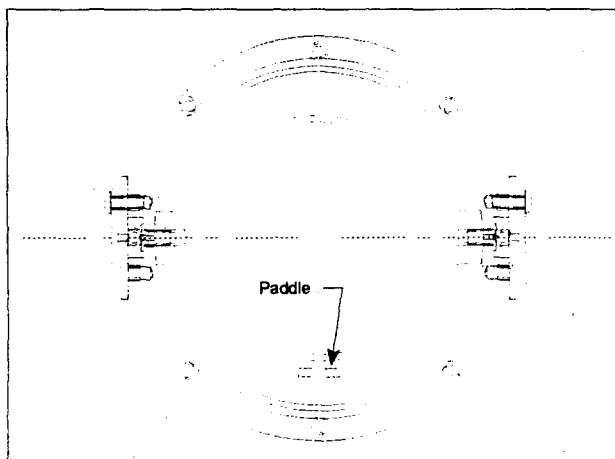


Figure 9. Cross section of the cavity and bulb.

Maser Fabrication

Cavity

The cavity, shown in Figures 14 and 15, was fabricated as planned. It was anticipated that the mechanical support structure would significantly decrease the resonant frequency from that determined by modeling. The resonant frequency was therefore measured before final machining of the electrode gap. The results of these measurements, which match well with the data obtained with a previous test version of the cavity (c.f. Interim Report), are shown in Figure 16.

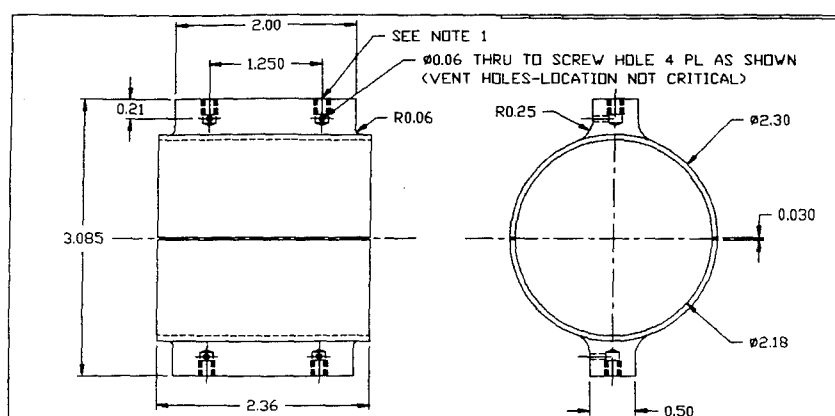


Figure 14. Drawing of the loop-gap resonator.

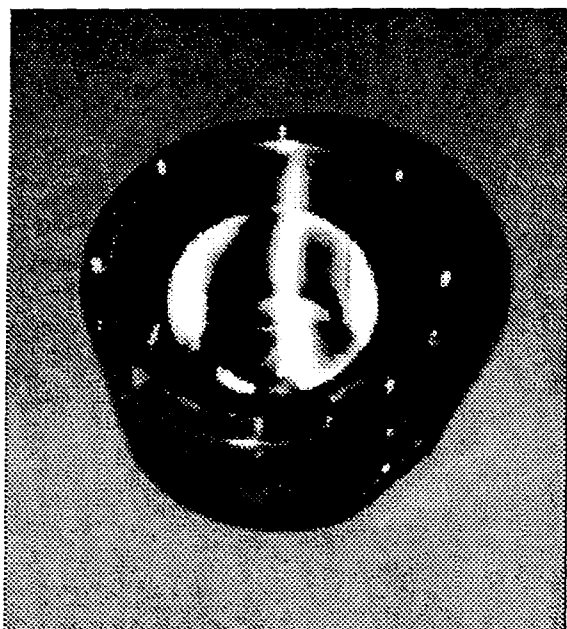


Figure 15. Photograph of the electrodes mounted inside the RF shield can of the loop-gap resonator.

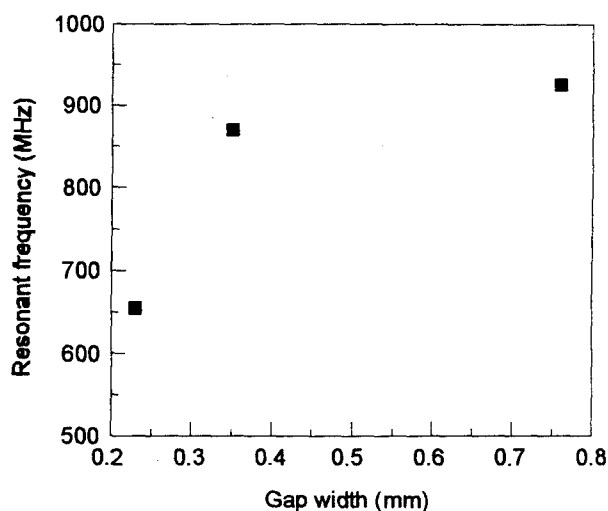


Figure 16. Results of the measurement of the resonant frequency of the loop-gap resonator as fabricated.

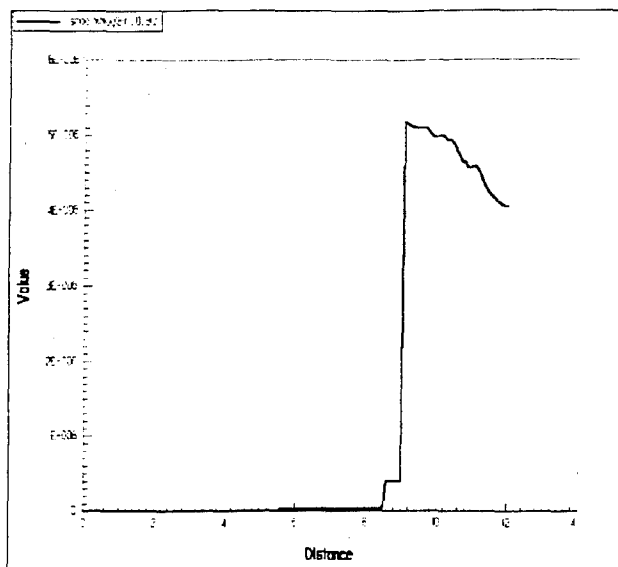


Figure 11. Magnetic field on the axis of the maser. The cavity extends from $z=0$ to $z=8$.

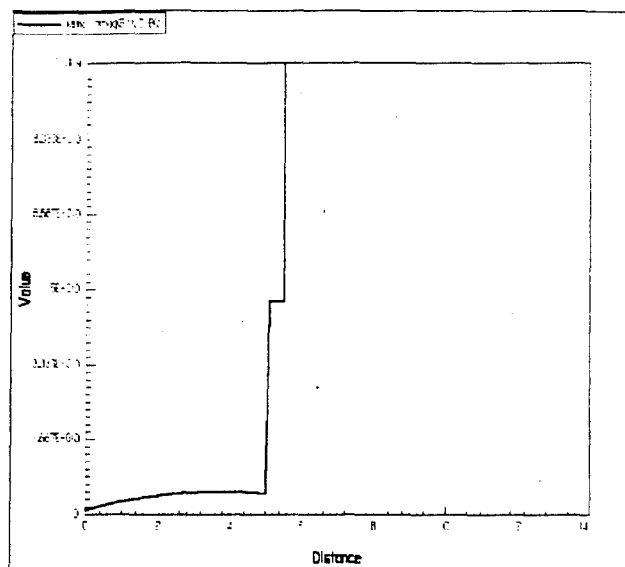


Figure 12. Magnified plot of the magnetic field along the z axis.

Figures 11 and 12 are plots of the magnetic field along the axis of the the shield. The center of the RF cavity is at $z=0$. The magnetic field is down by more than five orders of magnitude, typical of the shield arrangement.

In the AF-1, the c-field was produced by a 21 turn coil epoxied to the inside of the magnetic shield. As determined in tests of the maser in its unmodified state, the magnetic field produced by that coil was not uniform enough for the device to mase. It was therefore replaced by a new coil, with a variable turn density. This turn density was optimized to yield a flat field profile shown in Figure 13. Additionally, the coil was counter-wound, rather than having the single, longitudinal return wire of the original coil. This eliminated the non-solenoidal contribution from the return wire.

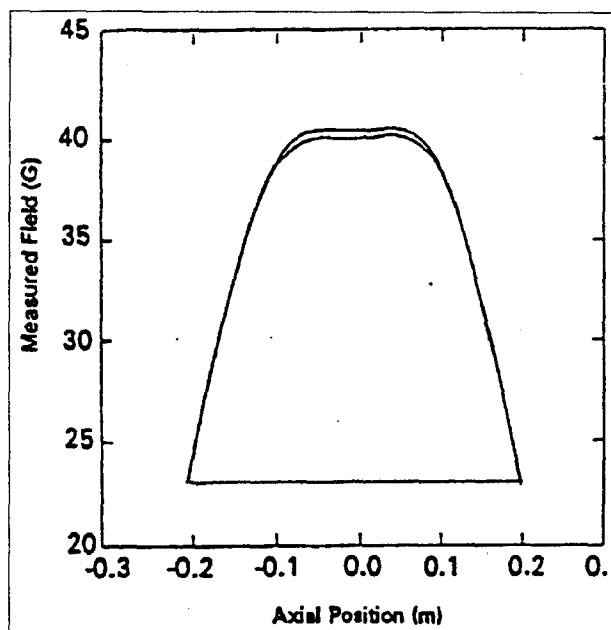


Figure 13. Profile of the C field produced by the new coil.

Parts Drawings

The drawings of the major parts are appended for future reference.

Measurements

Initial Tests (Tests of AF-1)

Our first step in the reconstruction of this maser was to benchmark the performance for the AF-1 maser before rebuilding it with the new elements. This would give us a relative measurement of the superconducting maser. The parameter chosen for comparison was the atomic line width, which parameter is relatively easy to measure. Other measures of performance take long to measure and are more dependent on systematic fluctuations. These fluctuations can often be corrected in engineering an optimized version of the maser.

During the benchmarking of AF-1, we replaced and repaired many of the original elements. The first element repaired was the original wiring. After years of disuse, the AF-1 had several blown transistors, and some bad wire contacts. The new c-field coil winding was used to give a more homogeneous magnetic field.

In operation, the refurbished maser performed very well. At c-field levels of about 100 mG, the measured maser line width was less than 1 Hz. This line width could only be achieved at high field levels because of residual magnetic field gradients at a low field that broadened the hydrogen resonance line. Since these tests, we have re-annealed all of the magnetic shielding elements in the maser. This should resolve any residual field issues and allow the measurement of the maser at much lower field levels of about 1 mG.

It should be noted that these measurements were made with the original cavity and bulb. This cavity was designed for active oscillation only. Therefore, it had only one microwave coupler. An interrogation signal was passed into the cavity and the return was measured using a directional coupler. The cavity designed for the Phase II program has two couplers for passive interrogation.

The maser will be operated in passive mode when tested with the copper cavity at temperatures from 300 K to 77 K. These tests will allow to isolate the effects of operation at low temperatures from those associated specifically with the superconductor, such as the cavity Q and the magnetic shielding.

Initial Operation

For the passive measurements we will use the vector impedance technique of cavity interrogation. Using the combined phase and amplitude information of the signal this technique is expected to reduce the effect of cavity pulling significantly.¹ These measurements will include the characterization of frequency shifts and relaxation processes associated mainly with the teflon coating of the bulb. For determining the frequency stability of the oscillator signal, the maser will be operated in the active mode with the superconducting cavity cooled to 77 K. These measurements are performed by comparing the maser's frequency with that of an atomic clock of known stability by using the Allen deviation as the statistical measure. The increased temperature sensitivity of the wall shift as well as the cavity pulling is expected to limit the stability of the operation of the compact maser at 77 K.

¹ Details of this technique are discussed in W.M. Golding, et al., "Reduction of Cavity Pulling in a Passive Hydrogen Maser", Proc. of the 20th PTTI (1988).

Tuning of the cavity was accomplished in several steps. The adjustment of the gap was the first, and would be done only prior to the final assembly. Once the cavity was in place, adjustment to the resonant frequency would be made by the sapphire paddle, positioned near one of the gaps. The paddle was connected to the glass bulb which could be rotated around its axis, as discussed below. The total frequency sweep would be greater than 15 MHz, as shown in Figure 17. The resolution of the positioner is about 1 micron, giving a frequency resolution of 1 kHz. The final, and most precise tuning, was provided by a varactor diode coupled to the cavity via a loop antenna on the top of the cavity. The maximum frequency shift produced in this manner is expected to be about 30 kHz.

Glass Bulb

The bulb, shown in Figures 19 and 18, was fabricated from quartz glass. The sapphire tuning paddle was connected to the bulb via two small posts so that rotation of the bulb produced a movement of the paddle across the cavity gap. The rotation of the bulb was done by a piezo-electric "inchworm" drive. The thermal expansion coefficients of the glass and sapphire are significantly different, and there was concern that the supports for the paddle would be broken during cool down. To avoid this, one of the two support holes in the paddle was opened up to form a slot. This arrangement proved to be very fragile, and in fact, failed. Finally, the paddle was attached at one end with low temperature epoxy.

As is usual for a hydrogen maser, the inside of the bulb was coated with Teflon™ to minimize the interaction of the wall with the hydrogen atoms. The coating was applied by Sigma Tau, Inc., a long-standing manufacturer of conventional hydrogen masers, using a complex proprietary process.

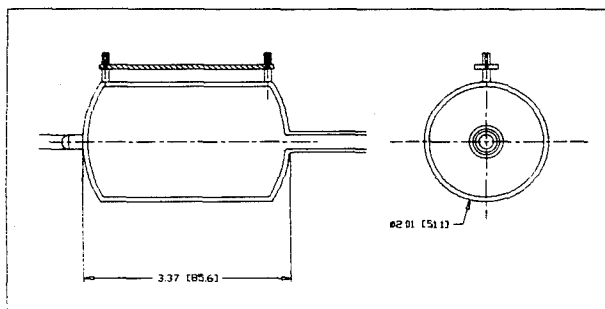


Figure 19. Drawing of the glass bulb for the hydrogen maser. The tuning paddle is shown on the right.

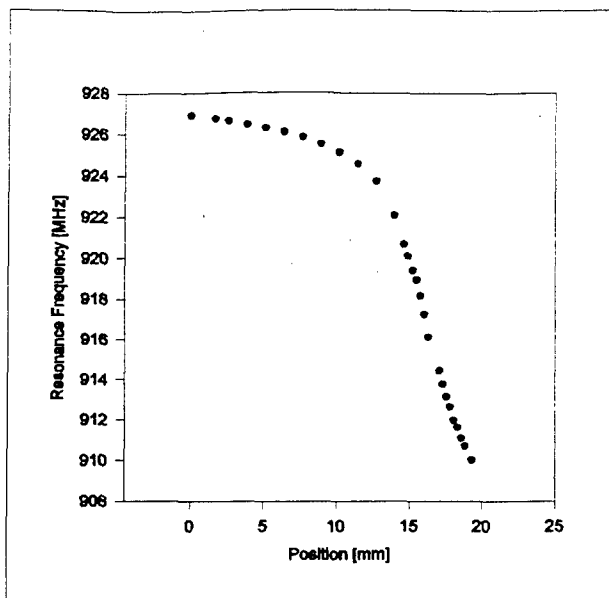


Figure 17. Shift in resonant frequency produced by rotating the paddle over 33 degrees (18.4 mm) across the cavity gap.

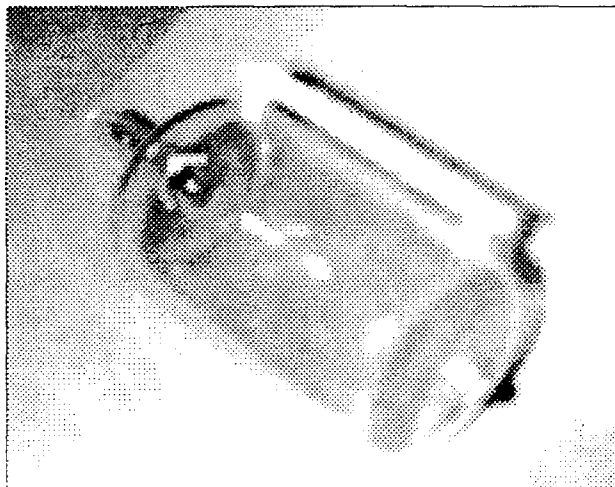


Figure 18. Photograph of the glass bulb, with tuning paddle, for the hydrogen maser.

Conclusions

Although the maser was not fully operational, several important conclusions were drawn. The first is that the maser would be more difficult to operate than anticipated. The primary cause for this was in its sensitivity to thermal fluctuations. This was due to operating at cryogenic temperatures, and was more than an order of magnitude higher than is found in a conventional (room temperature) hydrogen maser. The second was that the added complexity and volume of the elements needed for cryogenic operation significantly reduced the attractiveness of the maser as a commercial product. Given these two drawbacks, and the limited market for hydrogen masers in general, it was determined that no further effort should be made toward commercialization. However, the program was not without significant benefit. It established a technology base that has allowed PSI to embark on the development of a novel rubidium maser. This device is expected to have a relatively large commercial and military market, a perception backed by our industrial partner who is putting almost \$200,000 into the development in our Phase II.

Personnel Supported

The scientists who contributed to this research include David B. Opie, Michael E. Read, and Geoffrey Bird of Physical Sciences, Inc. and S.K. Remillard, H. E. Schone of the College of William and Mary.

Publications

"Magnetic Shielding By $Y_1Ba_2Cu_3O_{7.8}$ Thick Films" published in IEEE Transactions on Applied Superconductivity, Vol.3, No. 1, March 1993. This article contributors include: D.B. Opie, M.E. Read, S.K. Remillard, M. J. Brown, W. J. Kossler, H. E. Schone, T. W. Button and N. McAlford

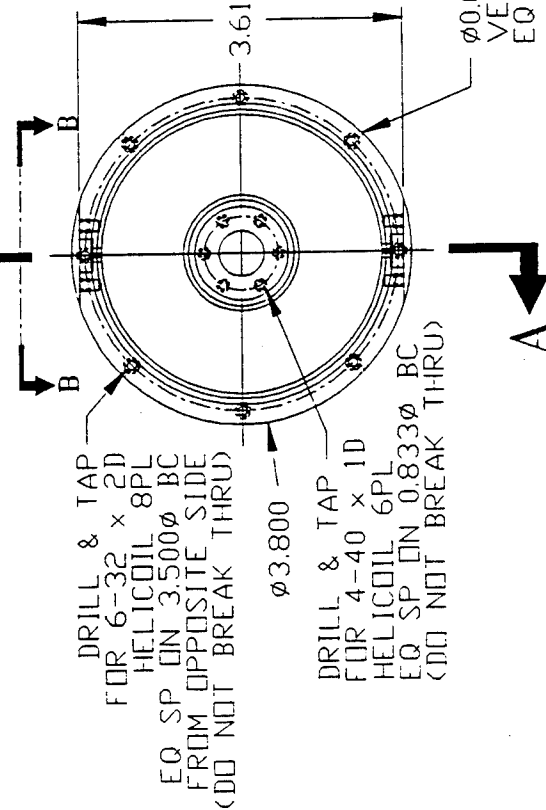
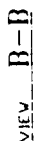
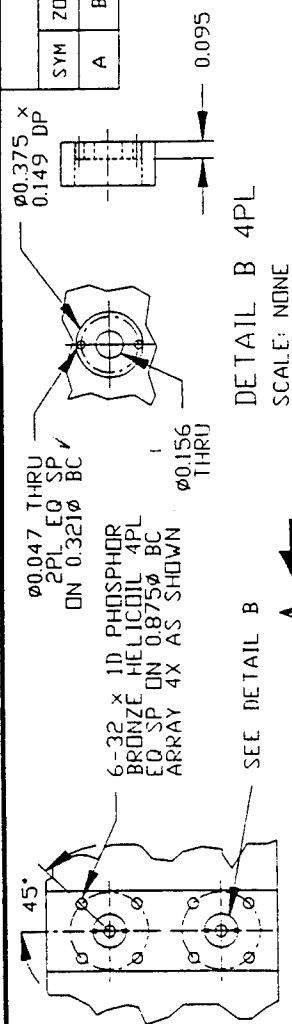
Appendix I

Magnetic Shielding by YBCO Thick Films

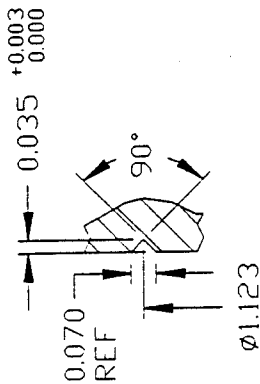
Consideration was given of using superconducting magnetic shields. These shields were expected to be much more effective than conventional mu-metal ones. However, after an initial investigation, it was decided that use of superconducting shields would entail an effort beyond the scope of the program, and that conventional shields would be used. A paper documenting these shields is appended.

Appendix II

Parts Drawings



SECTION A—A



TOLERANCES		DRAWN	TVP	5-17-94
ENGLISH	METRIC	CHECKED	X	X
INCHES	MILLIMETERS	APPROVED	X	X
FRACTIONAL	DECIMALS	APPROVED	X	X
XXX ± .005	.XX ± .01	RELEASED	X	X
XXXX ± .0005	ANGLES ± 1°-0'	SIGNATURE	DATE	

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

CAVITY BODY FOR MASER

PROJECT	SIZE	COMPUTER FILE	CAVITY.DWG	ISSUE
1190-3	A	MASR-0040		A
SCALE 1=2	DO NOT SCALE PRINT		SHEET 1	OF 1



4 3 2 1

Ø0.156 THRU
8PL EQ SP
ØN 3.500Ø BC

Ø3.234

Ø3.800

A

22.5°

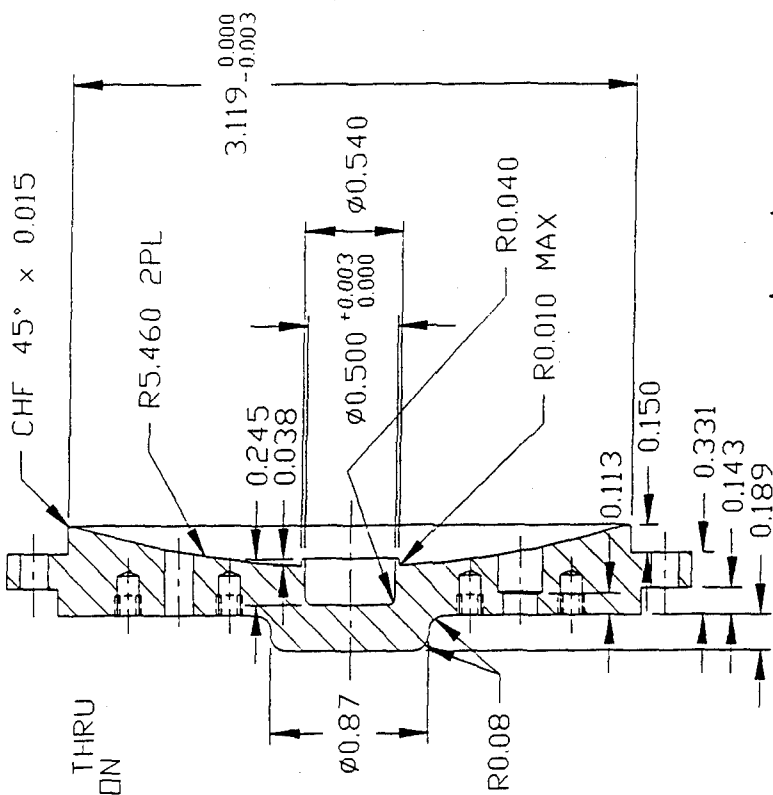
6-32UNC-2B THRU
4PL EQ SP ØN
3.500Ø BC

Ø0.160 THRU
2PL AS SHOWN
ØN 1.895Ø BC

DRILL & TAP FOR 4-40
X 1D HELICOILS
6PL EQ SP ØN 0.563Ø BC
ARRAY AS SHOWN
(DO NOT BREAK THRU)

Ø0.190 THRU
C'BORE Ø0.250
FROM OTHER SIDE
TO DEPTH SHOWN

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE
A	B2.4	Ø0.160 THRU MODIFIED FOR DIODE	7-19-94



SECTION A-A

TOLERANCES		DRAWN		TVP		3-24-94	
ENGLISH	METRIC	CHECKED		X		X	
INCHES	MILLIMETERS	APPROVED		X		X	
FRAC: 1/64	DECIMALS:	APPROVED		X		X	
DECIMALS:	XX ± 01	RELEASED		X		X	
XXX ± 005	XXXX ± .0005	SIGNATURE					
ANGLES ± 1°-0'		DATE					
MATERIAL ØFHC COPPER		FINISH 32					
PROJECT 1190-3		SIZE A		COMPUTER FILE CAVTCVR.DWG		ISSUE A	
SCALE 1=1		DO NOT SCALE PRINT		SHEET 1		OF 2	

PHYSICAL SCIENCES, INC.
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ALEXANDRIA, VA 22314

CAVITY COVER
FOR MASER

4 3 2 1

1

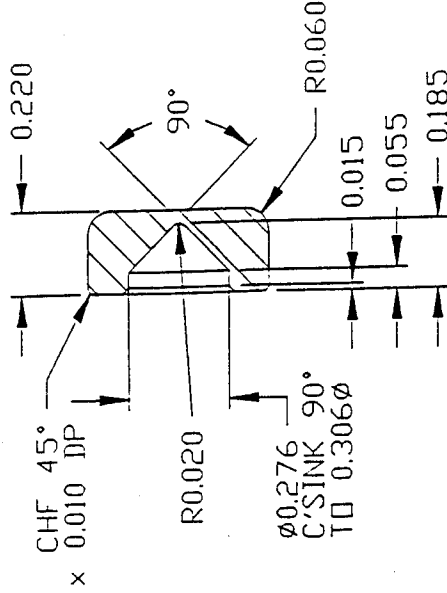
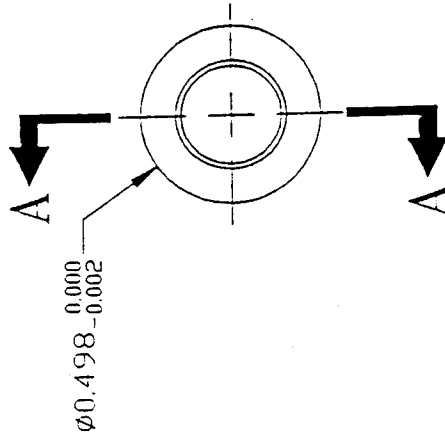
2

3

4

B

A



SECTION A-A

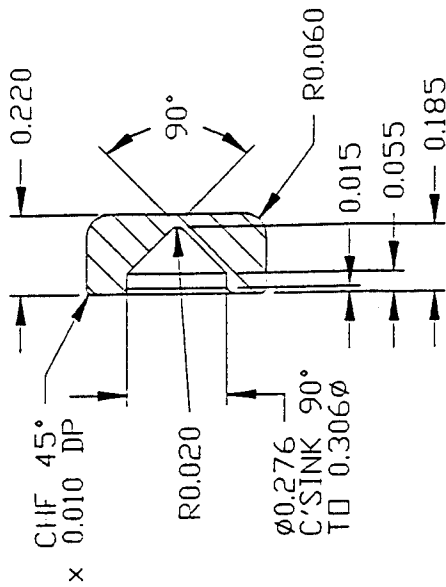
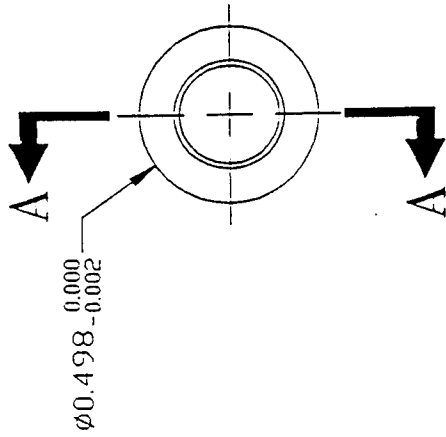
PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		PROJECT 1190-3		SIZE A		COMPUTER FILE BLBBRNG.DWG		ISSUE MASR-0049	
BULB BEARING FOR MASER		SCALE 2=1		DO NOT SCALE PRINT		SHEET 1 OF 1		1	
TOLERANCES ENGLISH INCHES FRACTIONAL DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1'-0"		METRIC MILLIMETERS DECIMALS .X ± .1 .XX ± .01		DATE 6-21-94		TVP X		SIGNATURE X	
MATERIAL TEFLON		FINISH 32		DRAWN CHECKED APPROVED APPROVED RELEASED		DATE 6-21-94		1	

1

2

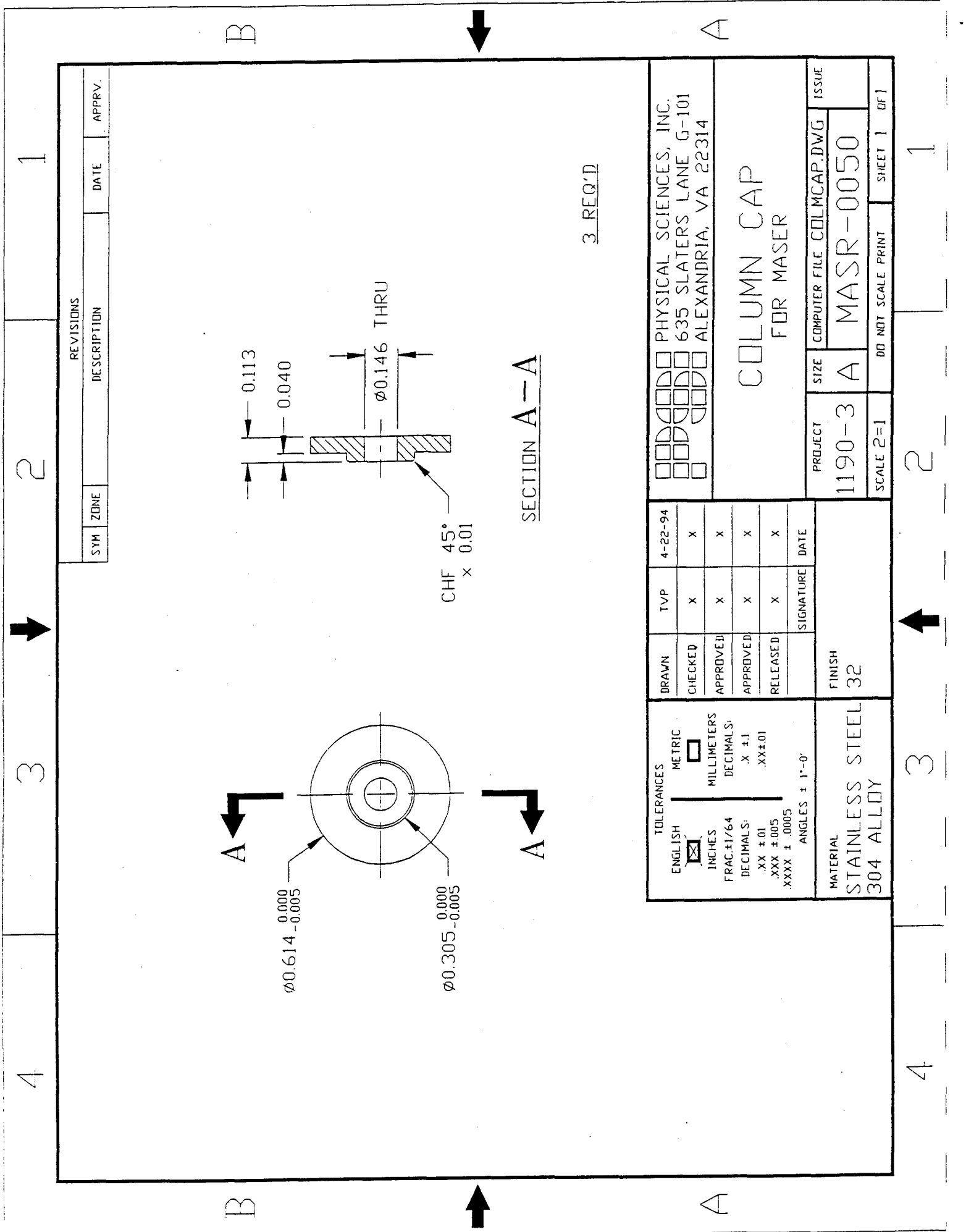
3

4



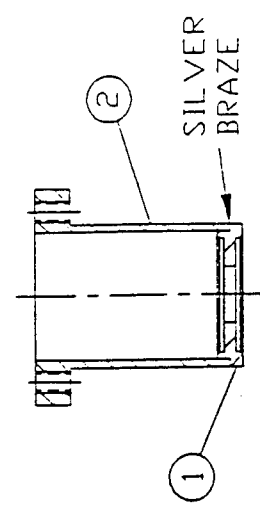
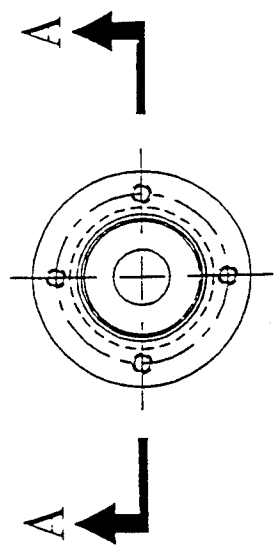
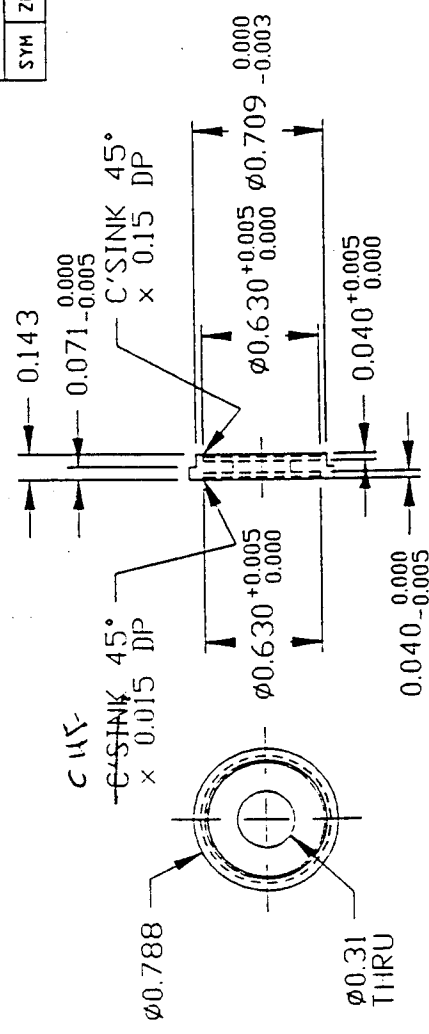
SECTION A-A

PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		PROJECT 1190-3		SIZE A		COMPUTER FILE BLBBRNG.DWG		ISSUE MASR-0049	
BULB BEARING FOR MASER		SCALE 2=1		DO NOT SCALE PRINT		SHEET 1 OF 1		1	
TOLERANCES ENGLISH INCHES DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1°-0'		METRIC MILLIMETERS DECIMALS .X ± .1 .XX ± .01 .XXX ± .005 .XXXX ± .0005		DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X		6-21-94 X X X X	
MATERIAL TEFLON		FINISH 32		SIGNATURE DATE		1190-3 A		1	



TOLERANCES		METRIC		ENGLISH	
INCHES		MILLIMETERS		FRACTIONAL	
DECIMALS		DECIMALS		DECIMALS	
.XX ± .01		.XX ± .01		.XX ± .01	
.XXX ± .005		.XXX ± .005		.XXX ± .005	
.XXXX ± .0005		.XXXX ± .0005		.XXXX ± .0005	
ANGLES ± 1°-0'		ANGLES ± 1°-0'		ANGLES ± 1°-0'	
MATERIAL		FINISH		DATE	
STAINLESS STEEL		32		4-22-94	
304 ALLOY					
DRAWN		TVP		4-22-94	
CHECKED		X		X	
APPROVED		X		X	
APPROVED		X		X	
RELEASED		X		X	
SIGNATURE		DATE		DATE	
PROJECT		SIZE		COMPUTER FILE	
1190-3		A		COLMCP.DWG	
SCALE 2=1		DO NOT SCALE PRINT		SHEET 1 OF 1	
COLUM CAP		FOR MASER		ISSUE	
MASR-0050					
PHYSICAL SCIENCES, INC.		635 SLATERS LANE G-101		ALEXANDRIA, VA 22314	

4 3 2 1



SECTION A-A ASSEMBLY

3 REQ'D

TOLERANCES		METRIC		ENGLISH	
MILLIMETERS		INCHES		FRACTIONAL	
DECIMALS		DECIMALS		DECIMALS	
.X ± .1		.XX ± .01		.XXX ± .005	
.XX ± .01		.XXX ± .005		.XXX ± .005	
.XXX ± .005		.XXX ± .005		.XXX ± .005	
ANGLES ± 1°-0'		ANGLES ± 1°-0'		ANGLES ± 1°-0'	

4-40UNC-2B
THRU 4PL
ON 0.938Ø BC

ITEM 2

CYLINDER

DRAWN	CHECKED	APPROVED	RELEASED	SIGNATURE	DATE
	X	X	X		4-25-94
	X	X	X		
	X	X	X		
	X	X	X		

PROJECT		SIZE		COMPUTER FILE		ISSUE	
1190-3		A		COLMFLNG.DWC		MASR-0051	
SCALE 1=1		DO NOT SCALE PRINT		SHEET 1		OF 1	

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

COLUMN FLANGE
ASSEMBLY
FOR MASER

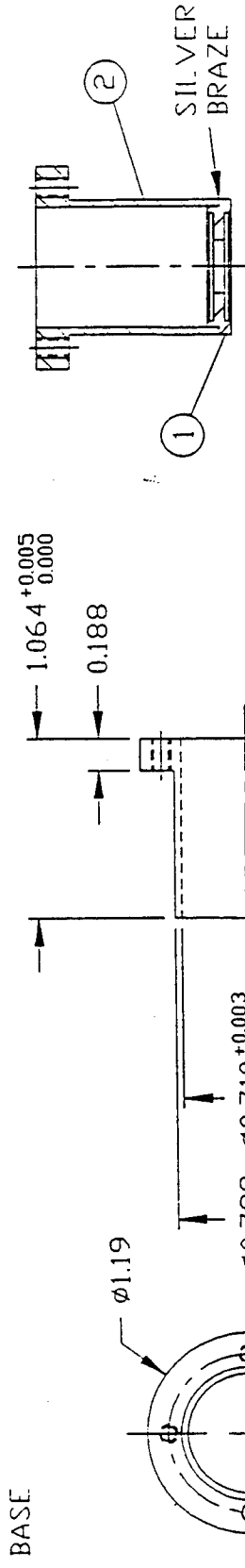
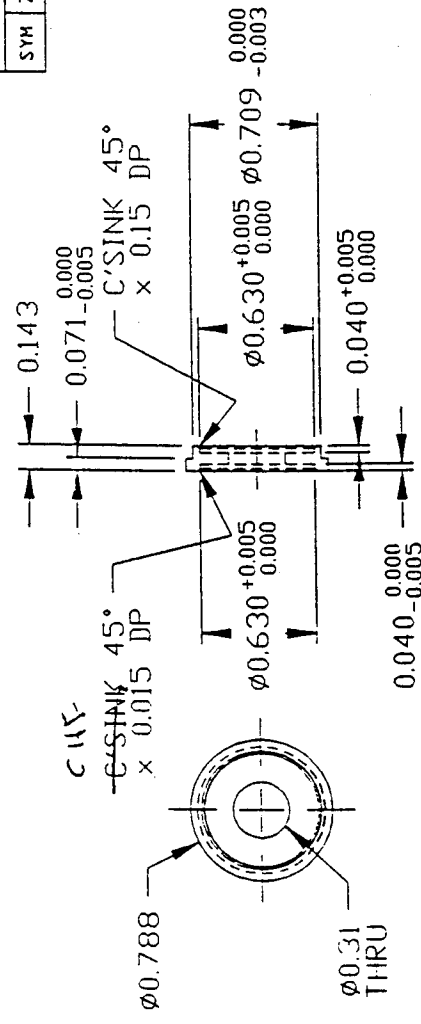
MATERIAL
STAINLESS STEEL
304 ALLOY

FINISH
32

4 3 2 1

4 3 2 1

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE



SECTION A-A ASSEMBLY

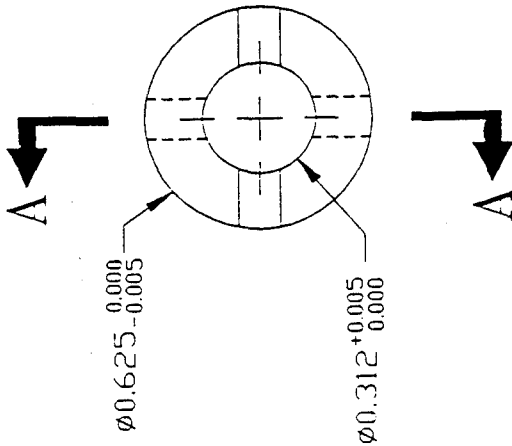
3 REQ'D

TOLERANCES		METRIC		ENGLISH	
MILLIMETERS		INCHES		FRACTIONS	
DECIMALS		DECIMALS		DECIMALS	
.XX ±.01		.XX ±.01		.XX ±.01	
.XXX ±.005		.XXX ±.005		.XXX ±.005	
.XXXX ±.0005		.XXXX ±.0005		.XXXX ±.0005	
ANGLES ± 1°-0'		ANGLES ± 1°-0'		ANGLES ± 1°-0'	
MATERIAL		FINISH		SCALE	
STAINLESS STEEL 304 ALLOY		32		1:1	
PROJECT		SIZE		ISSUE	
1190-3		A		MASR-0051	
COMPUTER FILE		COLMFLNG.DWG		SHEET 1 OF 1	

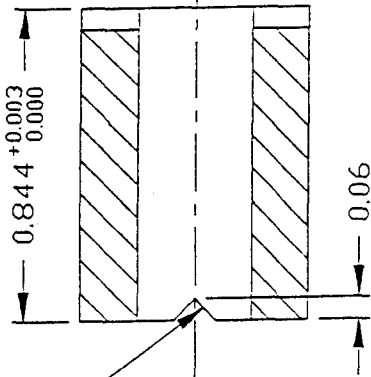
PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

COLUMN FLANGE
ASSEMBLY
FOR MASER

4 3 2 1



VENT GROOVE
2PL AS SHOWN
SEE NOTE 1



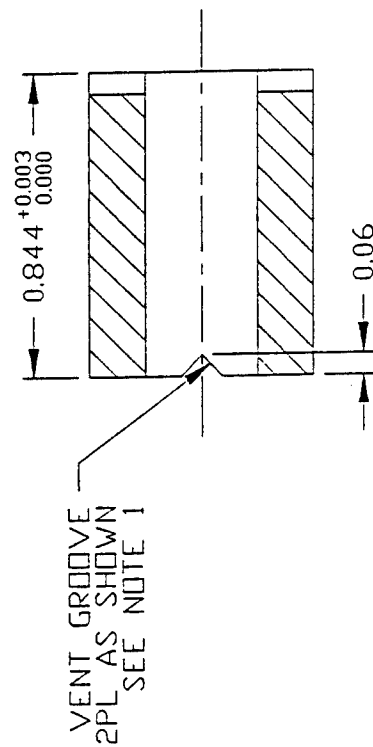
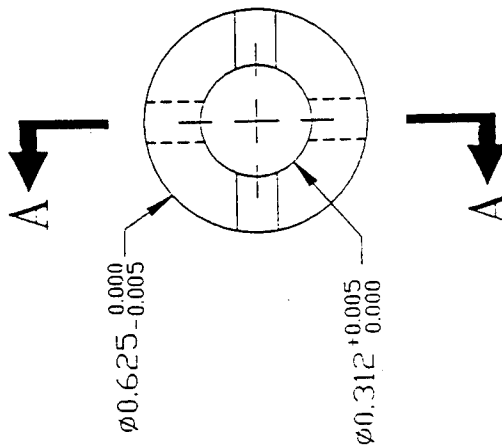
SECTION A-A

NOTES:

- GROOVE DIMS.
NOT CRITICAL

6 REQ'D

TOLERANCES ENGLISH INCHES DECIMALS: .XX ± 01 .XXX ± 005 .XXXX ± .0005 ANGLES ± 1°-0'		METRIC MILLIMETERS DECIMALS: .X ± 1 .XX ± 01		DRAWN CHECKED APPROVED APPROVED RELEASED	TVP X X X X	4-25-94 X X X X	PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		
COLUMN INSULATOR FOR MASER				PROJECT 1190-3 A		SIZE A		COMPUTER FILE COL MINS.DWG MASR-0052	
MATERIAL ZYAROCK				FINISH 32		SCALE 2=1		DO NOT SCALE PRINT	
SYM ZONE				DESCRIPTION		DATE		APPRV.	



SECTION A-A

NOTES:

- GROOVE DIMS. NOT CRITICAL

6 REQ'D

TOLERANCES ENGLISH ☒ INCHES METRIC ☐ MILLIMETERS DECIMALS: .XX ± .01 FRACTIONS: 1/64 ANGLES: ± 1°-0'		DRAWN CHECKED APPROVED APPROVED RELEASED	TVP X X X X	DATE 4-25-94 X X X X	FINISH 32	MATERIAL ZYAROCK
PROJECT 1190-3 A		SIZE A	COMPUTER FILE COLMINS.DWG		ISSUE MASR-0052	SCALE 2=1 DO NOT SCALE PRINT
SHEET 1 OF 1		SHEET 1 OF 1		SHEET 1 OF 1		SHEET 1 OF 1

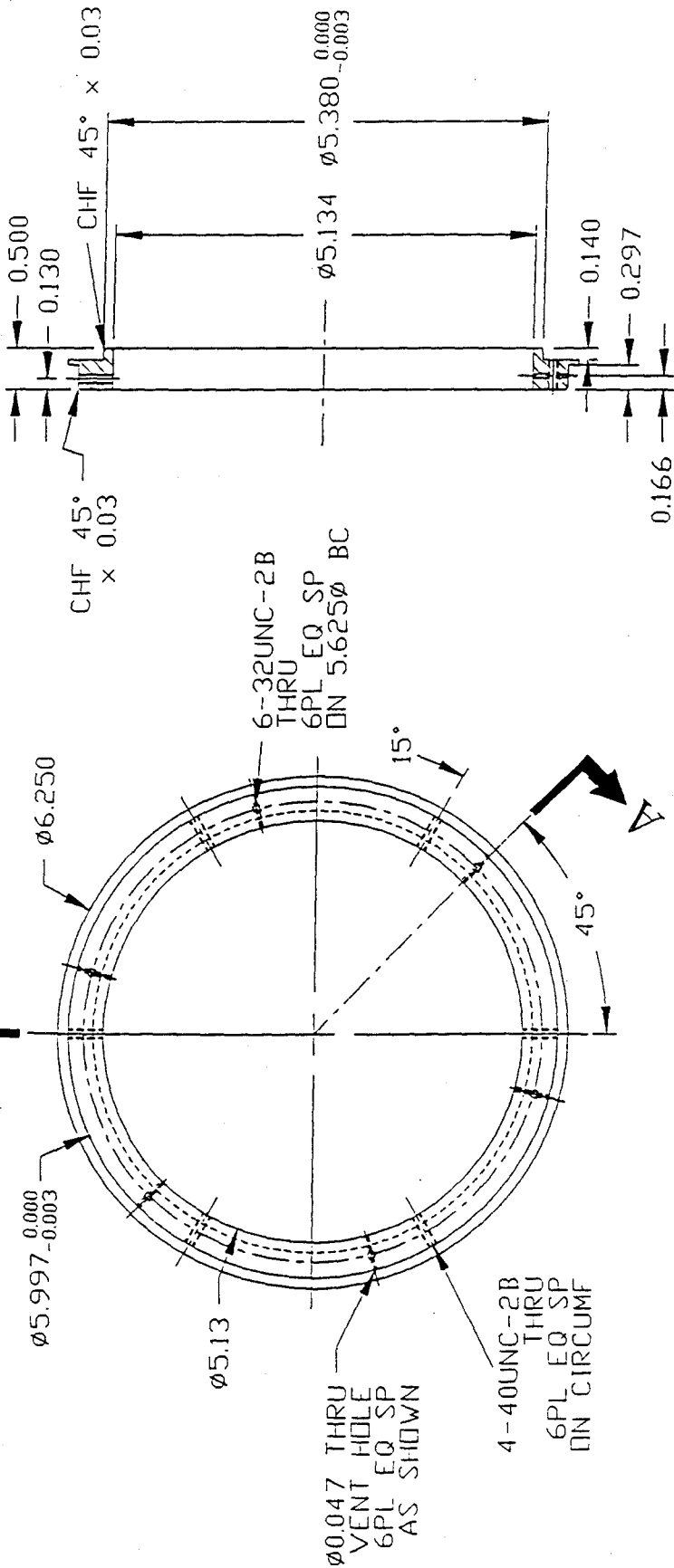
PHYSICAL SCIENCES, INC.
 635 SLATERS LANE G-101
 ALEXANDRIA, VA 22314

COLUMN INSULATOR
 FOR MASER

REVISIONS			
SYN	ZONE	DESCRIPTION	DATE
			APPRV.

4 3 2 1

A



SECTION A-A

TOLERANCES ENGLISH ☒ INCHES METRIC ☐ MILLIMETERS DECIMALS: .X ±.1 .XX ±.01 .XXX ±.005 .XXXX ±.0005 ANGLES ± 1°-0'		DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X		3-28-94 X X X X	
MATERIAL ALUMINUM 6061-T6		FINISH 32		SIGNATURE DATE		PROJECT 1190-3	
SIZE A		COMPUTER FILE DTRSHBAS.DWG		ISSUE MASR-0120		SCALE 1=2 DO NOT SCALE PRINT	

PHYSICAL SCIENCES, INC.
 635 SLATERS LANE G-101
 ALEXANDRIA, VA 22314
 OUTER SHIELD
 BASE PLATE
 FOR MASER

4 3 2 1

4

3

2

1

A

Ø5.997 ±0.000
-0.003

Ø5.13

Ø0.047 THRU
VENT HOLE
6PL EQ SP
AS SHOWN

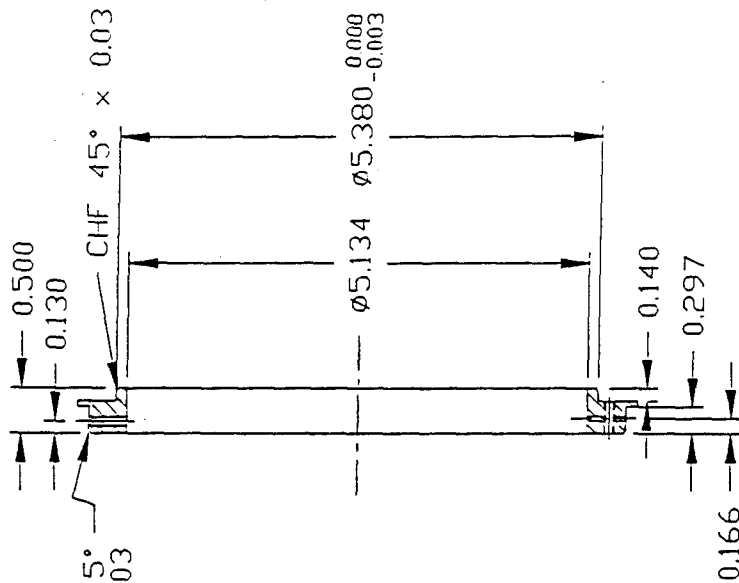
4-40UNC-2B
THRU
6PL EQ SP
IN CIRCUMF

Ø6.250

6-32UNC-2B
THRU
6PL EQ SP
ON 5.625Ø BC

15°

45°



SECTION A-A

TOLERANCES		METRIC	
ENGLISH	☒	INCHES	☐
FRACTIONAL	1/64	DECIMALS	±.1
XX	±.01	XXX	±.005
XXXX	±.0005	XXXX	±.0005
ANGLES ± 1°-0'			

MATERIAL
ALUMINUM
6061-T6

DRAWN	TVP	3-28-94
CHECKED	X	X
APPROVED	X	X
APPROVED	X	X
RELEASED	X	X
SIGNATURE		DATE

FINISH
32

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

OUTER SHIELD
BASE PLATE
FOR MASER

PROJECT	SIZE	COMPUTER FILE	ISSUE
1190-3	A	QTRSHBAS.DWC	
SCALE 1=2		MASR-0120	
DO NOT SCALE PRINT		SHEET 1 OF 1	

4

3

2

1

A

A

B

B

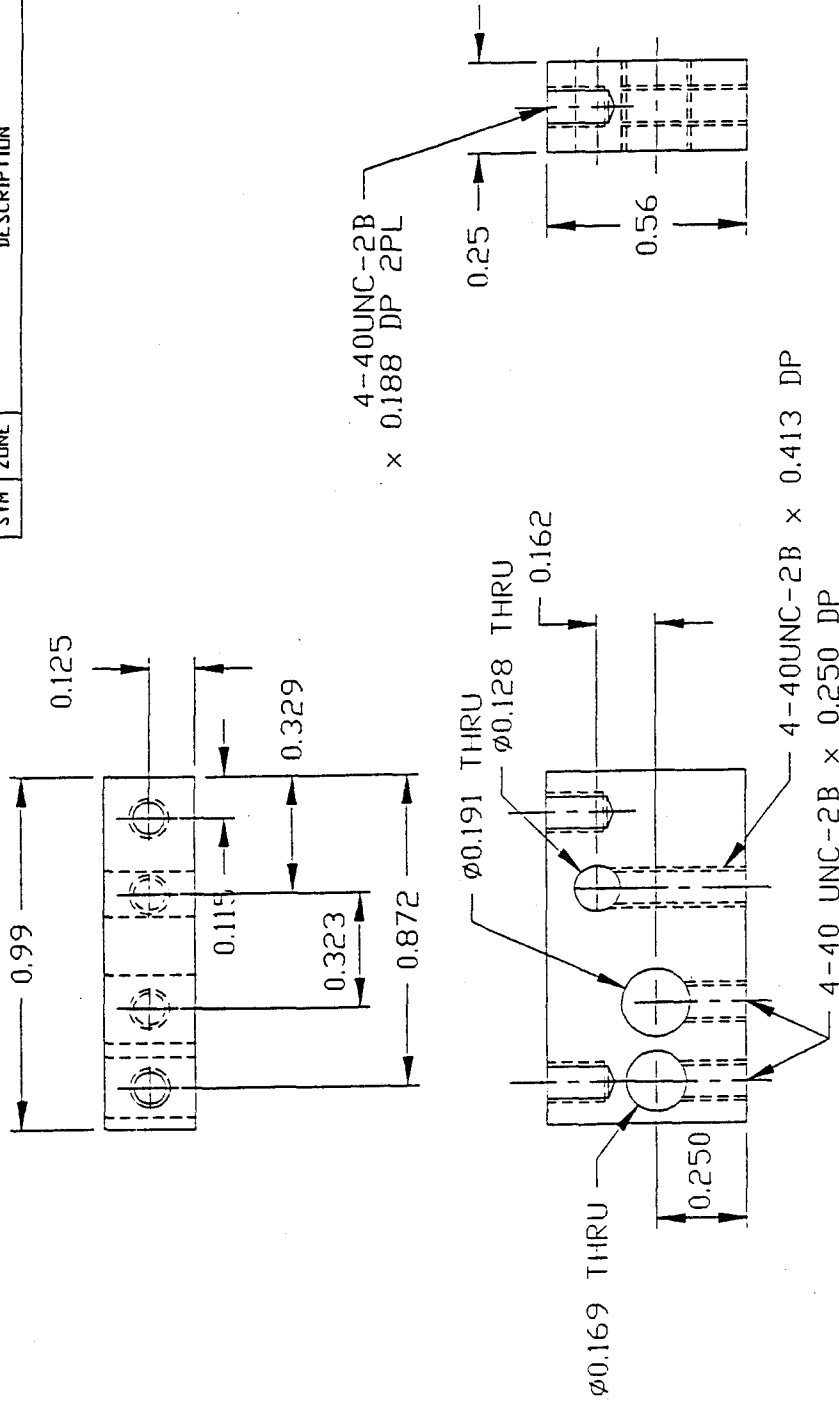
A

A

4 3 2 1

B B A A

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE
			APPRV.



PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		MOUNTING BRACKET FOR MASER		PROJECT 1190-3		SIZE A		COMPUTER FILE MBRKT.DWG MASR-0099		ISSUE 1	
TOLERANCES ENGLISH INCHES DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005		METRIC MILLIMETERS DECIMALS .X ± .1 .XX ± .01 .XXX ± .005		FINISH 32		SCALE 2=1		DO NOT SCALE PRINT		SHEET 1 OF 1	

4 3 2 1

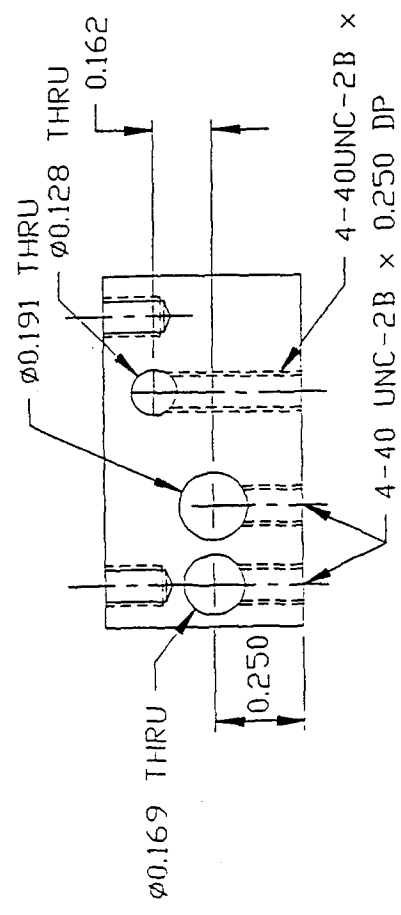
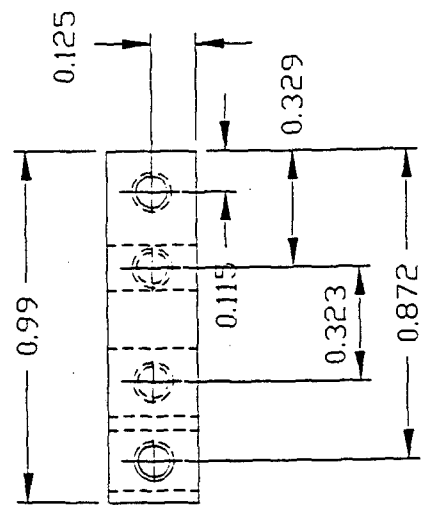
4

3

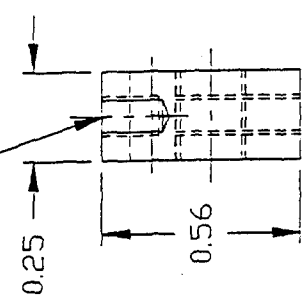
2

1

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE
			APPRV.



4-40UNC-2B
x 0.188 DP 2PL



TOLERANCES	
ENGLISH	METRIC
☒ INCHES	☐ MILLIMETERS
FRAC. 1/64	DECIMALS
DECIMALS: .X ± .1	.X ± .1
.XX ± .01	.XX ± .01
.XXX ± .005	.XXX ± .005
.XXXX ± .0005	
ANGLES ± 1°-0'	

MATERIAL
ALUMINUM
6061-T6

DRAWN	TVP	4-19-94
CHECKED	X	X
APPROVED	X	X
APPROVED	X	X
RELEASED	X	X
SIGNATURE	DATE	

FINISH
32

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

MOUNTING BRACKET
FOR MASER

PROJECT	SIZE	COMPUTER FILE	MBRKT.DWG	ISSUE
1190-3	A	MASR-0099		
SCALE 2=1		DO NOT SCALE PRINT	SHEET 1	(IF)

4

3

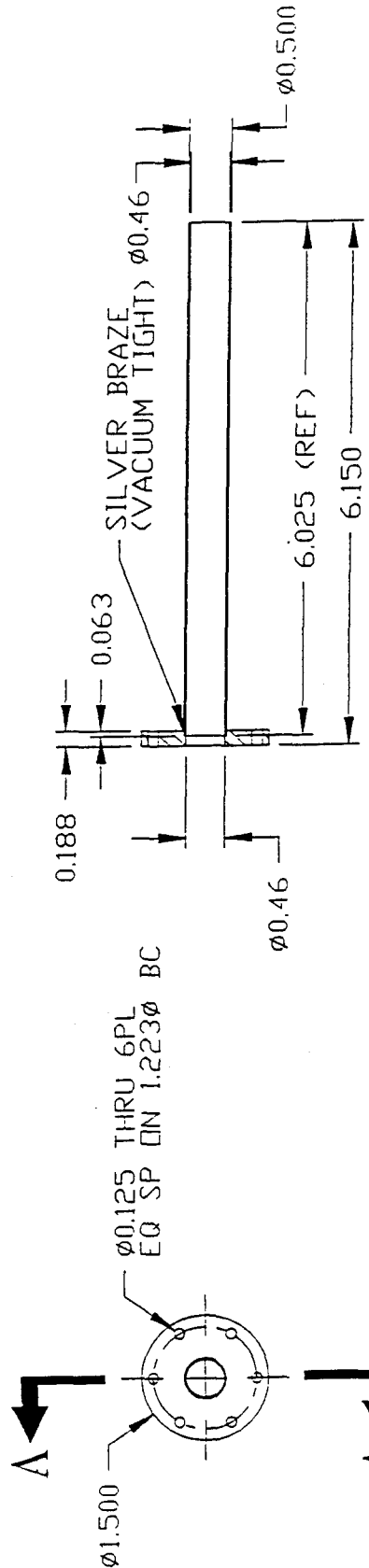
2

1

4 3 2 1

B B

A A



SECTION A-A

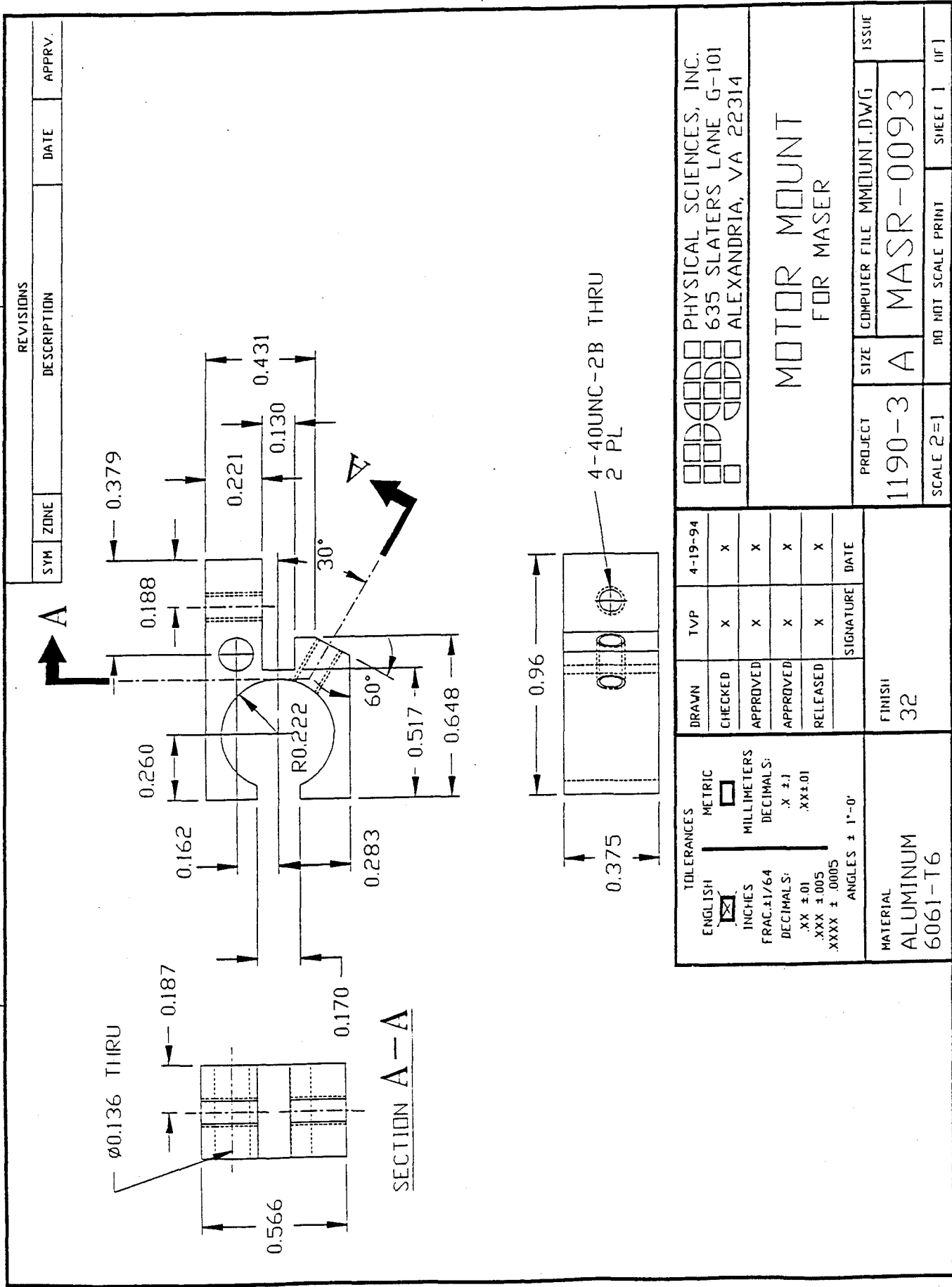
		PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314	
FILL TUBE ASSEMBLY FOR MASER			
PROJECT	SIZE	COMPUTER FILE	ISSUE
1190-3	A	FILTUBE.DWG	MASR-0082
SCALE 1=2		DO NOT SCALE PRINT	
SHEET 1		OF 1	

DRAWN	TVP	6-9-94
CHECKED	X	X
APPROVED	X	X
APPROVED	X	X
RELEASED	X	X
SIGNATURE		DATE
FINISH 32		

TOLERANCES ENGLISH ☒ INCHES METRIC ☐ MILLIMETERS DECIMALS: .X ±.1 DECIMALS: .XX ±.01 DECIMALS: .XXX ±.005 DECIMALS: .XXXX ±.0005 ANGLES ± 1°-0'		MATERIAL STAINLESS STEEL
---	--	-----------------------------

4 3 2 1

4 3 2 1



REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPRV.

PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		MOTOR MOUNT FOR MASER		PROJECT 1190-3 A		SIZE A		COMPUTER FILE MMOUNT.DWG		ISSUE MASR-0093					
TOLERANCES ENGLISH INCHES FRACTIONAL DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005		METRIC MILLIMETERS DECIMALS .X ± .1 .XX ± .01		ANGLES ± 1°-0'		DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X		DATE 4-19-94		SIGNATURE DATE			
MATERIAL ALUMINUM 6061-T6				FINISH 32				SCALE 2=1				DO NOT SCALE PRINT		SHEET 1 (OF)	

4 3 2 1

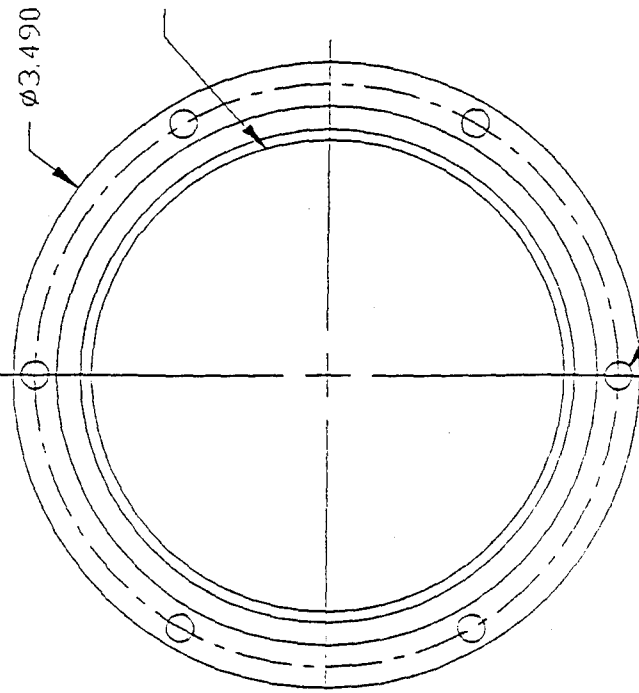
4

3

2

1

A



B

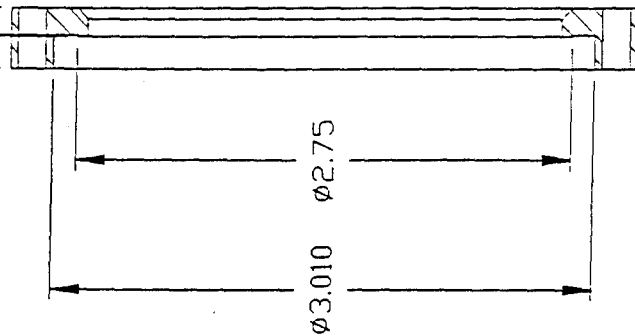
A

REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPRV.
-----	------	-------------	------	--------

0.333

0.010

 $\phi 3.010$ $\phi 2.75$ $\phi 2.633$ THRU
C'SINK $90^\circ \times 0.06$ DP $\phi 0.156$ THRU 6PL
EQ SP ON 3.250 BC

SECTION A-A

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

FILLPLATE CLAMP
FOR MASER

ENGLISH	METRIC	TVP	6-8-94
☒ INCHES	☐ MILLIMETERS	☒	☒
FRAC. 1/64	DECIMALS	☒	☒
.XX ± .01	.X ± .1	☒	☒
.XXX ± .005	.XX ± .01	☒	☒
XXXX ± .0005		☒	☒
ANGLES ± 1'-0"		SIGNATURE	DATE

PROJECT	SIZE	COMPUTER FILE	FILE	AMP	DWG	ISSUE
1190-3	A	MASR-0080				
SCALE 1=1	DO NOT SCALE PRINT	SHEET 1	OF 1			

4

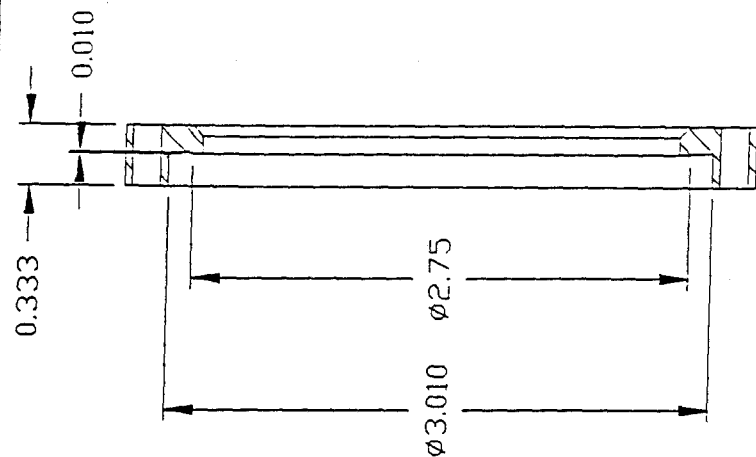
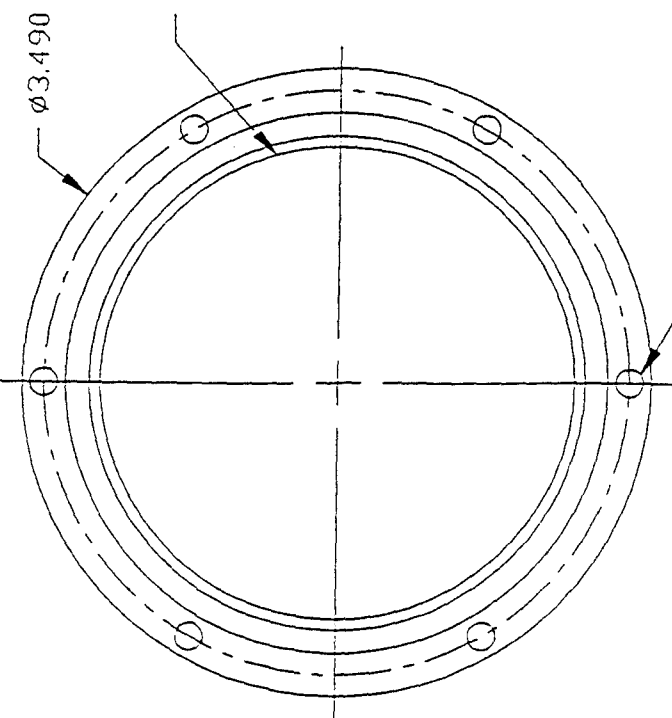
3

2

1

4 3 2 1

A



B

SECTION A-A

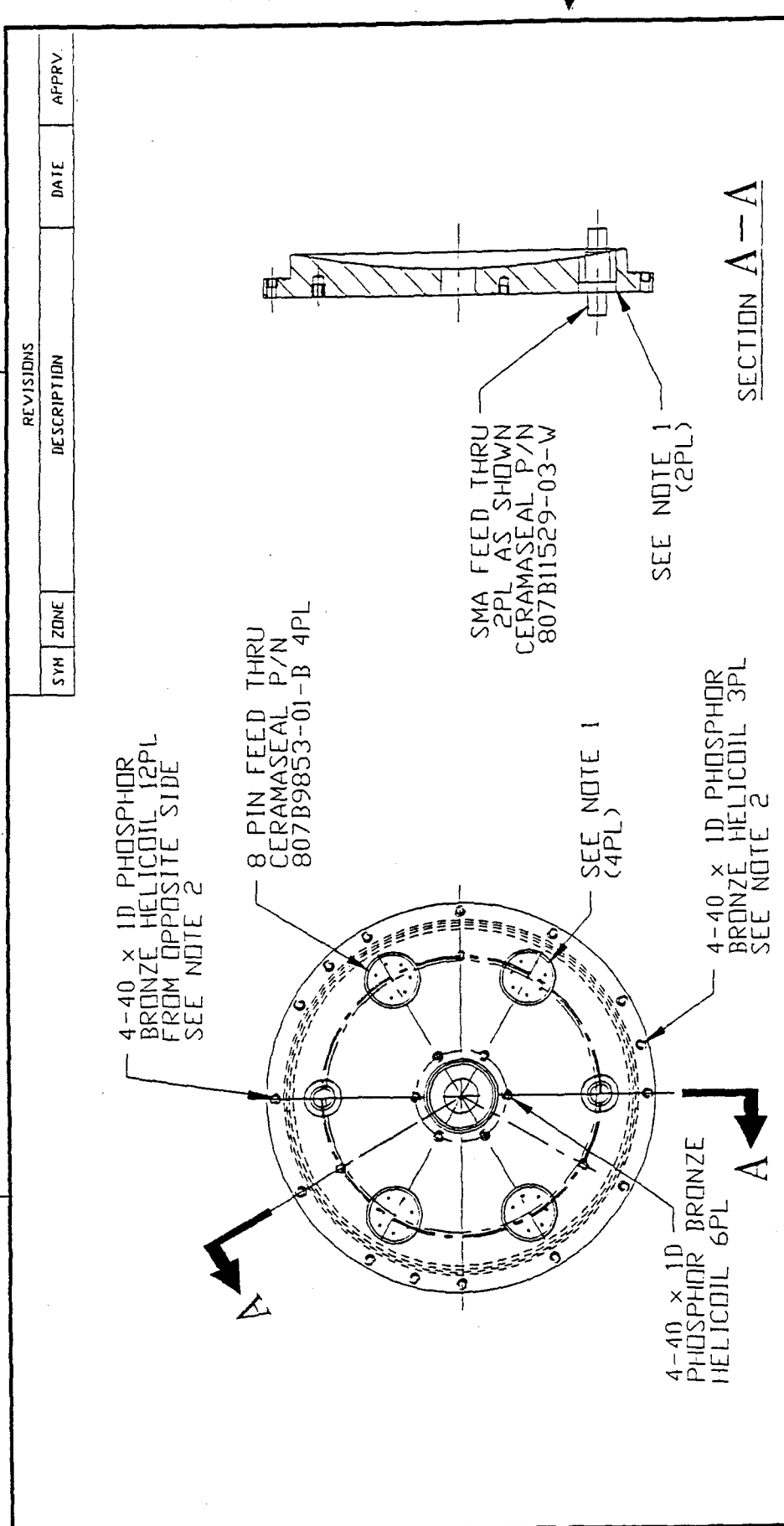
TOLERANCES ENGLISH ☒ INCHES METRIC ☐ MILLIMETERS DECIMALS: .X ±.1 .XX ±.01 .XXX ±.005 .XXXX ±.0005 ANGLES ± 1°-0'		DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X		6-8-94 X X X X		SIGNATURE DATE	
MATERIAL ALUMINUM 6061-T6		FINISH 32		PROJECT 1190-3		SIZE A		COMPUTER FILE FILCLAMP.DWG	
SCALE 1=1		DO NOT SCALE PRINT		SHEET 1 OF 1		PROJECT 1190-3		ISSUE MASR-0080	

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

FILLPLATE CLAMP
FOR MASER

4 3 2 1

4 3 2 1



NOTES:

1. HYDROGEN FURNACE BRAZE USING NICRO 80 ALLOY OR BETTER (HIGH VACUUM TIGHT)
2. INSTALL HELICOILS AFTER BRAZING

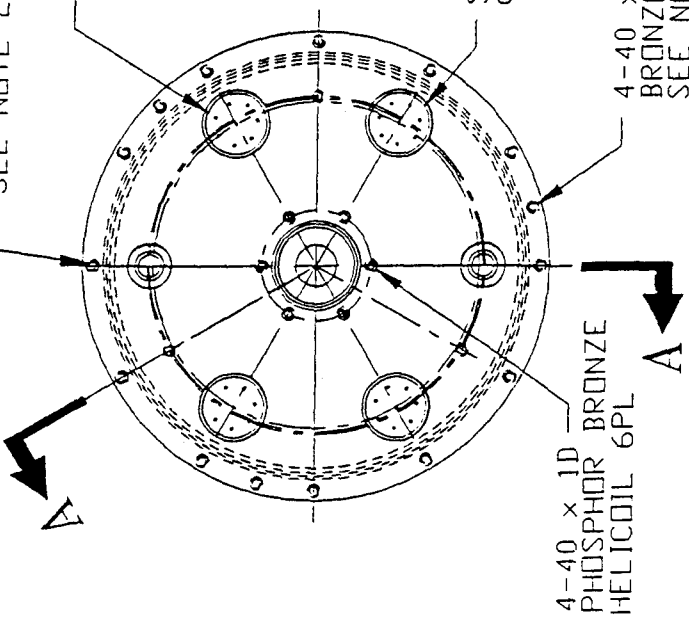
TOLERANCES		METRIC		7-12-94	
ENGLISH	☒ INCHES	DRAWN	TVP	GB	7-12-94
FRAC $\pm 1/64$	DECIMALS $\pm .1$	CHECKED	GB	DO	7-12-94
XX $\pm .01$	XXX $\pm .005$	APPROVED			
XXXX $\pm .0005$	ANGLES $\pm 1^{\circ}-0'$	APPROVED			
		RELEASED			
MATERIAL DFHC COPPER		SIGNATURE		DATE	
FINISH 32					
PROJECT 1190-3		SIZE A		COMPUTER FILE CRYSTASY.DWG	
SCALE 1=2		DO NOT SCALE PRINT		SHEET 2 OF 2	
CRYSTAT COVER ASSEMBLY FOR MASER		MASR-0062		ISSUE	
PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314					

4 3 2 1

REVISIONS		
SYM	ZONE	DESCRIPTION
		DATE
		APPRV.

4-40 x 1D PHOSPHOR
BRONZE HELICOIL 12PL
FROM OPPOSITE SIDE
SEE NOTE 2

8 PIN FEED THRU
CERAMASEAL P/N
807B9853-01-B 4PL



SMA FEED THRU
2PL AS SHOWN
CERAMASEAL P/N
807B11529-03-W

SEE NOTE 1
(4PL)

4-40 x 1D PHOSPHOR
BRONZE HELICOIL 3PL
SEE NOTE 2

SEE NOTE 1
(2PL)

SECTION A-A

NOTES:

1. HYDROGEN FURNACE BRAZE USING NICRO 80 ALLOY OR BETTER (HIGH VACUUM TIGHT)
2. INSTALL HELICOILS AFTER BRAZING

TOLERANCES	
ENGLISH	METRIC
☒ INCHES	☐ MILLIMETERS
FRACTIONAL: 1/64	DECIMALS: .X ± .1
DECIMALS: .XX ± .01	DECIMALS: .XX ± .01
.XXX ± .005	DECIMALS: .XXX ± .005
.XXXX ± .0005	DECIMALS: .XXXX ± .0005
ANGLES ± 1°-0'	ANGLES ± 1°-0'

MATERIAL
OFHC
COPPER

FINISH
32

DRAWN	TVP	7-12-94
CHECKED	GB	7-12-94
APPROVED	DD	7-12-94
APPROVED		
RELEASED		
SIGNATURE	DATE	

CRYOSTAT COVER
ASSEMBLY
FOR MASER

PROJECT	SIZE	COMPUTER FILE	CRYSTASY.DWG	ISSUE
1190-3	A			
SCALE 1=2		DO NOT SCALE PRINT		

SHEET 2 OF 2

4

3

2

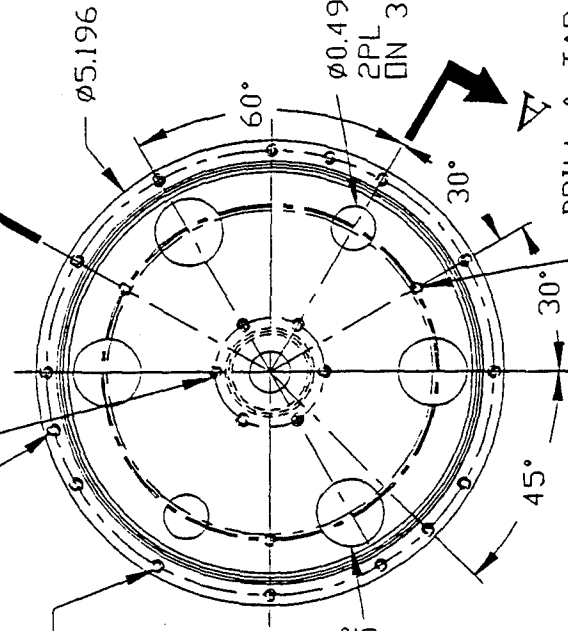
1

REVISIONS		
SYM	ZONE	DESCRIPTION
		DATE
		APPRV.

DRILL & TAP FOR 4-40
x 1D HELICOIL 6PL
EQ SP ON 1.223 ϕ BC
FROM OPPOSITE SIDE
(DO NOT BREAK THRU)

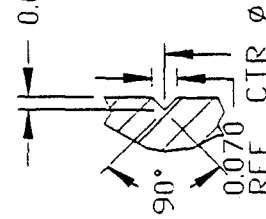
4-40 x 1D HELICOIL 3PL
EQ SP ON 4.974 ϕ BC

DRILL & TAP
FOR 4-40 x 1D
HELICOIL 12PL
EQ SP ON 4.974 ϕ BC

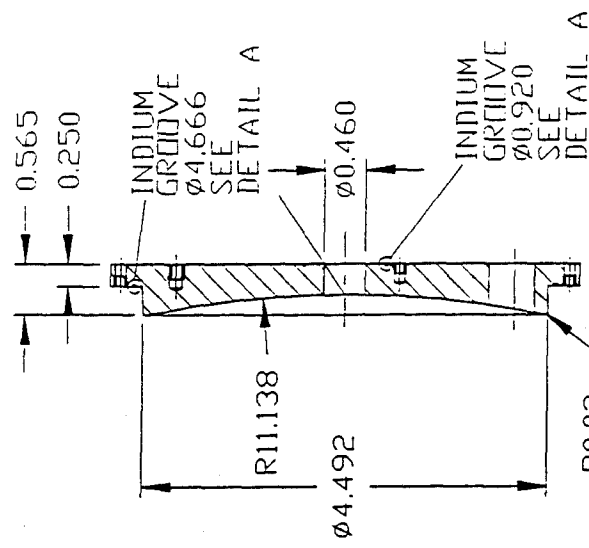


DRILL & TAP FOR 6-32 x 2D
HELICOIL 3PL EQ SP ON 3.750 ϕ BC
FROM OPPOSITE SIDE
(DO NOT BREAK THRU)

0.035 +0.003
-0.000



DETAIL A
SCALE 2=1



SECTION A-A

PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		PROJECT 1190-3		SIZE A		COMPUTER FILE CRYNOSVR.DWG		ISSUE MASR-0062	
TOLERANCES ENGLISH ☒ INCHES FRACTIONAL DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1'-0"		METRIC ☐ MILLIMETERS DECIMALS .X ± .1 .XX ± .01 .XXX ± .005 .XXXX ± .0005		TVP GB DD DD		DATE 6-2-94 7-12-94 7-12-94		SIGNATURE DATE	
MATERIAL OFHC COPPER		FINISH 32		SCALE 1=2		DO NOT SCALE PRINT		SHEET 1 OF 2	

A

B

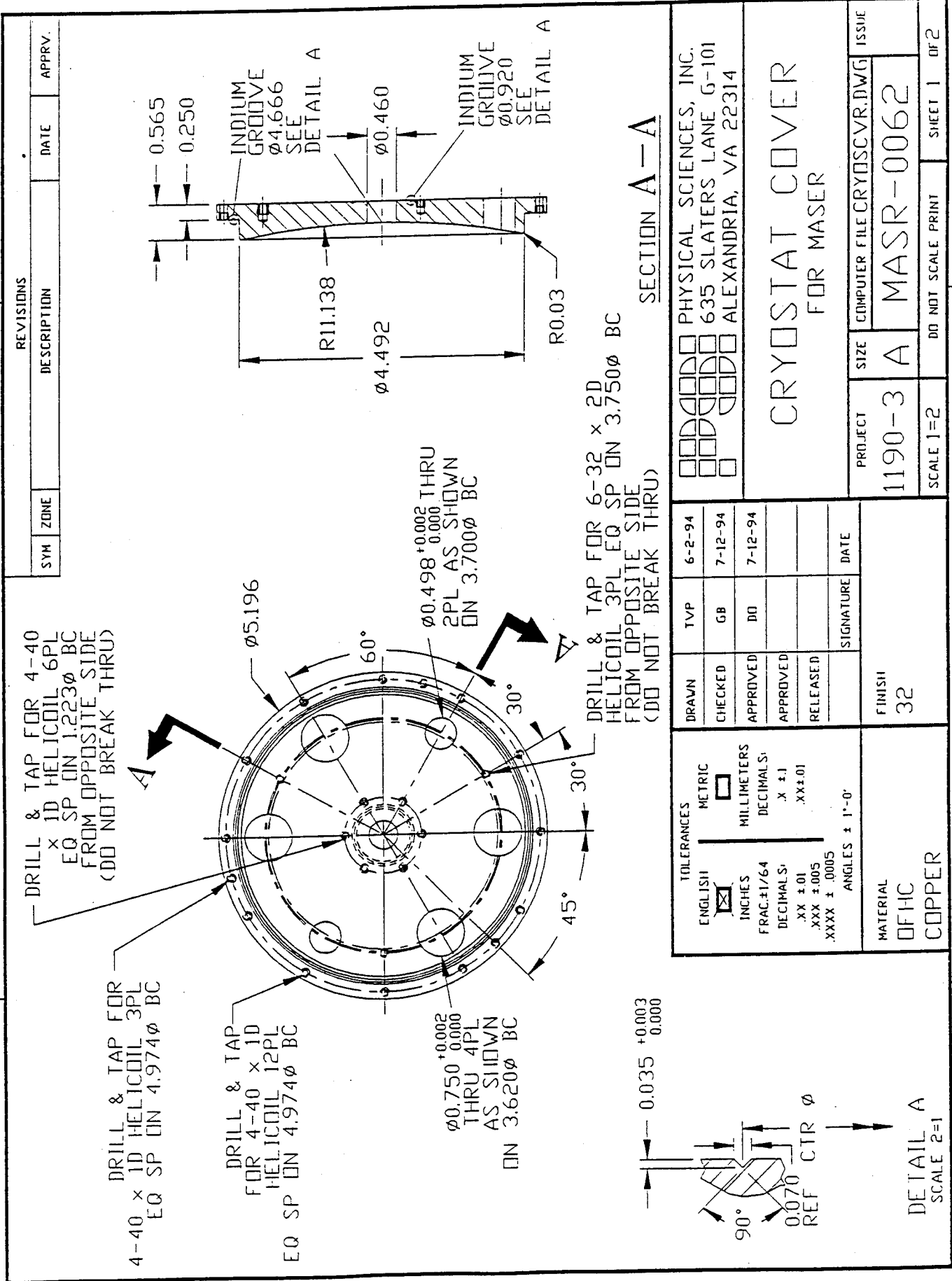
4

3

2

1

4 3 2 1

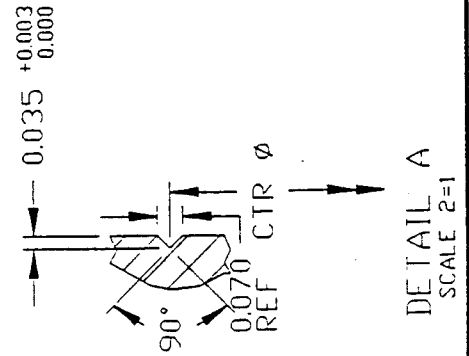


CRYOSTAT COVER FOR MASER		PROJECT 1190-3 A		SIZE A		COMPUTER FILE CRYOSTCVR.DWG		ISSUE MASR-0062	
SCALE 1=2		DO NOT SCALE PRINT		SHEET 1		OF 2			

TOLERANCES ENGLISH INCHES DECIMALS .XX $\pm$.01 .XXX $\pm$.005 .XXXX $\pm$.0005 ANGLES $\pm$ 1'-0"		METRIC MILLIMETERS DECIMALS .X $\pm$.1 .XX $\pm$.01	
--	--	---	--

DRAWN CHECKED APPROVED APPROVED RELEASED	TVP GB DO	6-2-94 7-12-94 7-12-94	SIGNATURE DATE
--	-----------------	------------------------------	-------------------

MATERIAL OFHC COPPER	FINISH 32
----------------------------	--------------

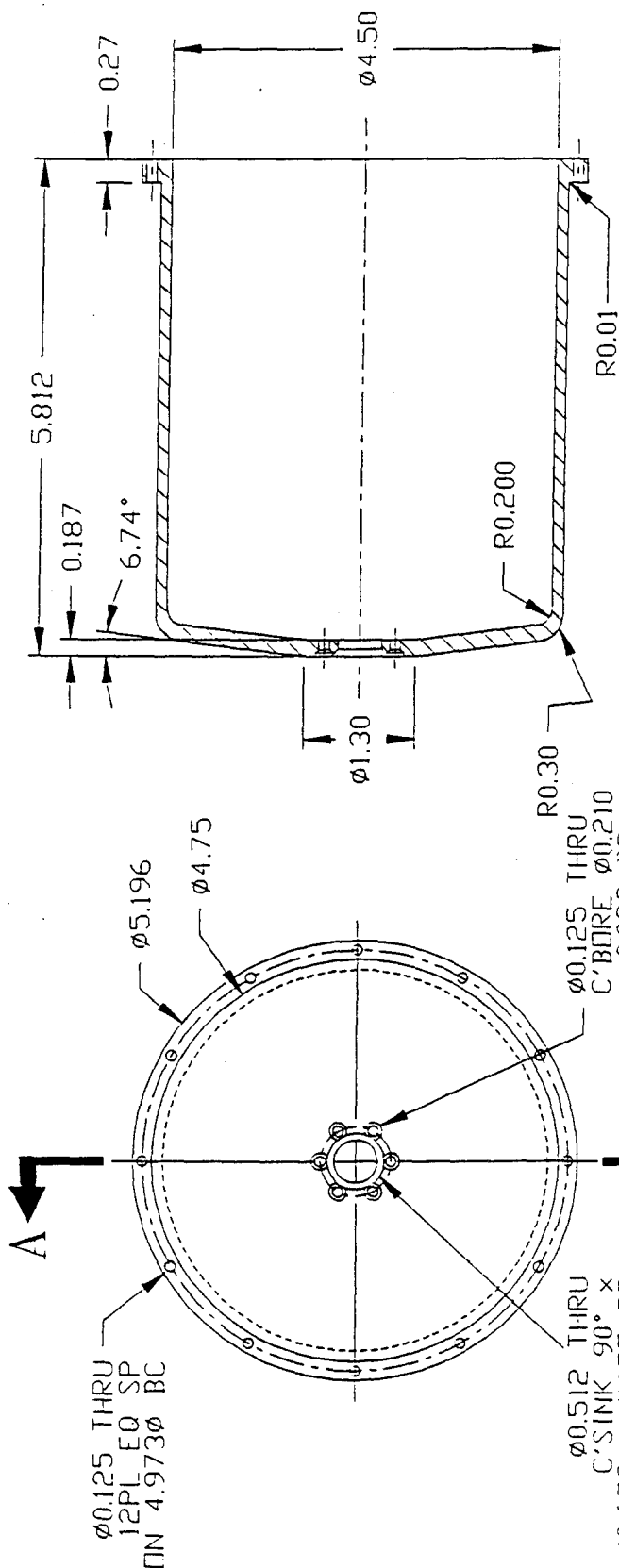


1 2 3 4

4 3 2 1

4 3 2 1

REVISIONS		
SYN	ZONE	DESCRIPTION
		DATE
		APPRV.



SECTION A-A

PHYSICAL SCIENCES, INC.
 635 SLATERS LANE G-101
 ALEXANDRIA, VA 22314

CRYOSTAT BODY
 FOR MASER

DRAWN	TVP	6-8-94
CHECKED	X	X
APPROVED	X	X
APPROVED	X	X
RELEASED	X	X
SIGNATURE		DATE

PROJECT	SIZE	COMPUTER FILE	ISSUE
1190-3	A	CRYOSTAT.DWG	
SCALE 1=2		MASR-0061	
		DO NOT SCALE PRINT	SHEET 1 OF 1

TOLERANCES	
ENGLISH	METRIC
☒ INCHES	☐ MILLIMETERS
FRAC: 1/64	DECIMALS: .X ± .1
DECIMALS: .XX ± .01	XX ± .01
XXX ± .005	XXX ± .005
XXXX ± .0005	XXXX ± .0005
ANGLES ± 1°-0'	

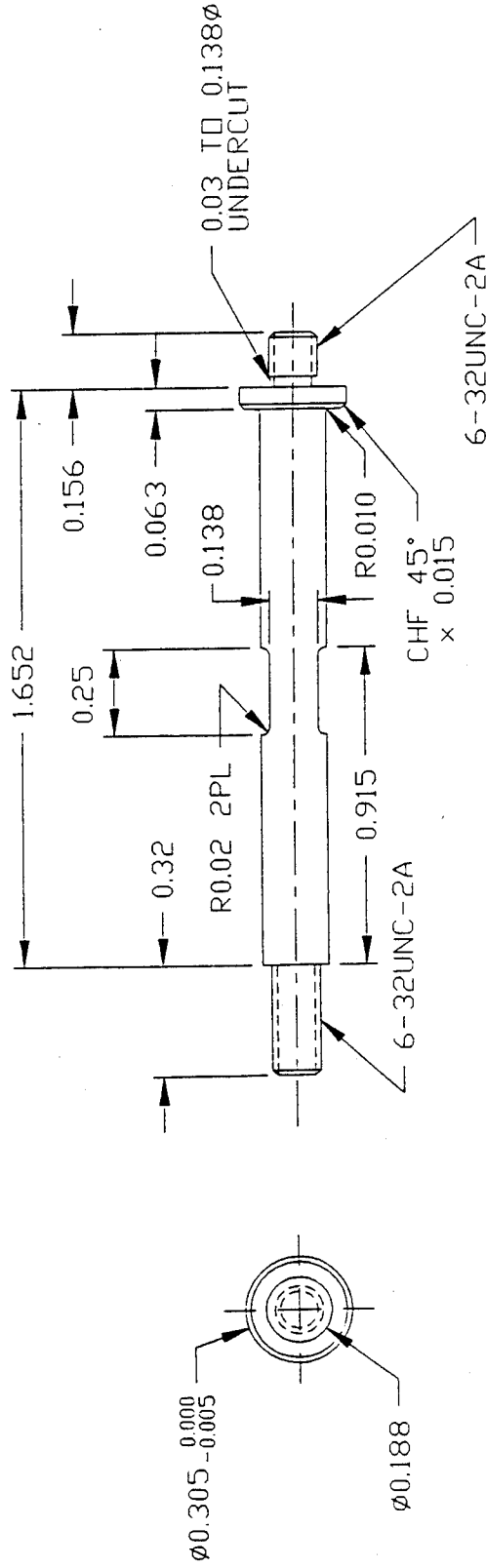
MATERIAL
 BRASS

FINISH
 32

$\phi 0.125$ THRU
 12PL EQ SP
 ON 4.973 ϕ BC

$\phi 0.512$ THRU
 C'SINK 90° x
 $\phi 0.672$ x 0.055 DP

$\phi 0.125$ THRU
 C'BORE $\phi 0.210$
 x 0.039 DP
 C'SINK 100° x
 0.210 x 0.036 DP
 6PL EQ SP
 ON 0.833 ϕ BC



3 REQ'D

TOLERANCES ENGLISH ☒ INCHES METRIC ☐ MILLIMETERS FRAC. ± 1/64 DECIMALS: .X ± .1 .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1° - 0'		DRAWN CHECKED APPROVED APPROVED RELEASED SIGNATURE DATE		TVP X X X X X	4-25-94 X X X X X
MATERIAL STAINLESS STEEL 304 ALLOY		FINISH 32			

PROJECT 1190-3		SIZE A	COMPUTER FILE COLMSTUD.DWG	ISSUE
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SCALE 2=1		DO NOT SCALE PRINT	SHEET 1 OF 1
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□ □	PHYSICAL SCIENCES, INC. 635 SLATERS LANE ALEXANDRIA, VA 22314
--	---

COLUMN STUD FOR MASER	
--------------------------	--

4

3

2

1

DETAIL A
6PL EQ SP
AS SHOWN
BOTH ENDS

Ø6.250

Ø6.00
NOMINAL

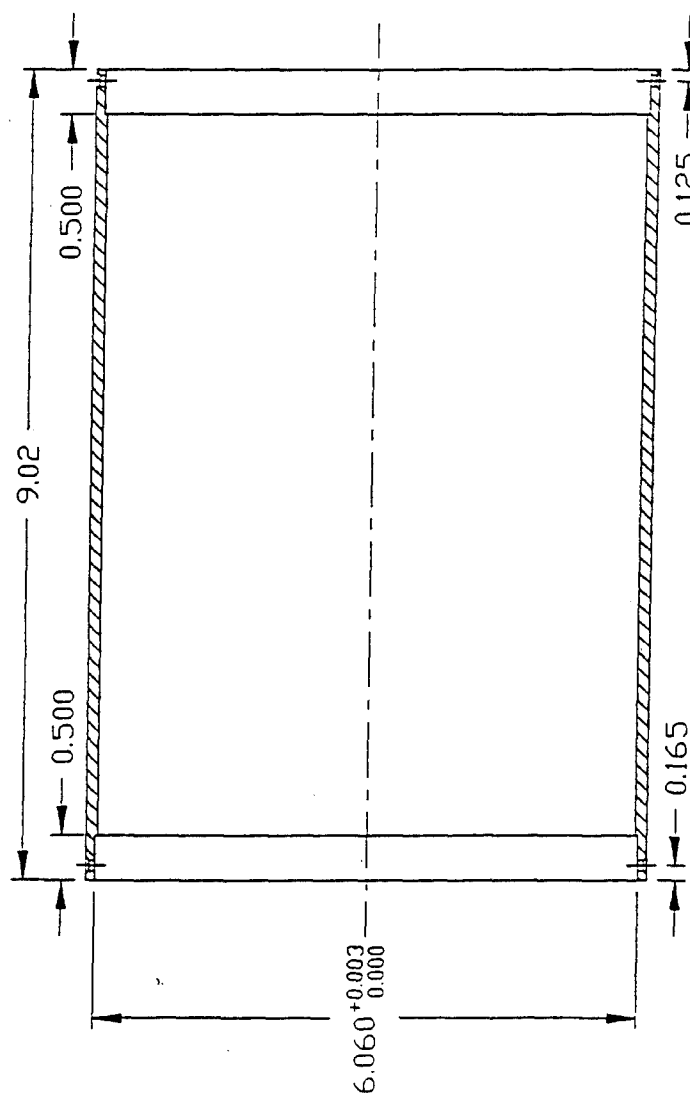
Ø0.210

Ø0.125 THRU
C'SINK 82°
TO Ø SHOWN

DETAIL A
SCALE 1=1

REVISIONS

SYH	ZONE	DESCRIPTION	DATE	APPRV.
A		.030 C'BORE ADDED & DETAIL A MOD.	4-5-95	TVP



SECTION A-A

DRAWN	TVP	3-18-94
CHECKED	X	X
APPROVED	X	X
APPROVED	X	X
RELEASED	X	X
SIGNATURE	DATE	

TOLERANCES	METRIC	INCHES
FRAC. 1/64	DECIMALS	DECIMALS
XX ± .01	XX ± .1	XX ± .01
XXX ± .005	XXX ± .005	XXX ± .005
XXXX ± .0005	XXXX ± .0005	XXXX ± .0005
ANGLES ± 1°-0'		

FINISH
32

MATERIAL
ALUMINUM
6061-T6

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

OUTER SHIELD
CYLINDER
FOR MASER

PROJECT	SIZE	COMPUTER FILE	ISSUE
1190-3	A	QTRSI CYL.DWG	A

SCALE 1=2 DO NOT SCALE PRINT SHEET 1 OF 1

4

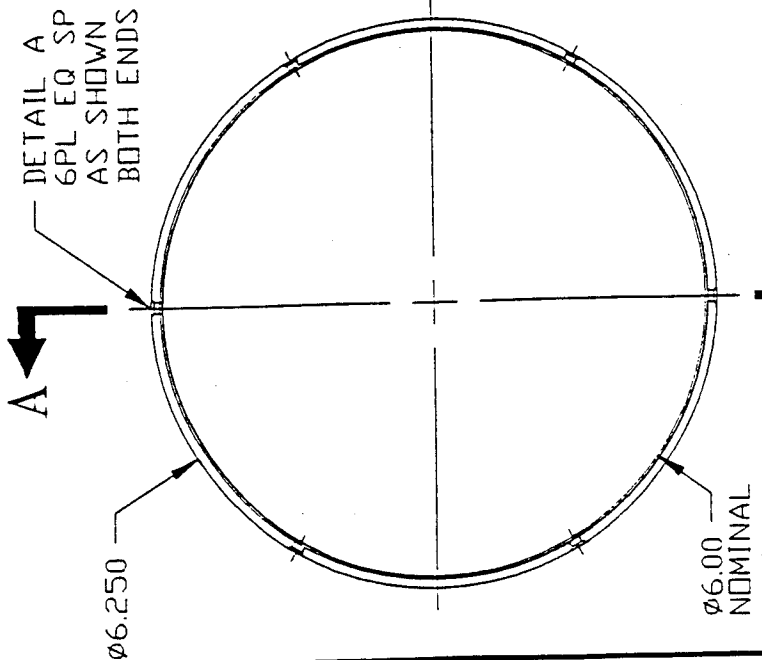
3

2

1

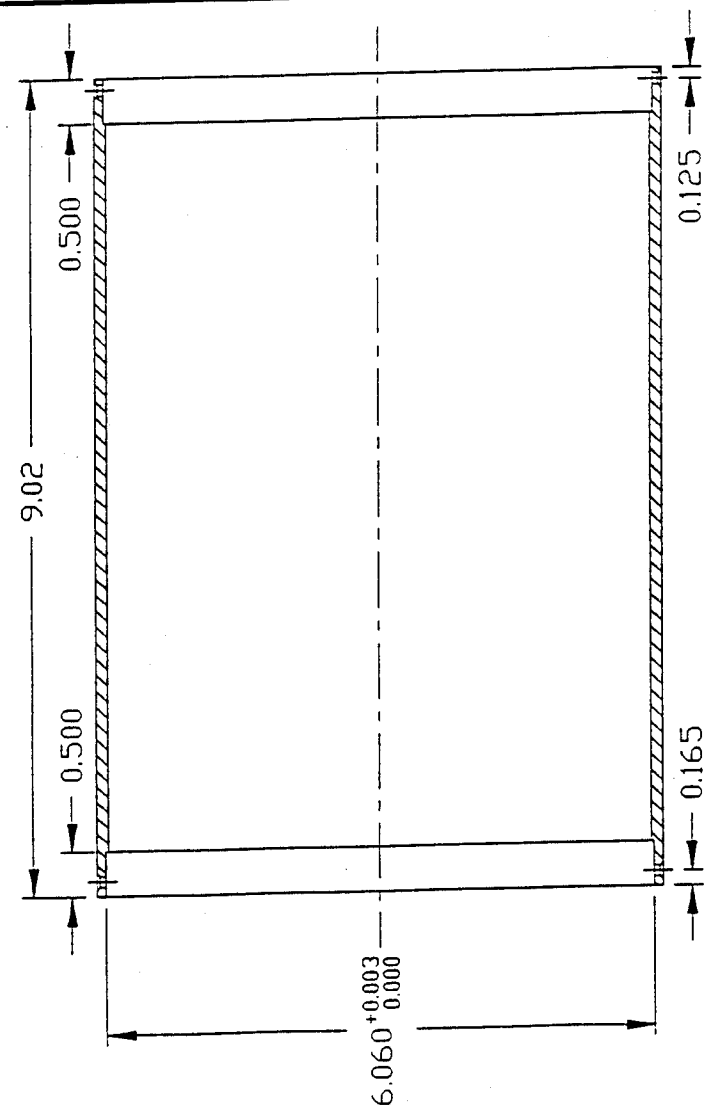
4 3 2 1

DETAIL A
6PL EQ SP
AS SHOWN
BOTH ENDS



DETAIL A
SCALE 1=1

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE
A		.030 C'BORE ADDED & DETAIL A MOD.	4-5-95
			TVP



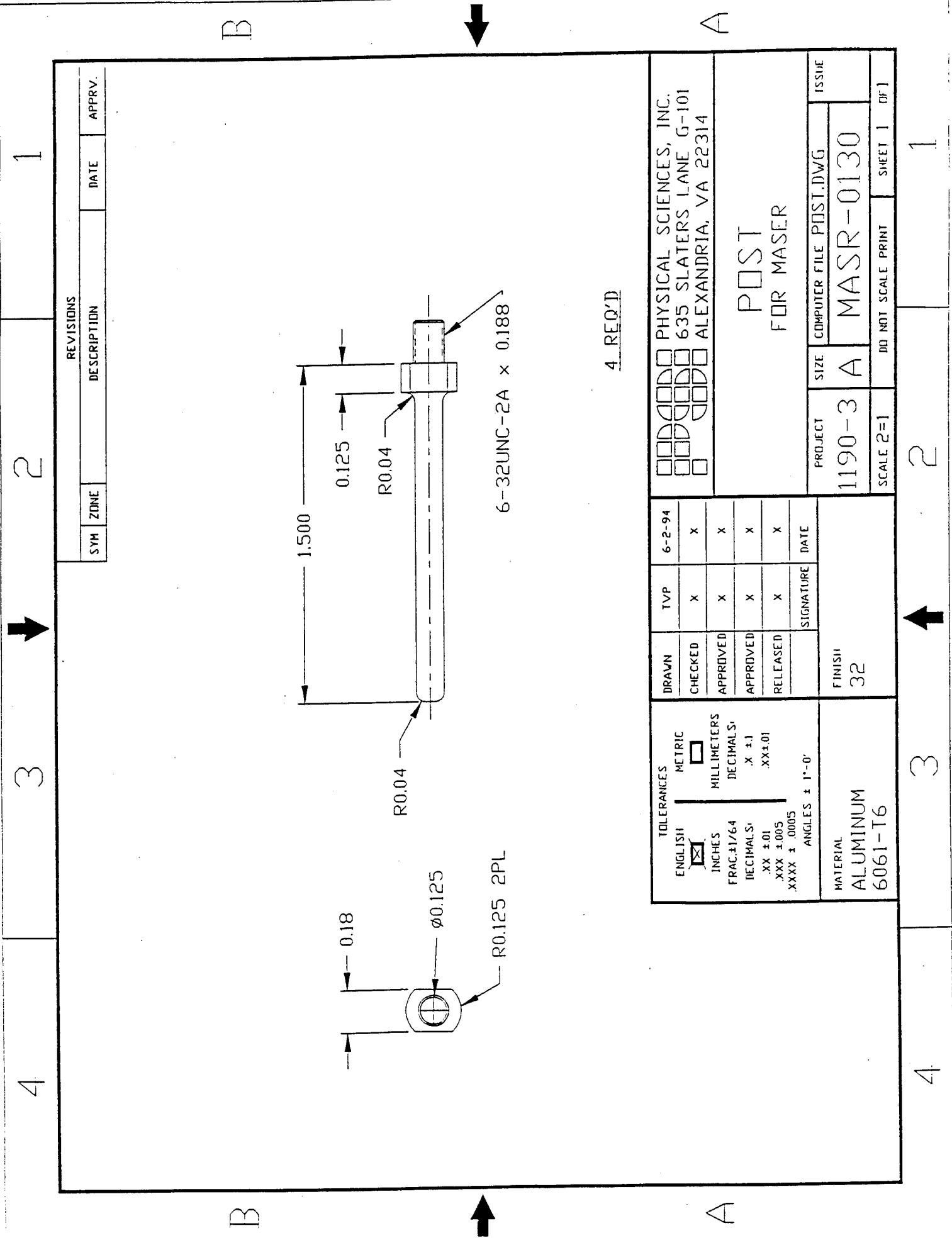
SECTION A-A

PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		OUTER SHIELD CYLINDER FOR MASER	
PROJECT	SIZE	COMPUTER FILE	ISSUE
1190-3	A	OTRSHCYL.DWG	A
SCALE 1=2		SHEET 1 OF 1	

DRAWN	TVP	3-18-94
CHECKED	X	X
APPROVED	X	X
APPROVED	X	X
RELEASED	X	X
SIGNATURE		DATE
FINISH		32

TOLERANCES ENGLISH: INCHES FRACTIONAL DECIMALS METRIC: MILLIMETERS DECIMALS		MATERIAL ALUMINUM 6061-T6
ANGLES ± 1°-0'		

4 3 2 1

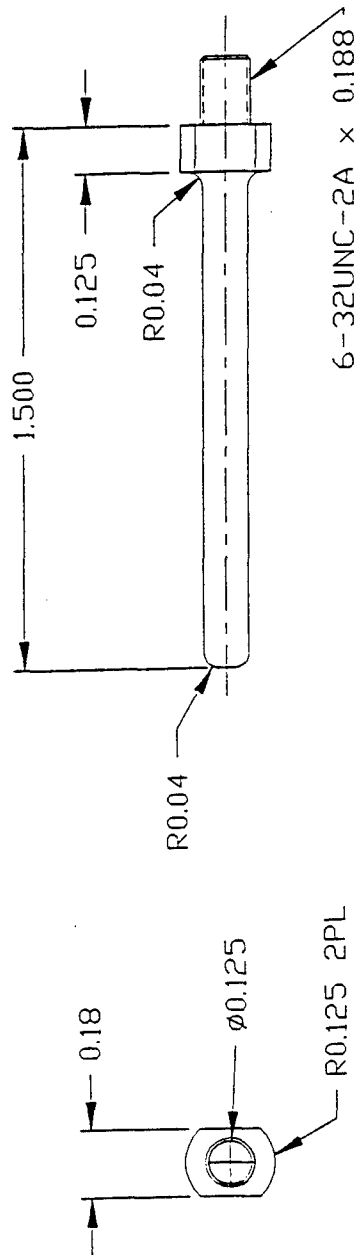


4 3 2 1

B

A

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE
			APPRV.



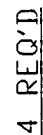
4 REQ'D

TOLERANCES ENGLISH ☒ INCHES METRIC ☐ MILLIMETERS DECIMALS: .X ±.1 DECIMALS: .XX ±.01 DECIMALS: .XXX ±.005 DECIMALS: .XXXX ±.0005 ANGLES ± 1°-0'		DRAWN CHECKED APPROVED APPROVED RELEASED	TVP X X X X	6-2-94 X X X X	PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314	
MATERIAL ALUMINUM 6061-T6		FINISH 32		POST FOR MASER		
PROJECT 1190-3		SIZE A	COMPUTER FILE POST.DWG MASR-0130		ISSUE	
SCALE 2=1		DO NOT SCALE PRINT		SHEET 1 OF 1		

4 3 2 1

B

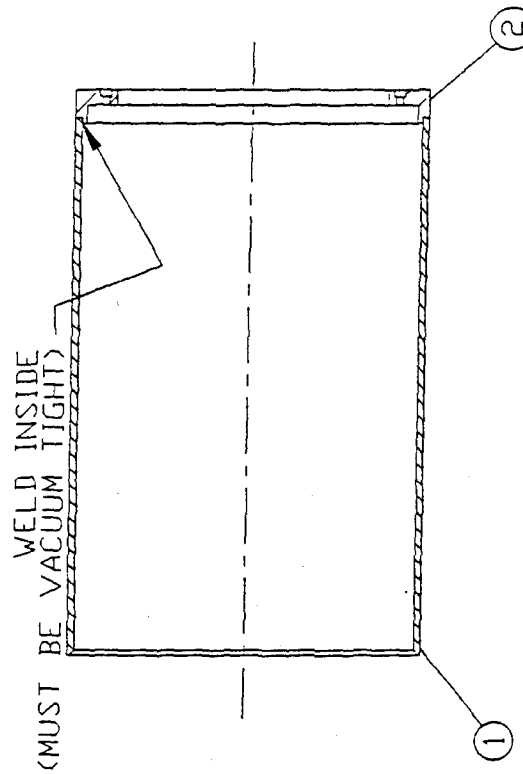
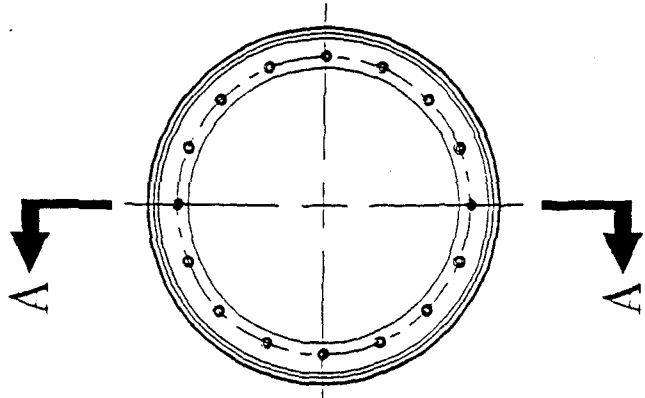
A



SCALE 2=1	DO NOT SCALE PRINT	SHEET 1 OF 1
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4 3 2 1

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE
			APPRV.



SECTION A-A

2	MASR-0134	VACUUM ENCLOSURE TDP	
1	MASR-0133	VACUUM ENCLOSURE CYLINDER	
DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X	5-19-94 X X X X
TOLERANCES ENGLISH INCHES DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1°-0'		METRIC MILLIMETERS DECIMALS .X ± .1 .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1°-0'	
MATERIAL ALUMINUM 6061-T6		FINISH 32	
PROJECT 1190-3		SIZE A	COMPUTER FILE VACENCL.S:DWG
SCALE 1/4"=1'-0"		ISSUE MASR-0131	
DO NOT SCALE PRINT		SHEET 1 OF 1	

VACUUM ENCLOSURE
ASSEMBLY
FOR MASER

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

4 3 2 1

4

3

2

1

REVISIONS

SYH

ZONE

DESCRIPTION

DATE

APPRV.

WELD INSIDE
(MUST BE VACUUM TIGHT)

1

2

SECTION A-A

ENGLISH

☒

INCHES

FRAC. 1/64

DECIMALS

.XX ± .01

.XXX ± .0005

ANGLES ± 1°-0'

METRIC

☐

MILLIMETERS

DECIMALS

.X ± .1

.XX ± .01

TOLERANCES

FINISH

32

2

MASR-0134

VACUUM ENCLOSURE TOP

1

MASR-0133

VACUUM ENCLOSURE CYLINDER

DRAWN

CHECKED

APPROVED

APPROVED

RELEASED

SIGNATURE

DATE

5-19-94

X

X

X

X

PHYSICAL SCIENCES, INC.

635 SLATERS LANE G-101

ALEXANDRIA, VA 22314

VACUUM ENCLOSURE

ASSEMBLY

FOR MASER

PROJECT

1190-3

SIZE

A

COMPUTER FILE

VACENCLS.DWG

ISSUE

MASR-0131

SCALE

1=4

DO NOT SCALE

PRINT

SHEET

1

OF

1

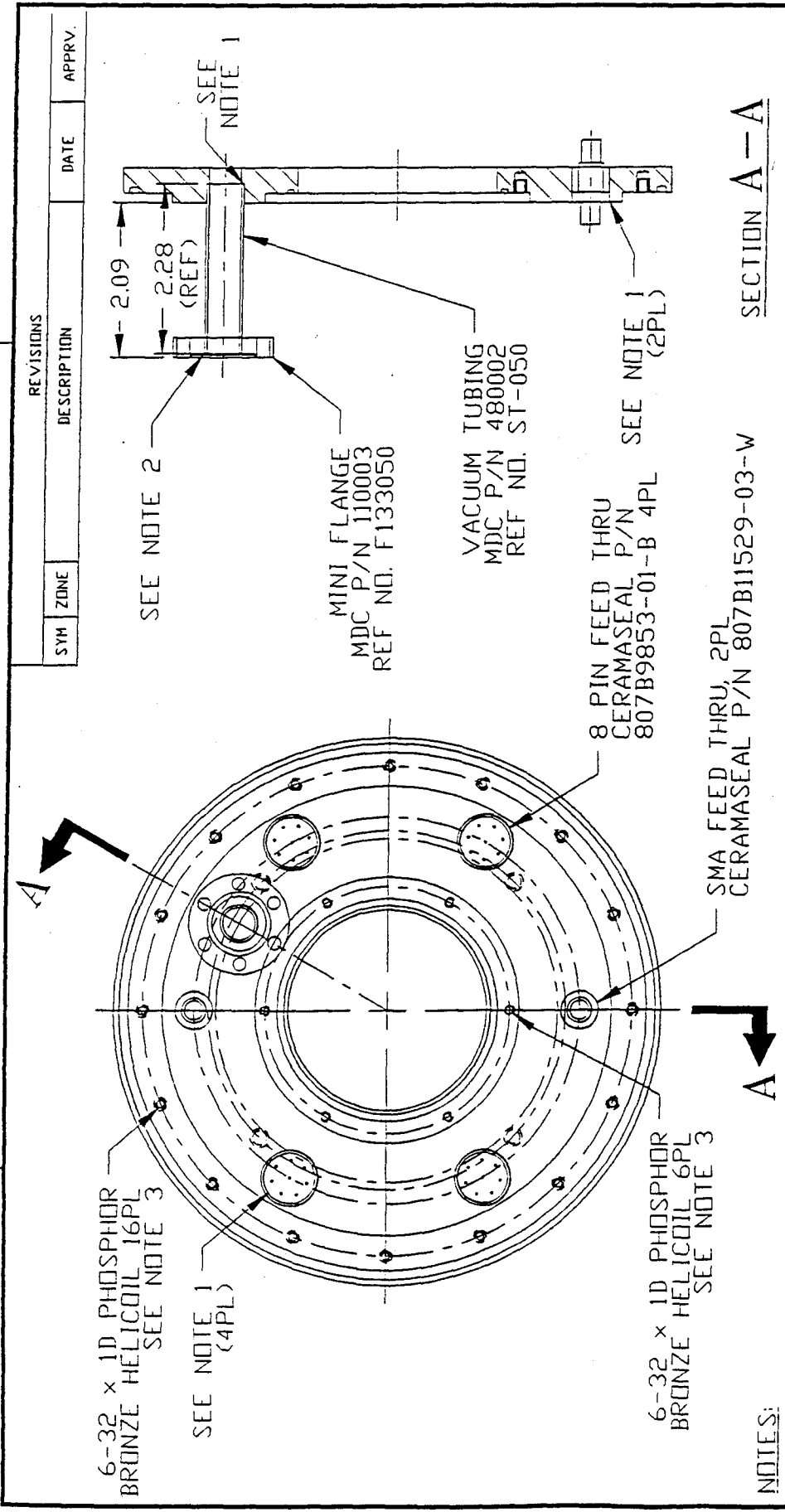
4

3

2

1

4 3 2 1



SECTION A-A

NOTES:

1. HYDROGEN FURNACE BRAZE USING NICRO 80 ALLOY OR BETTER (HIGH VACUUM TIGHT)
2. FUSE WELD FLANGE AFTER BRAZING (HIGH VACUUM TIGHT)
3. INSERT HELICOILS AFTER BRAZING

TOLERANCES		METRIC	
ENGLISH	☒ INCHES	☐ MILLIMETERS	☐ DECIMALS
FRAC. ±1/64	DECIMALS: .XX ±.01		XX ±.01
.XXX ±.005	XXX ±.005		
ANGLES ± 1°-0'			

MATERIAL	OFHC COPPER
FINISH	32

DRAWN	TVP	6-30-94
CHECKED	GB	7-12-94
APPROVED	DO	7-14-94
APPROVED		
RELEASED		
SIGNATURE	DATE	

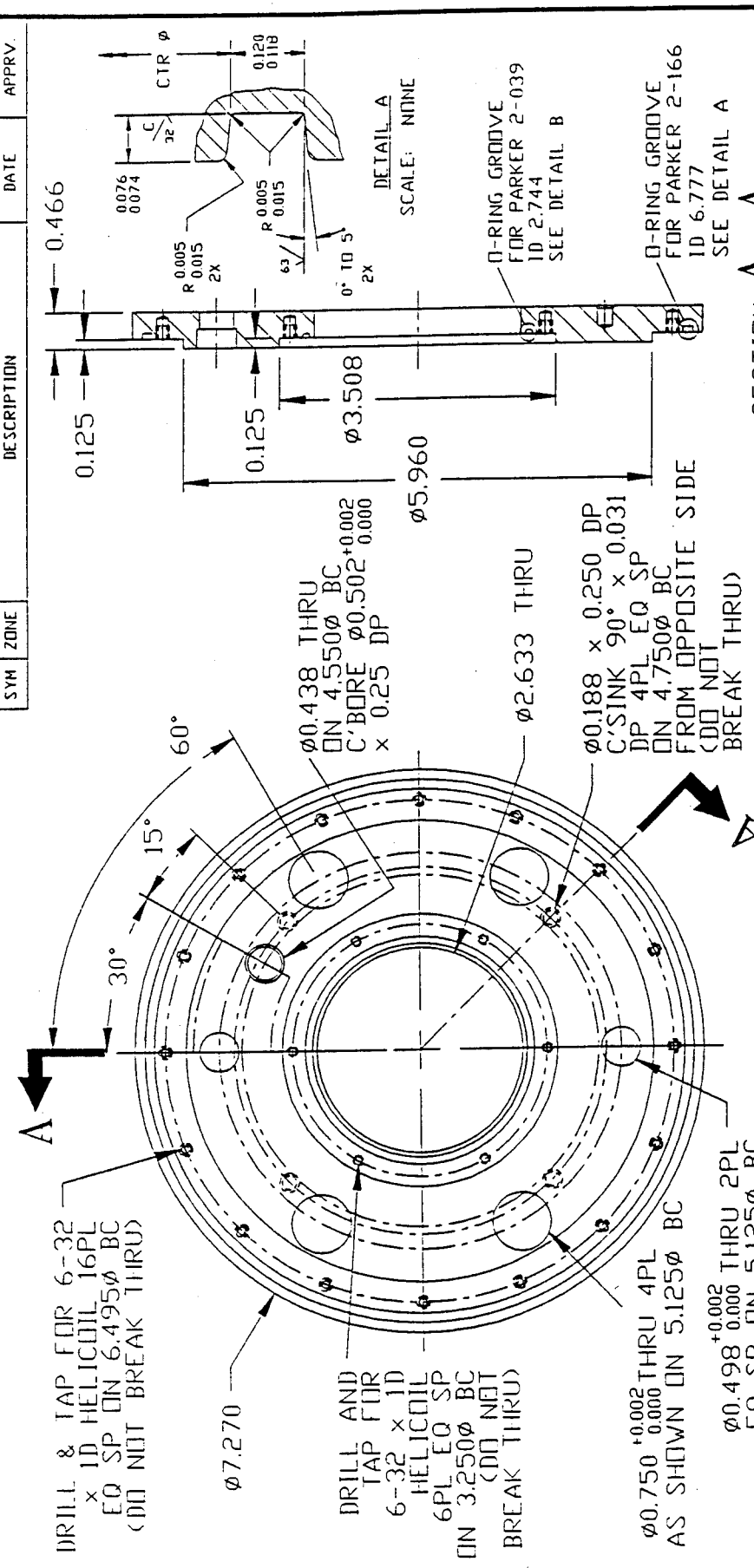
PROJECT		SIZE	COMPUTER FILE	VACVRASY.DWG	ISSUE
1190-3		A	MASR-0132		
SCALE 1=2		DO NOT SCALE PRINT		SHEET 2 OF 2	

VACUUM ENCLOSURE COVER ASSEMBLY FOR MASER

PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

4 3 2 1

4 3 2 1

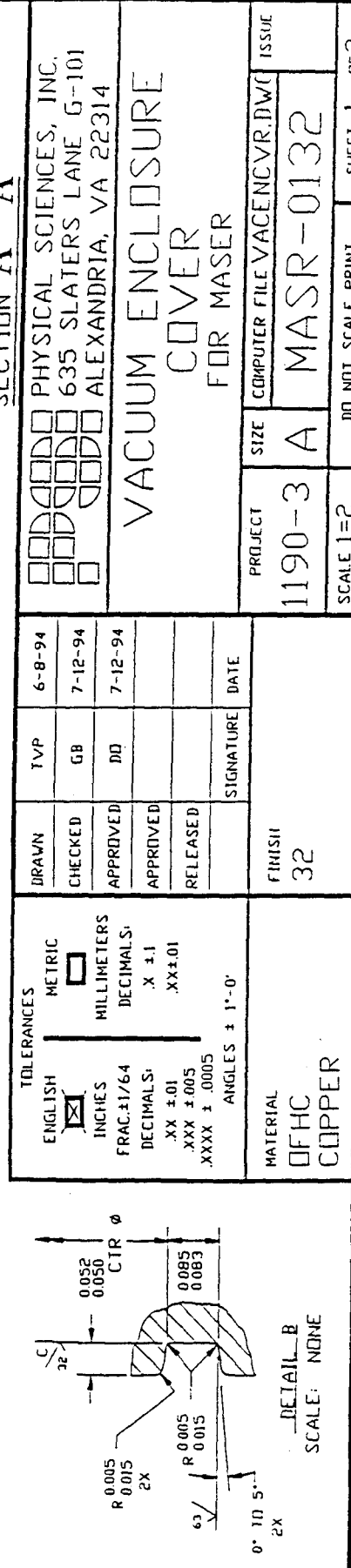


SECTION A-A

PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		PROJECT 1190-3 A		SIZE A		COMPUTER FILE VACENCVR.DWG		ISSUE MASR-0132	
VACUUM ENCLOSURE COVER FOR MASER		SCALE 1=2		DO NOT SCALE PRINT		SHEET 1		OF 2	

TOLERANCES ENGLISH INCHES DECIMALS .XX $\pm$.01 .XXX $\pm$.005 .XXXX $\pm$.0005		METRIC MILLIMETERS DECIMALS .X $\pm$.1 .XX $\pm$.01		FINISH 32	
MATERIAL OFHC COPPER		ANGLES $\pm$ 1 $^{\circ}$ -0'		SIGNATURE	
DRAWN CHECKED APPROVED APPROVED RELEASED		TVP GB DD		DATE 6-8-94 7-12-94 7-12-94	

4 3 2 1



PROJECT	1190-3	SIZE	A	COMPUTER FILE VACANCY R.D.W.	ISSUE
SCALE 1/2				MASR-0132	

TOLERANCES		FINISH	
ENGLISH	METRIC		
			
INCHES	MILLIMETERS		
FRAC. ± 1/64	DECIMALS:		
DECIMALS:	.X ± .1	APPROVED	DATE
.XX ± .01	.XX ± .01	SIGNATURE	
.XXX ± .005			
.XXXX ± .0005			
ANGLES ± 1°-0'			
MATERIAL		32	
OFHC			
COPPER			

0.052
0.050
CTR ϕ

0.085
0.083

R 0.005
0.015
2X

R 0.005
0.015
2X

63
10
5
0° 10 5
2X

DETAIL B
SCALE: NONE

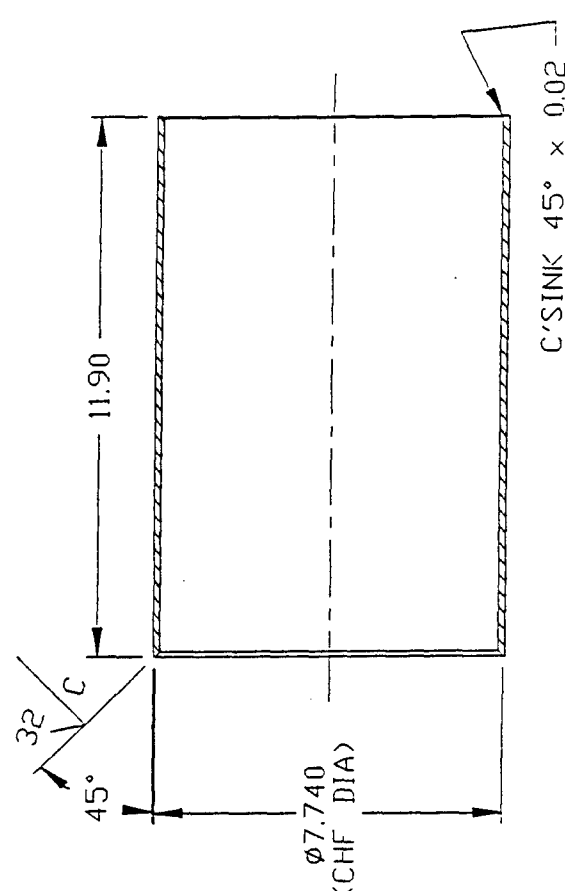
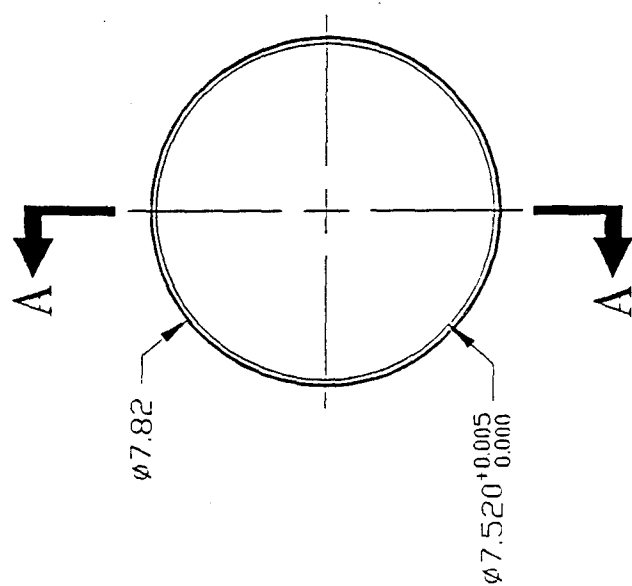
4	3	←	2	1	SHEET 1	OF 2
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4

3

2

1



SECTION A-A

NOTES:

1. NEXT ASS'Y:
MASR-0131

TOLERANCES		METRIC		MILLIMETERS		DECIMALS		X ± .1		XX ± .01		XXX ± .005		XXXX ± .0005		ANGLES ± 1°-0'	
ENGLISH		INCHES		FRACTIONAL		DECIMALS		XX ± .01		XXX ± .005		XXXX ± .0005		ANGLES ± 1°-0'			
MATERIAL		ALUMINUM		6061-T6													

DRAWN		TVP		5-19-94		DATE	
CHECKED		X		X		X	
APPROVED		X		X		X	
APPROVED		X		X		X	
RELEASED		X		X		X	
SIGNATURE							
FINISH		32					

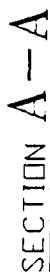
PROJECT		1190-3		SIZE		A		COMPUTER FILE VACENCYL.DWG		ISSUE	
SCALE		J=4		DO NOT SCALE PRINT		SHEET 1		OF 1			
VACUUM ENCLOSURE		CYLINDER		FOR MASER							
PHYSICAL SCIENCES, INC.		635 SLATERS LANE G-101		ALEXANDRIA, VA 22314							
MASR-0131											

4

3

2

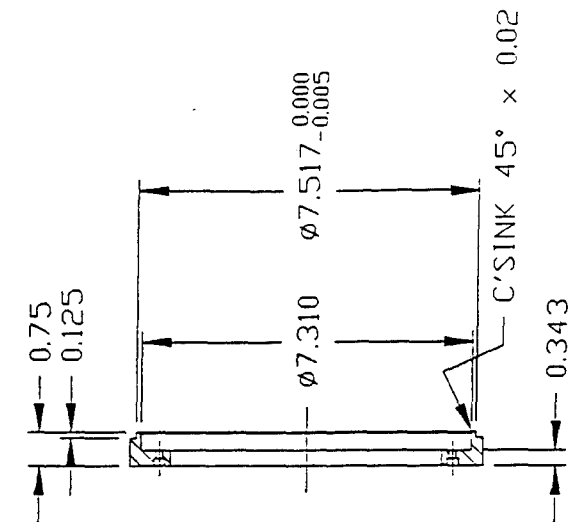
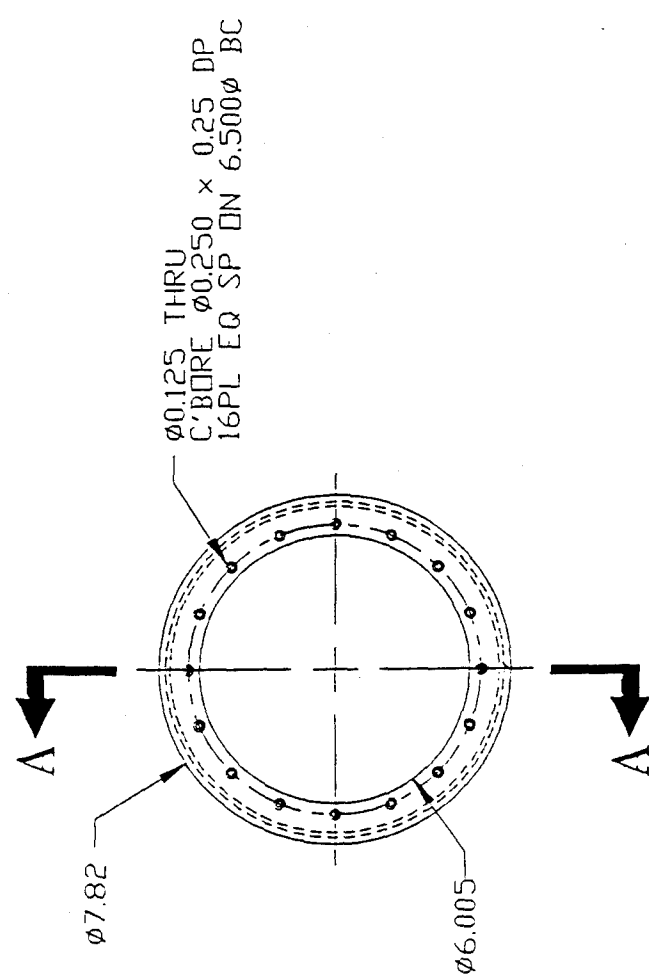
1



1. NEXT ASS'Y:
MASR-0131

2	3	4
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4 3 2 1



SECTION A-A

NOTES:

1. NEXT ASS'Y:
MASR-0131

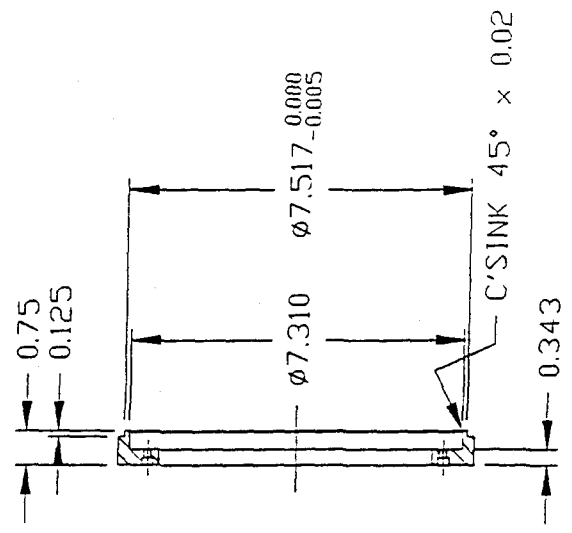
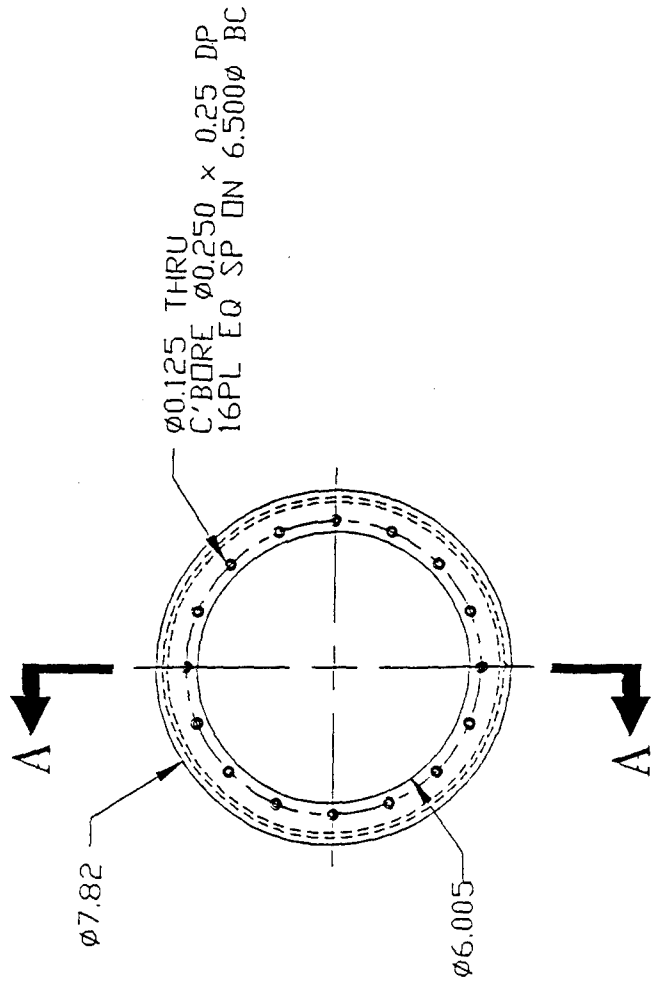
TOLERANCES		MATERIAL	
ENGLISH	METRIC	ALUMINUM	6061-T6
☒ INCHES	☐ MILLIMETERS		
FRAC. $\pm 1/64$	DECIMALS		
.XX ± 0.1	.X ± 1		
.XXX ± 0.005	.XX ± 0.1		
.XXX $\pm .0005$			
ANGLES $\pm 1^\circ-0'$			

DRAWN	TVP	5-19-94
CHECKED	X	X
APPROVED	X	X
APPROVED	X	X
RELEASED	X	X
SIGNATURE		DATE
FINISH		32

PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		PROJECT	SIZE	COMPUTER FILE	TOP	DWG	ISSUE
VACUUM ENCLOSURE TOP SECTION FOR MASER		1190-3	A	MASR-0134			
SCALE 1:4		DO NOT SCALE PRINT		SHEET 1		DF 1	

4 3 2 1

4 3 2 1



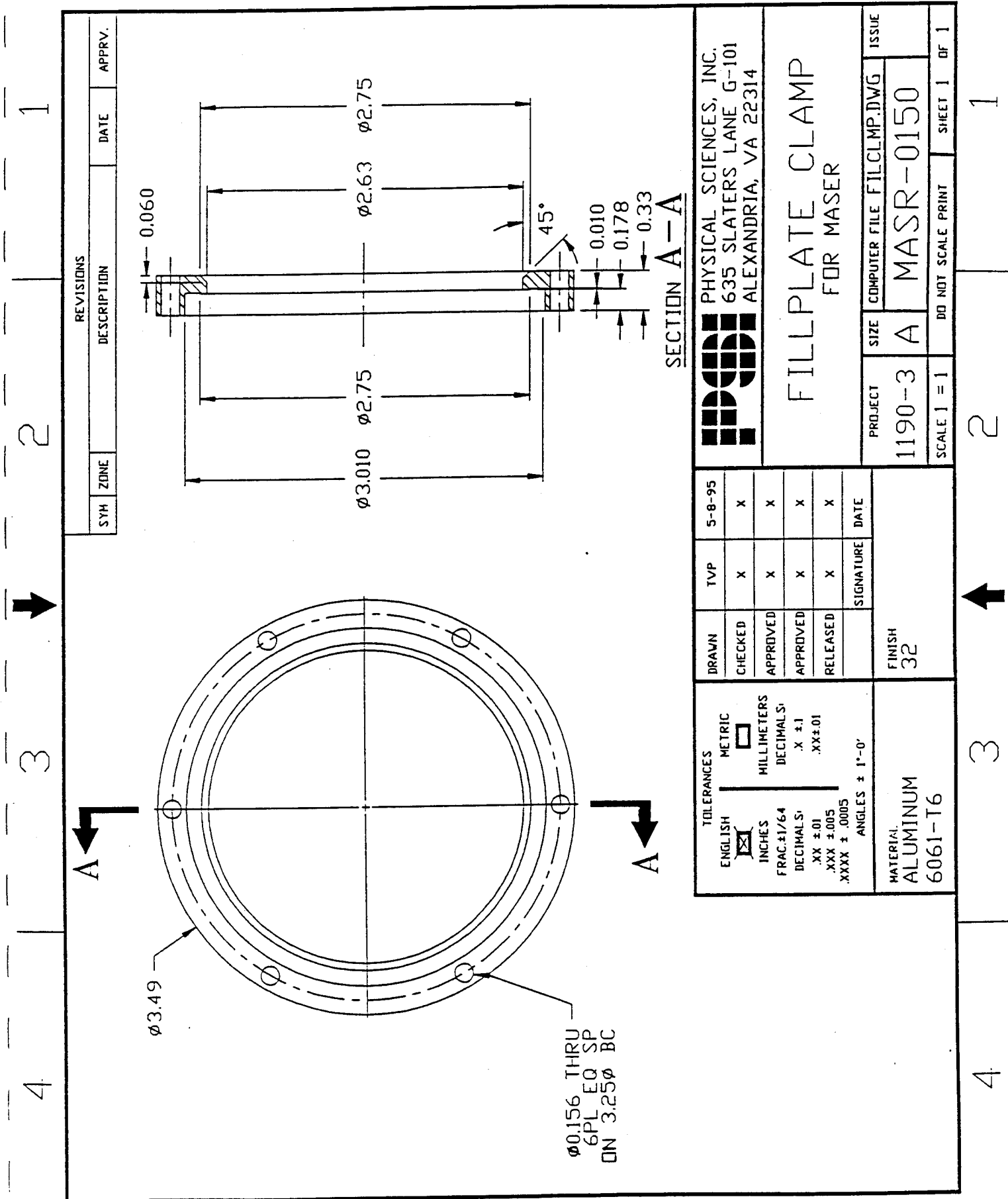
SECTION A-A

NOTES:

- NEXT ASS'Y:
MASR-0131

PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		PROJECT 1190-3		SIZE A		COMPUTER FILE VACENTOP.DWG		ISSUE			
VACUUM ENCLOSURE TOP SECTION FOR MASR		SCALE 1"=4"		DO NOT SCALE PRINT		SHEET 1 OF 1		MASR-0134			
TOLERANCES ENGLISH INCHES FRACTIONAL 1/64 DECIMALS .XX $\pm .01$.XXX $\pm .005$.XXX $\pm .0005$ ANGLES $\pm 1^\circ-0'$		METRIC MILLIMETERS DECIMALS .X $\pm .1$.XX $\pm .01$.XXX $\pm .005$ ANGLES $\pm 1^\circ-0'$		DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X		5-19-94 X X X X		SIGNATURE DATE	
MATERIAL ALUMINUM 6061-T6		FINISH 32									

4 3 2 1

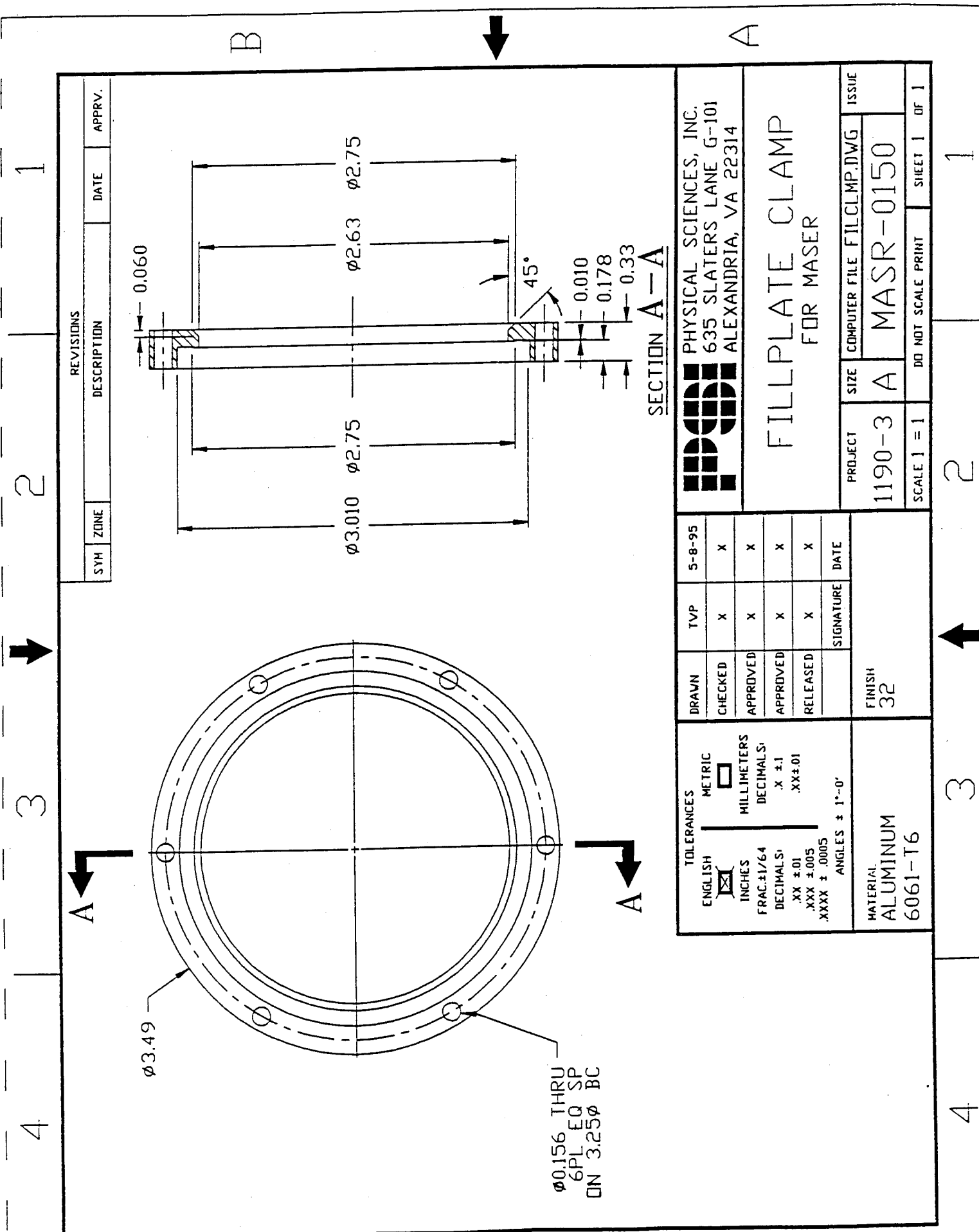


REVISIONS			
SYM	ZONE	DESCRIPTION	DATE

		PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314	
PROJECT 1190-3		SIZE A	COMPUTER FILE FILCLMP.DWG
SCALE 1 = 1		ISSUE MASR-0150	
MATERIAL ALUMINUM 6061-T6		FINISH 32	
TOLERANCES ENGLISH INCHES DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005		METRIC MILLIMETERS DECIMALS .X ± .1 .XX ± .01	
ANGLES ± 1°-0'		SIGNATURE DATE	
DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X	
5-8-95		X X X X	

SECTION A-A

FILLPLATE CLAMP
FOR MASER



REVISIONS			DATE	APPRV.
SYH	ZONE	DESCRIPTION		

TOLERANCES		METRIC		5-8-95	
ENGLISH	☒	INCHES	☐	DECIMALS	☐
FRAC. 1/64		DECIMALS			
.XX ± .01		.XX ± .01			
.XXX ± .005		.XXX ± .005			
.XXXX ± .0005					
ANGLES ± 1°-0'		SIGNATURE		DATE	
MATERIAL		FINISH		32	
ALUMINUM					
6061-T6					

PROJECT		SIZE		COMPUTER FILE		FILCLMP.DWG		ISSUE	
1190-3		A				MASR-0150			
SCALE 1 = 1		DO NOT SCALE PRINT		SHEET 1		OF 1			

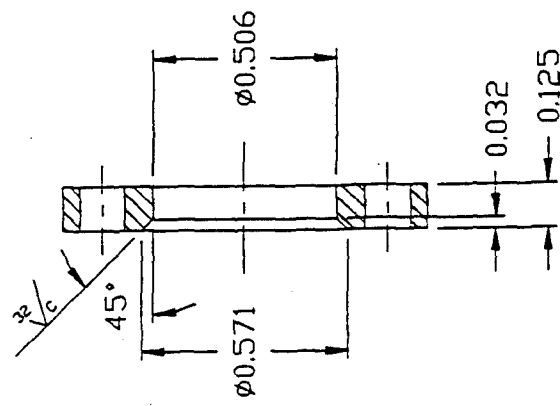
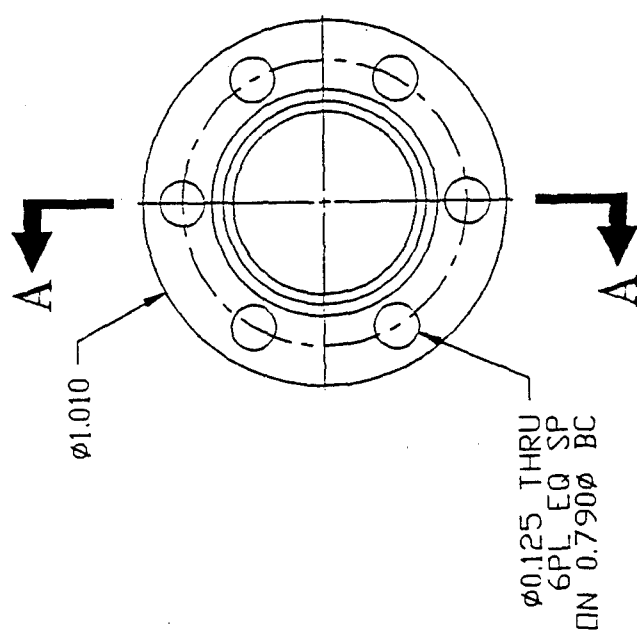

 PHYSICAL SCIENCES, INC.
 635 SLATERS LANE G-101
 ALEXANDRIA, VA 22314

FILLPLATE CLAMP FOR MASER

SECTION A-A

4 3 2 1

REVISIONS			
SYH	ZONE	DESCRIPTION	DATE
			APPRV.

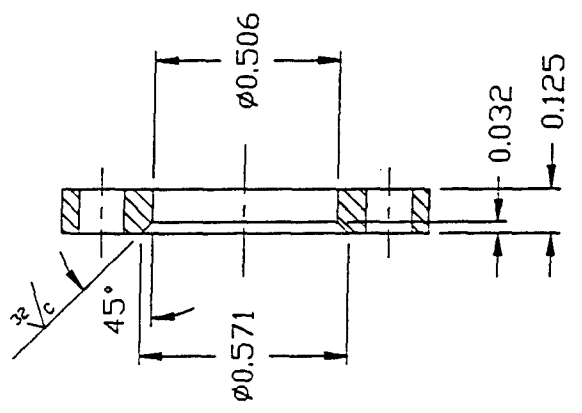
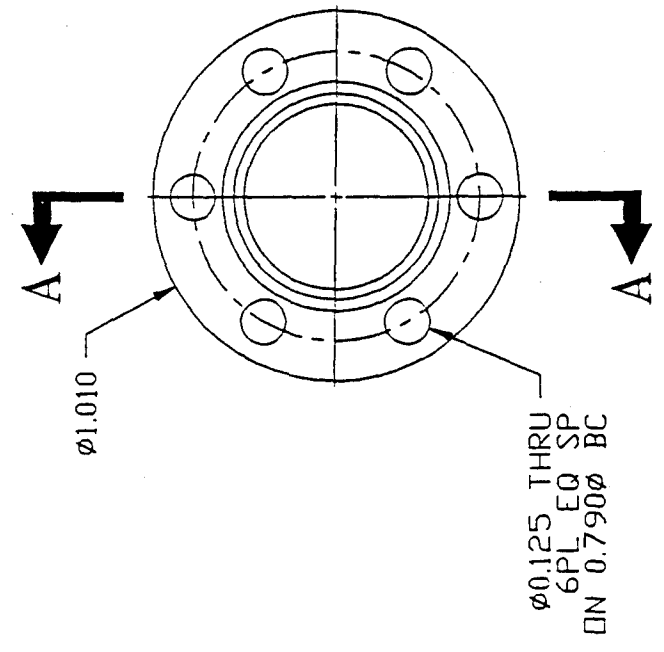


SECTION A-A

 PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314		PROJECT 1190-3		SIZE A		COMPUTER FILE FLPLTCLR.DWG		ISSUE MASR-0151	
TOLERANCES ENGLISH ☒ INCHES DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1°-0'		METRIC ☐ MILLIMETERS DECIMALS .X ± .1 .XX ± .01		DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X		DATE 5-8-95 X X X X	
MATERIAL ALUMINUM 6061-T6		FINISH 32		SCALE 2 = 1		DO NOT SCALE PRINT		SHEET 1 OF 1	

4 3 2 1

4 3 2 1



SECTION A-A

		PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314	
FILLPLATE COLLAR FOR MASER			
PROJECT	SIZE	COMPUTER FILE	FLPTCLR.DWG
1190-3	A	MASR-0151	
SCALE 2 = 1		DO NOT SCALE PRINT	
SHEET 1		OF 1	

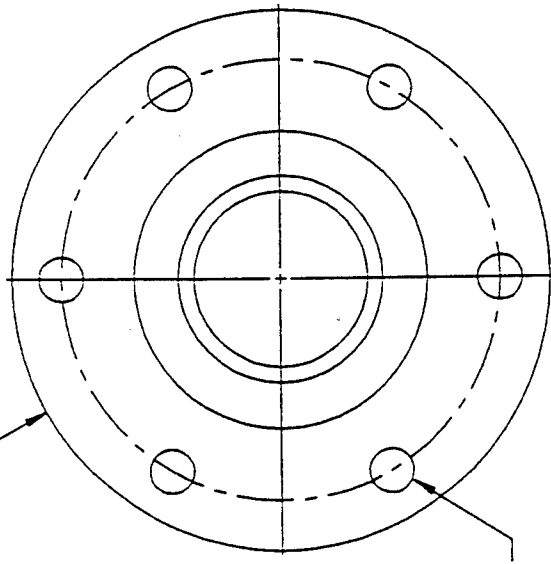
TOLERANCES		5-8-95	
ENGLISH	METRIC	DRAWN	TVP
☒ INCHES	☐ MILLIMETERS	CHECKED	X
FRAC. 1/64	DECIMALS	APPROVED	X
DECIMALS	.X ± .1	APPROVED	X
.XX ± .01	.XX ± .01	RELEASED	X
.XXX ± .005		SIGNATURE	DATE
.XXXX ± .0005			
ANGLES ± 1°-0'		FINISH 32	
MATERIAL ALUMINUM 6061-T6			

4 3 2 1

4 3 2 1

A

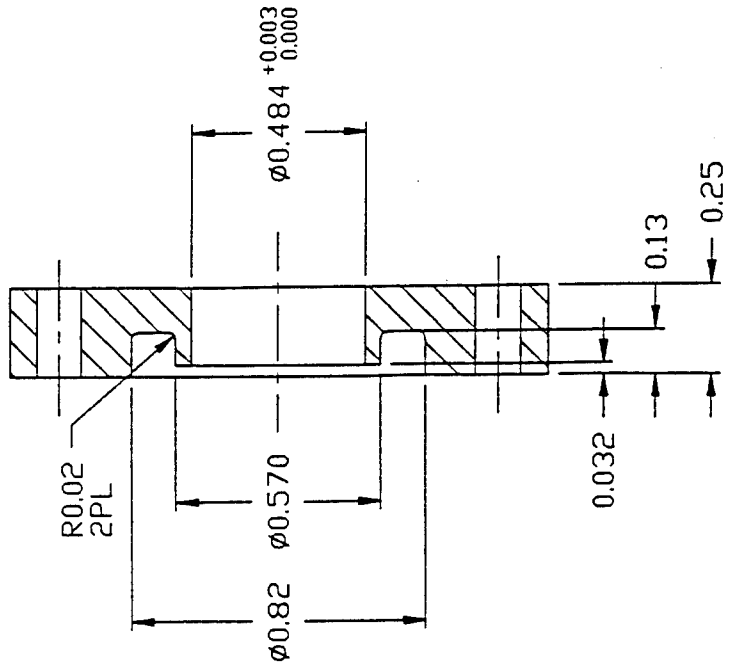
Ø1.50



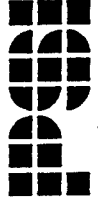
Ø0.125 THRU
6PL EQ SP
ON 1.223Ø BC

A

B B

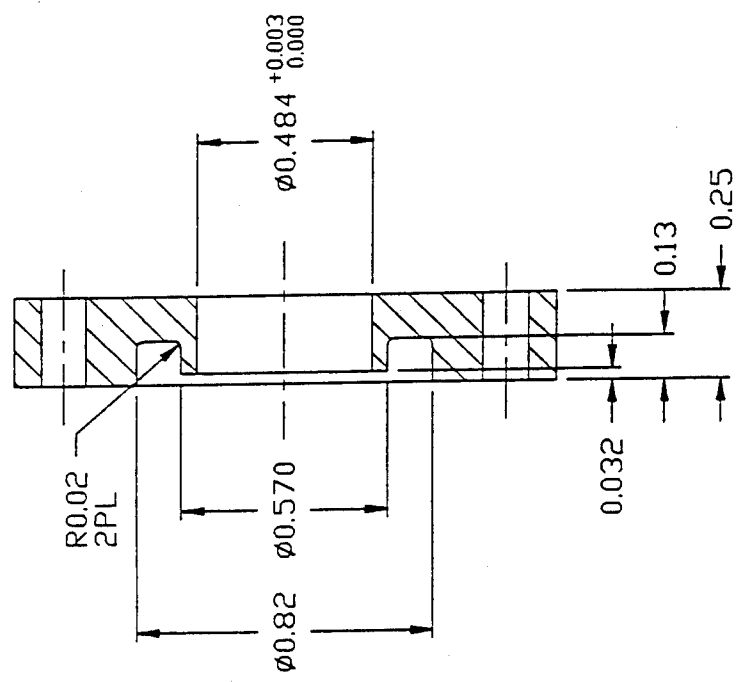
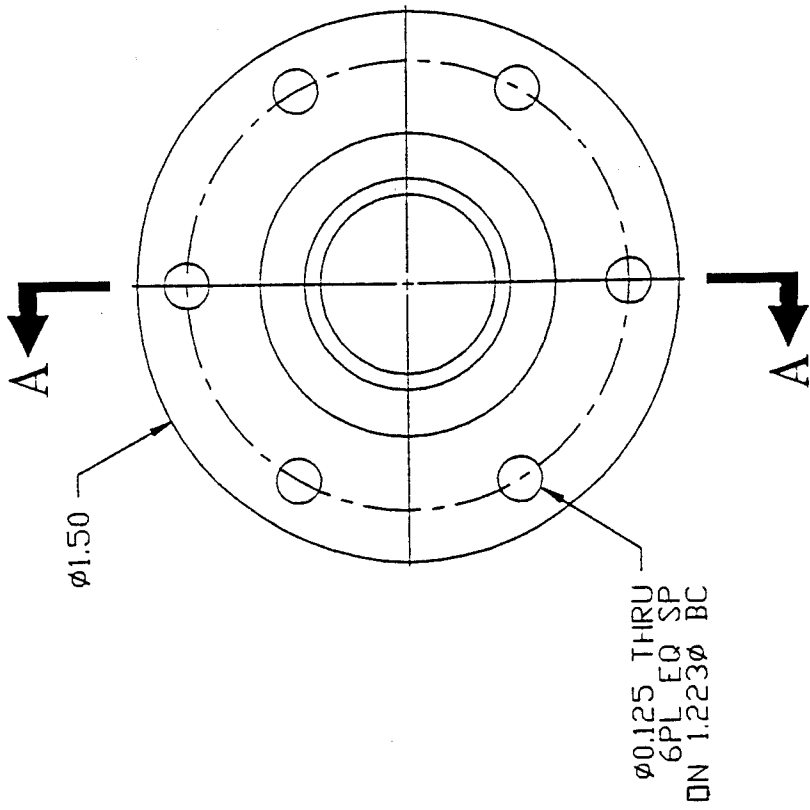


SECTION A-A

		PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314	
LN2 FLANGE FOR MASER			
PROJECT	SIZE	COMPUTER FILE	ISSUE
1190-3	A	LN2FLNG.DWG	MASR-0152
SCALE 2 = 1		DO NOT SCALE PRINT	SHEET 1 OF 1
TOLERANCES		FINISH	
ENGLISH	METRIC	32	
☒ INCHES	☐ MILLIMETERS		
FRAC. 1/64	DECIMALS .1		
DECIMALS .1	DECIMALS .1		
.XX ± .01	.XX ± .01		
.XXX ± .005	.XXX ± .005		
.XXXX ± .0005	.XXXX ± .0005		
ANGLES ± 1°-0'			
MATERIAL			
SS			
304			

4 3 2 1

4 3 2 1



SECTION A-A

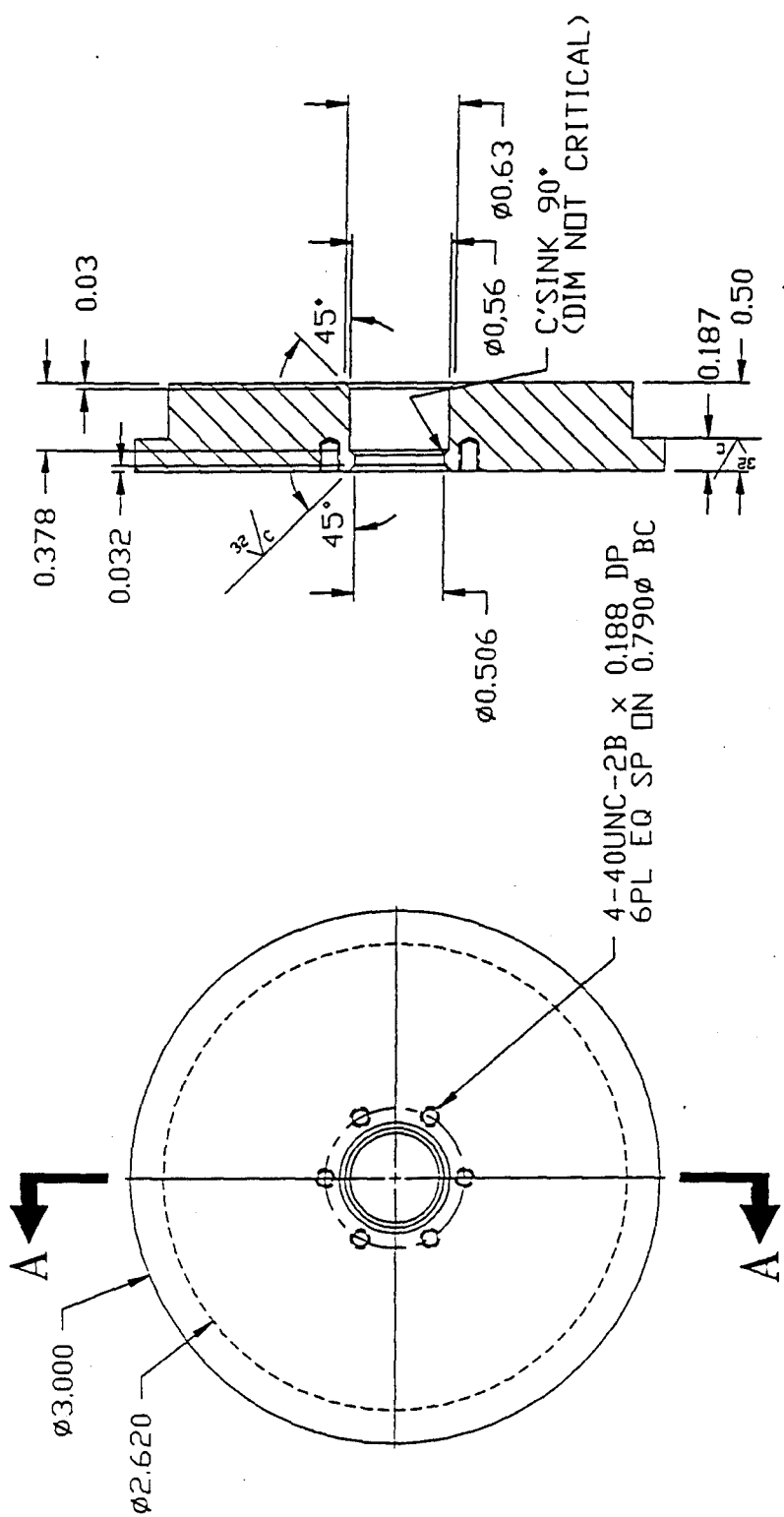
		PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314	
LN2 FLANGE FOR MASER			
PROJECT 1190-3	SIZE A	COMPUTER FILE LN2FLNG.DWG	ISSUE MASR-0152
SCALE 2 = 1		DO NOT SCALE PRINT	
SHEET 1 OF 1		1	

TOLERANCES ENGLISH INCHES FRAC. $\pm 1/64$ DECIMALS .XX $\pm .01$.XXX $\pm .005$.XXXX $\pm .0005$	METRIC MILLIMETERS DECIMALS .X $\pm .1$.XX $\pm .01$.XXX $\pm .005$.XXXX $\pm .0005$	5-8-95	TVP	DATE
DRAWN CHECKED APPROVED APPROVED RELEASED	SIGNATURE	FINISH 32	MATERIAL SS 304	ANGLES $\pm 1^\circ-0'$

4 3 2 1

4 3 2 1

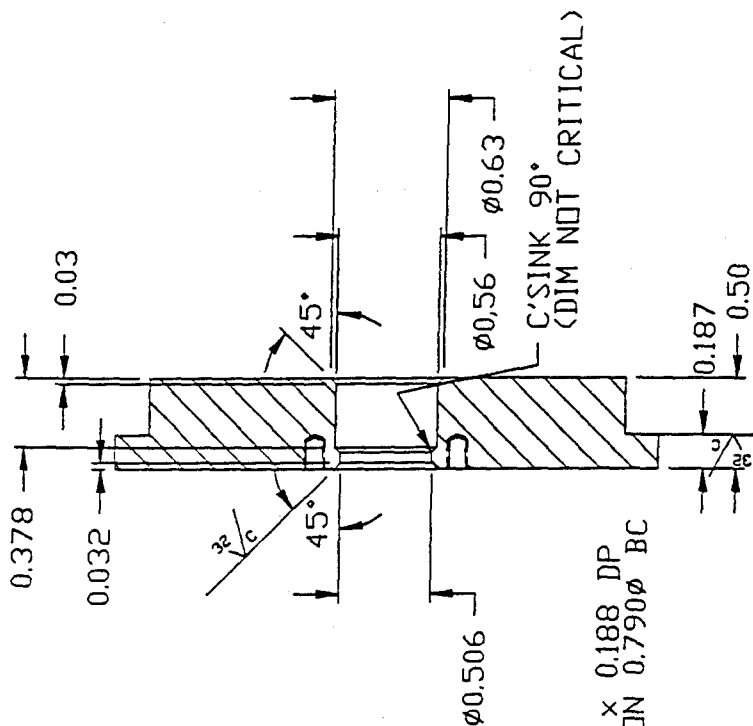
REVISIONS			DATE	APPRV.
SYM	ZONE	DESCRIPTION		



SECTION A-A

		PHYSICAL SCIENCES, INC. 635 SLATERS LANE G-101 ALEXANDRIA, VA 22314	
PROJECT 1190-3		SIZE A	
COMPUTER FILE FILPLAT.DWG		ISSUE MASR-0153	
SCALE 1 = 1		DO NOT SCALE PRINT SHEET 1 OF 1	
TOLERANCES ENGLISH INCHES DECIMALS .XX ± .01 .XXX ± .005 .XXXX ± .0005 ANGLES ± 1°-0'		METRIC MILLIMETERS DECIMALS .X ± .1 .XX ± .01	
MATERIAL ALUMINUM 6061-T6		FINISH 32	
DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X	
SIGNATURE		DATE	

4 3 2 1



PHYSICAL SCIENCES, INC.
635 SLATERS LANE G-101
ALEXANDRIA, VA 22314

FILL PLATE FOR MASER

TOLERANCES ENGLISH  INCHES METRIC  MILLIMETERS FRAC. 1/64 DECIMALS .X ±.1 .XX ±.01 .XXX ±.005 .XXXX ± .0005 ANGLES ± 1°-0'		DRAWN CHECKED APPROVED APPROVED RELEASED		TVP X X X X	5-12-95 X X X X
MATERIAL ALUMINUM 6061-T6		FINISH 32			

FINISH
32

MATERIAL
ALUMINUM
6061-T6

