national accelerator laboratory

TM-645
1600.000

HEAT LEAK MEASUREMENTS ON A D-10' CRYOSTAT

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ABSTRACT

Boil-off measurements confirm the expected values of 15 watts shield load and 2.1 watts liquid load. Information on pump-down time, cooldown time, shield performance, support performance and vacuum were also obtained.

INTRODUCTION

One of 5 cryostats intended for canning the D series Energy Doubler magnets, 10' long, was assigned for this heat leak measurement. Junction boxes and transfer tubes were built terminating the cryostat. They permitted the flowing of cold He gas through the cryostat shield and the filling of its single-phase and two-phase spaces with liquid He.

In order to properly stress the insulating supports, the single-phase space was provided with magnet simulating pieces and sections of laminations compressing the supports were welded on the outside. An Appendix with some of the actual engineering drawings used in assembling the cryostat is included in lieu of a description of the D series cryostat.

METHOD

The cryostat was installed at an angle of 25^{o} with the horizontal. This did not make for too tall a set-up and still permitted the observation of the heat leak contribution due to individual supports as they emerged through the lowering liquid level.

The lower junction box had U tuk connecting the two-phase with the single-phase space and the shield IN with the shield OUT tubes. These U tubes were instrumented with resistance thermometers (glassy carbon and germanium respectively) as well as with heaters for introduction of calibrated power.

A 500 liter storage dewar equipped with a heater supplied the cold gas to the shield. Heaters and a platinum thermometer in the gas stream kept the temperature of the gas coming into the shield constant by means of a negative feedback circuit. The temperature of the incoming and outgoing gas was measured with commercially calibrated (germanium and platinum respectively) resistance thermometers immersed in the gas stream. The heat leak into the shield was determined from the flow rate and the increase in enthalpy of the gas[1] going through it.

Once the flow through the shield was stable at the desired controlled condition, the cryostat was filled up, the two-phase and single-phase parts connected together and the flow rate of the evaporating liquid measured as a function of the total amount of gas coming out.

EQUIPMENT

The resistance thermometers were connected in series, energized with a reversible 10μA constant current supply and read with a digital nanovoltmeter. An electronic counter counting pulses of an internally generated 1Hz was used as a clock in flow rate measurements. Industrial type gas meters were used to totalize the amount of gas flow from both the shield and the liquid. A wet test meter and the clock were used to measure the flow rate of the evaporating liquid to within 2%. This sensitivity allowed us to resolve structure in the boil-off curve, to compare different boil-off curves and to interpret the structure in terms of the liquid level receding from the magnet simulating slices.

The plumbing connecting the cryostat to the gas meters was made out of copper tubing with strip heaters and a long section immersed in water in order to bring the gas to room temperature before the meters. Thermometers and pressure gauges were used just before the meters to assure that the gas was being measured under reasonably constant pressure and temperature.

A special effort was made to keep the measurements simple and straightforward. A moderate amount of automation, however, is intended for future measurements of this kind to relieve manual data taking over long hours.

EXPERIMENTAL RESULTS

Besides heat load measurements obtained in the boil-off runs, relevant information on vacuum and cooldown characteristics were obtained.

a. Vacuum: The 4" oil diffusion pump used in the second cooldown brought the vacuum from 3.3×10^{-3} to 3.3×10^{-4} torr in 21 hours at which time cooling and cryopumping improved the vacuum by 2 orders of magnitude. The ion gauge measuring this pressure was located on the opposite junction box to the one with the vacuum pump. A pressure of $\sim2\times10^{-6}$ torr existed during boil-off measurements and it was quite sensitive to warmup of cold parts. The He background measured after the second run was 9.2×10^{-8} atm cc/sec.

b. Cooldown: By connecting the liquid space in series with the shield, fairly efficient cooldowns were carried out using the cold exhaust He gas from the fill-up operation of the storage dewar which supplied the shield gas. This avoided precooling with liquid N_2 and its usual drying out operation without undue He consumption. Eight hours and 135 liters of He were typical numbers; the cryostat has a capacity of about 25 liters and a fill-up operation took on the order of 40 liters.

c. Boil-off: In a process of successive improvements of procedures, we had 2 closings. In the second closing after 4 preliminary boil-offs, measurements were obtained on complete boil-off runs with shield under different controlled conditions.

Figures 1, 2, and 3 show the data obtained in the 5th, 6th, and 7th boil-offs respectively. The meaning of the letters is explained below. The shield condition and load during these runs are summarized in Table I.

TABLE I

SHIELD CONDITION

BOIL-OFF	SHIELD IN TEMP	SHIELD OUT TEMP	SHIELD LOAD
5th	20.0±.9K	26.6±1.1K	14.2±.1W
6th	36.8±.8K	45.4±1.1K	14.5±.5W
7th	79.1±.7K	78.0±.2K	

The reproducibility of the boil-off pattern observed in the data taken on different days (and nights) by different experimenters is very satisfying. The horizontal sections (constant flow rate sections) indicate a load independent of liquid level and the sloping sections indicate a variable load due to the liquid level receding from a magnet simulating piece. It should be pointed out that the horizontal sections indicate a proper operation for the shield as far as intercepting infrared radiation. The slight increase before the final slope is connected with the geometry of the cryostat near the lower junction, which besides trapping part of the evaporated liquid temporarily can cause oscillations and increased evaporation. These features and our knowledge of the geometrical dimensions of the cryostat allow us to identify the load contribution from the individual supports.

Figure 4 is a schematic of the set-up showing the position of the magnet simulating pieces and other factors affecting the evaporation rate. In it we have labeled with letters the levels delimiting the regions in contact with a magnet simulating piece, as well as other levels needed in the interpretation of the data.

A rough calculation indicates that the volumes between levels A and B, C and D, E and F, G and H, I and J are of the order of 1.5 liters and the volumes between levels B and C, D and E, F and G, H and I, J and K are of the order of 2.2 liters. This plus the detection of the liquid receding level N or reaching level O allows us to identify the "slope discontinuities" in the data of Figures 1, 2, and 3 with the labeled levels. A not perfect match is expected since these "slope discontinuities" depend also on factors like spread of the hot region near the support contact points and other not well defined parameters.

The change in flow rate due to the liquid clearing a magnet simulating piece gives directly the heat load from the support associated with this piece (see indications in Figure 3). Table II presents this information as extracted from the data using the equivalence of .01 CF/sec to 1 watt, corresponding to an estimated error of less than 20%.

TABLE II

HEAT LOAD AT 4.2K DUE TO INDIVIDUAL SUPPORTS

SUPPORT	SHIELD AT 23.±4.K	SHIELD AT 41.±5.K	SHIELD AT 78.±1.K
EF	.29 watts	.36	.41
GH	.46	.48	.41
IJ	.21	.24	.29
Average	.32	.36	.37

d. Shield Temperature Profile: The shield, made out of .018" thick stainless steel, was heat sunk to the tubes carrying cold gas by means of soft soldered copper braids. In order to verify the effectiveness of this scheme and the need for a grid of enamel insulated copper wires in order to smooth the temperature profile, five carbon thermometers were strategically located in the shield. These homemade and calibrated thermometers indicated that the copper wires are not needed in the absence of eddy currents. Furthermore they revealed that the shield temperature near a support can be 10K above the rest of the shield.

DISCUSSION

a. Equilibrium: A steady state flow is essential if we are to equate the measured flow with the evaporation rate. This steady state was not reached before the liquid receded below level D. A dramatic evidence of the need for equilibrium is shown in the 6th boil-off when 1.00 watts were supplied electrically to the liquid for

1000 sec. The time for emptying the cryostat was usually of the order of 12 hours for all runs, and this was sufficient to insure us that most of the measurements were taken under steady state flow. The 4th boil-off data shown in Figure 5 shows how fast equilibrium is reached. This data was taken under the same conditions as the 5th boil-off run (Shield IN: 20.0K, Shield OUT: 26.6K) but started with almost 1/3 of the usual starting amount of liquid. The flow rate reached its corresponding value in the 5th boil-off within 3% after evaporating 73 CF.

b. <u>Systematic Error</u>: In order to bring the gas to room temperature before measuring the flow we used a long 7/16" i.d. copper tube with an external strip heater and a section coiling in a water bath at known temperature. A calculation of the pressure drop through this impedence indicates that the pressure at the boiling surface could be higher by 15%. At the measuring end, high flow rates never elevated the pressure to more than 7" H_2O (i.e., 2%). The largest correction involved is the one due to the replacement of liquid by gas near the liquid level. By assuming a pressure of 1.2 atm at this surface the temperature will be 4.42K and the heat of evaporization 19.14 J/g yielding for the heat load, h, into the liquid the expression $h = 109.\dot{V}$ watts where $\dot{V}$ is given in CF/sec under the measuring conditions of temperature and pressure. Therefore, the relation used of 100 watts for 1.0CF/sec is within the error margin sought for these measurements. Higher accuracy is intended for cryostats with more definitive design.

c. Comments: The relative independence of the heat load into the liquid with respect to the shield temperature was unexpected. It can however be explained as due to improper heat interception by the shield. This insensitivity to shield temperature indicates that the shield can be operated at higher temperatures with considerable refrigeration savings.

Essentially only the contributions of 3 supports were examined (see Table II). Their individual heat loads varied over a factor of 2.; the approximate load per support is .35 watts.

Based on these values (Tables I and II) we estimate the whole cryostat to have a heat load of 2.1 watts at 4.2K and a measured load of 15 watts into the shield. These values are in excellent agreement with calculations[2] carried out in September 1975.

ACKNOWLEDGEMENTS

A large number of people contributed to different stages of this work, in particular, G.Biallas and C.Rode and their groups. J.Tague and Larry Harris helped with the data taking.

REFERENCES

1. R.D.McCarty; "Thermophysical Properties of Helium -4 from 2 to 1500K"; NBS Technical Note 631 (Nov 1972)

2. M.Kuchnir; "Refrigeration Estimating Program (REP)". This program, which is under continuing evolution, estimates total refrigeration requirements based on actual design values of Energy Doubler/Saver cryostats. Current listing available from the author.

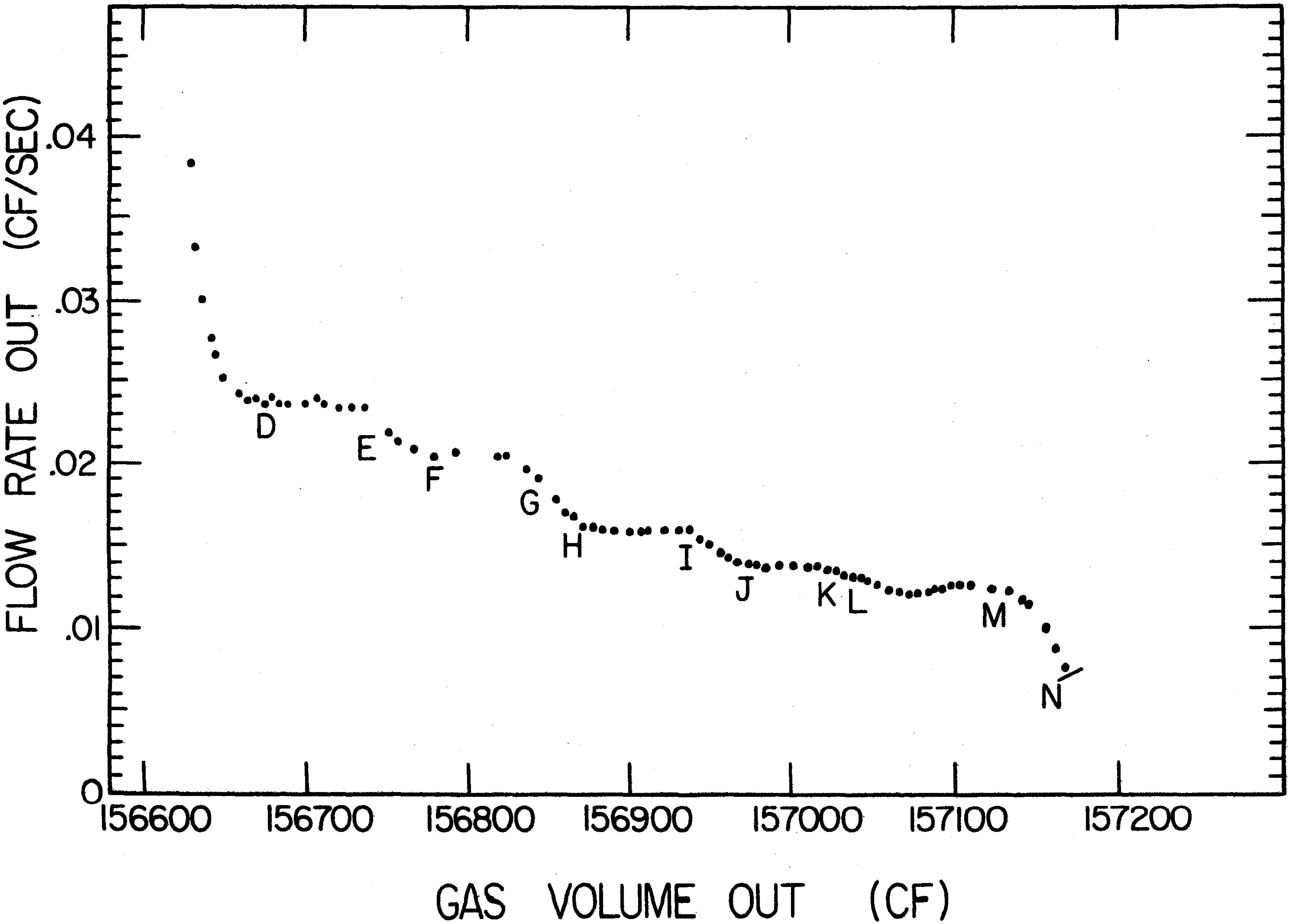
FLOW RATE OUT (CF/SEC)
.04
.03
.02
.01
0
156600
156700
156800
156900
157000
157100
157200
GAS VOLUME OUT (CF)
D
E
F
G
H
I
J
K
L
M
N

Figure 1.

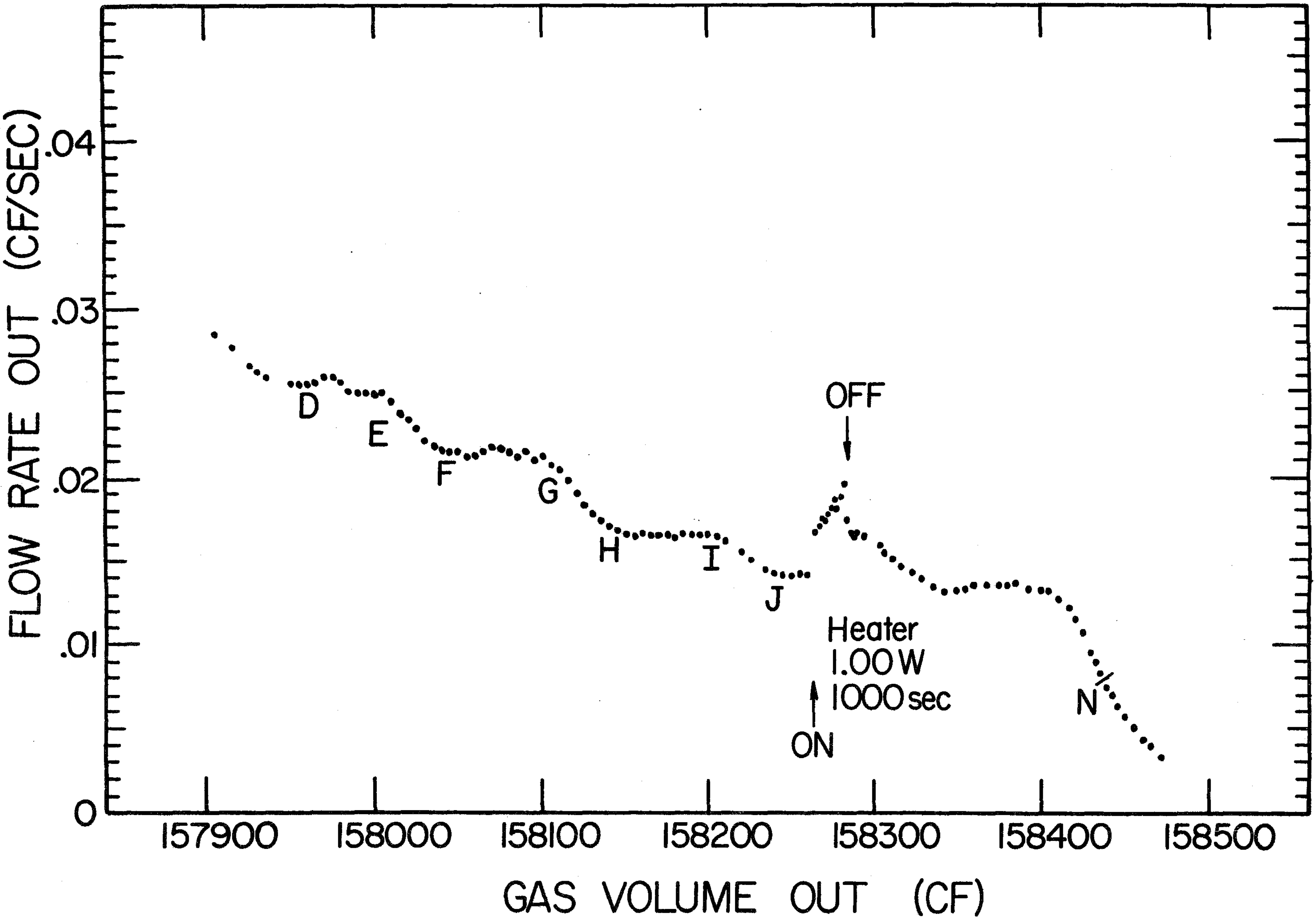

Figure 2.

Sixth Boil-Off Data. Average shield temperature: 41.1K

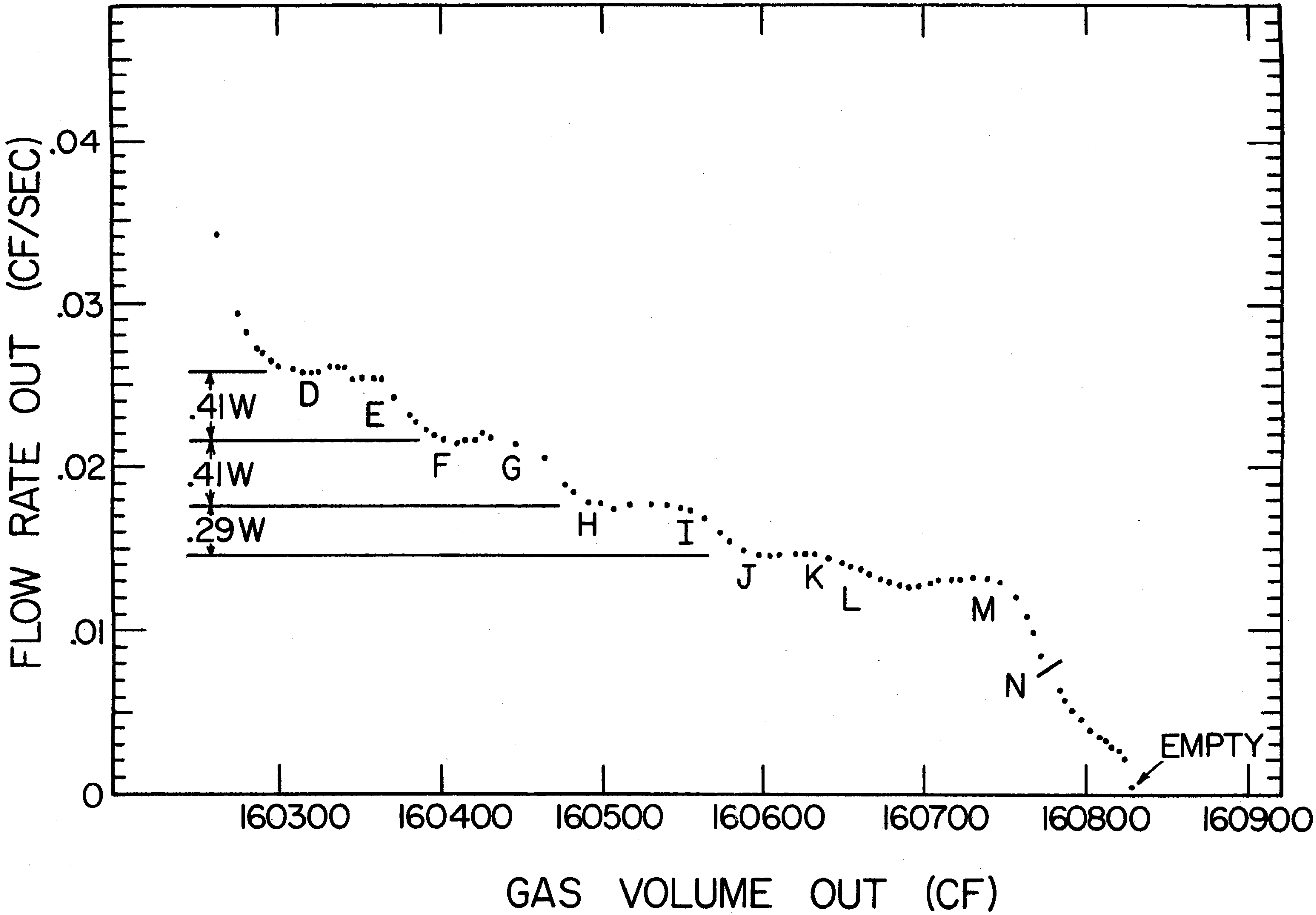

Figure 3.

Seventh Boil-Off Data. Average shield temperature: 78.5K

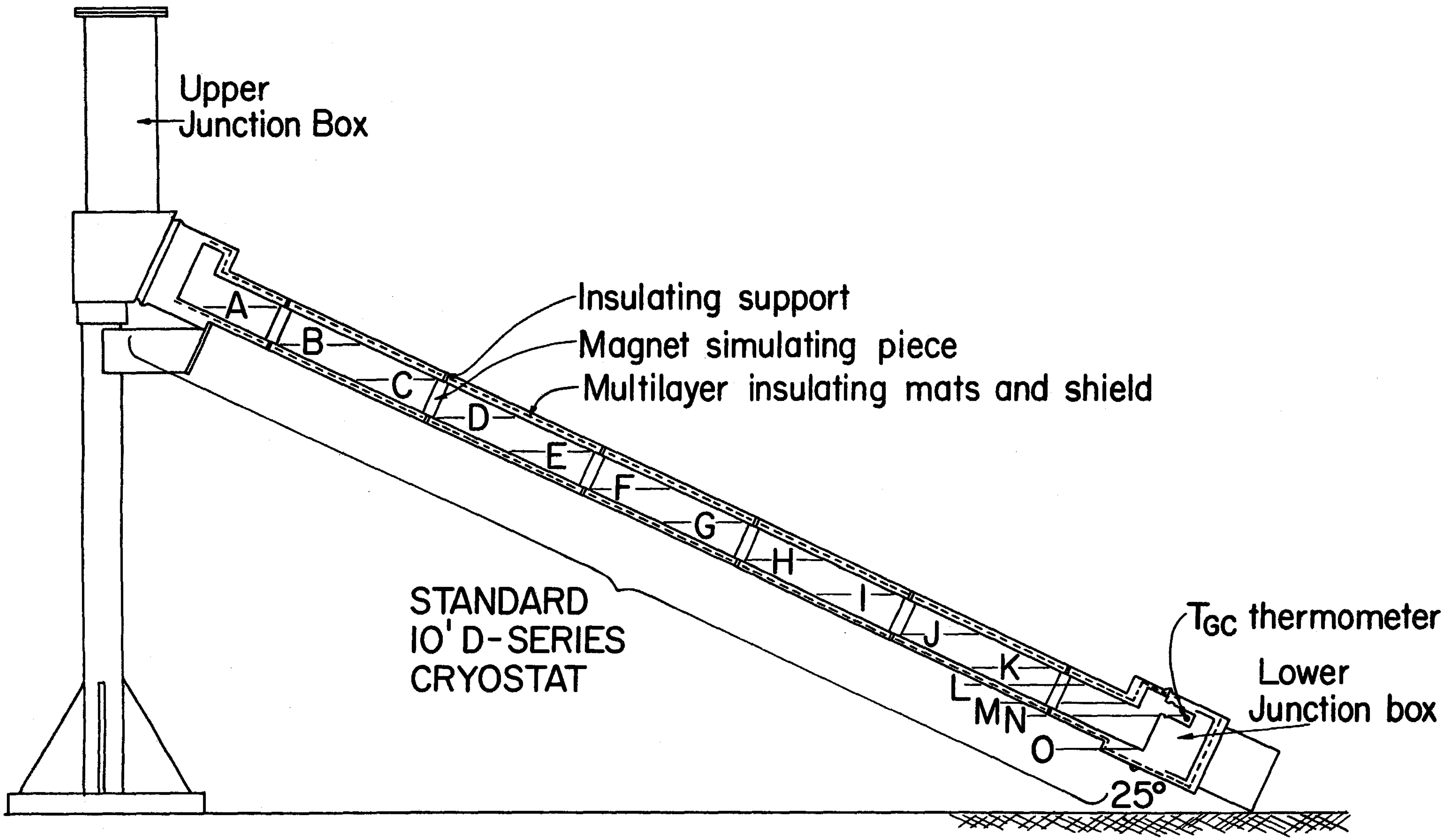

Figure 4.

Boil-Off Setup.

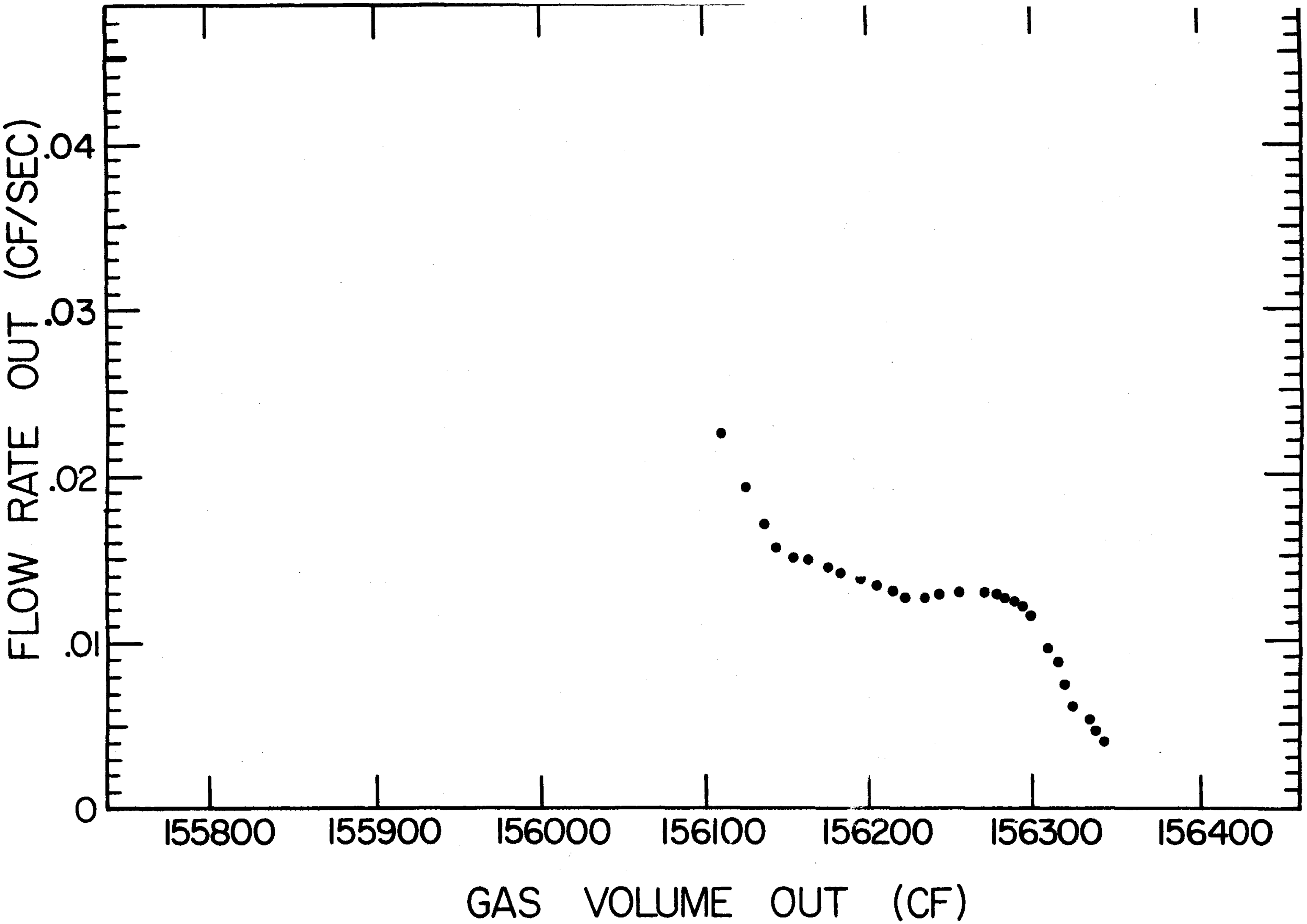

Figure 5.

Fourth Boil-Off Data.

Same conditions as Figure 1., but partially filled cryostat.

APPENDIX

SOME DRAWINGS USED IN THE CONSTRUCTION AND ASSEMBLY OF A D SERIES CRYOSTAT

Complementing the drawings that follow, the following stainless steel tube outside diameters should be given:

Beam Tube: 1-1/2"

2-Phase Tube: 1-3/4"

4K Vac Wall: 4.284"

300K Vac Wall: 6-1/8" (this tube has 2 omega convolutions along its length)

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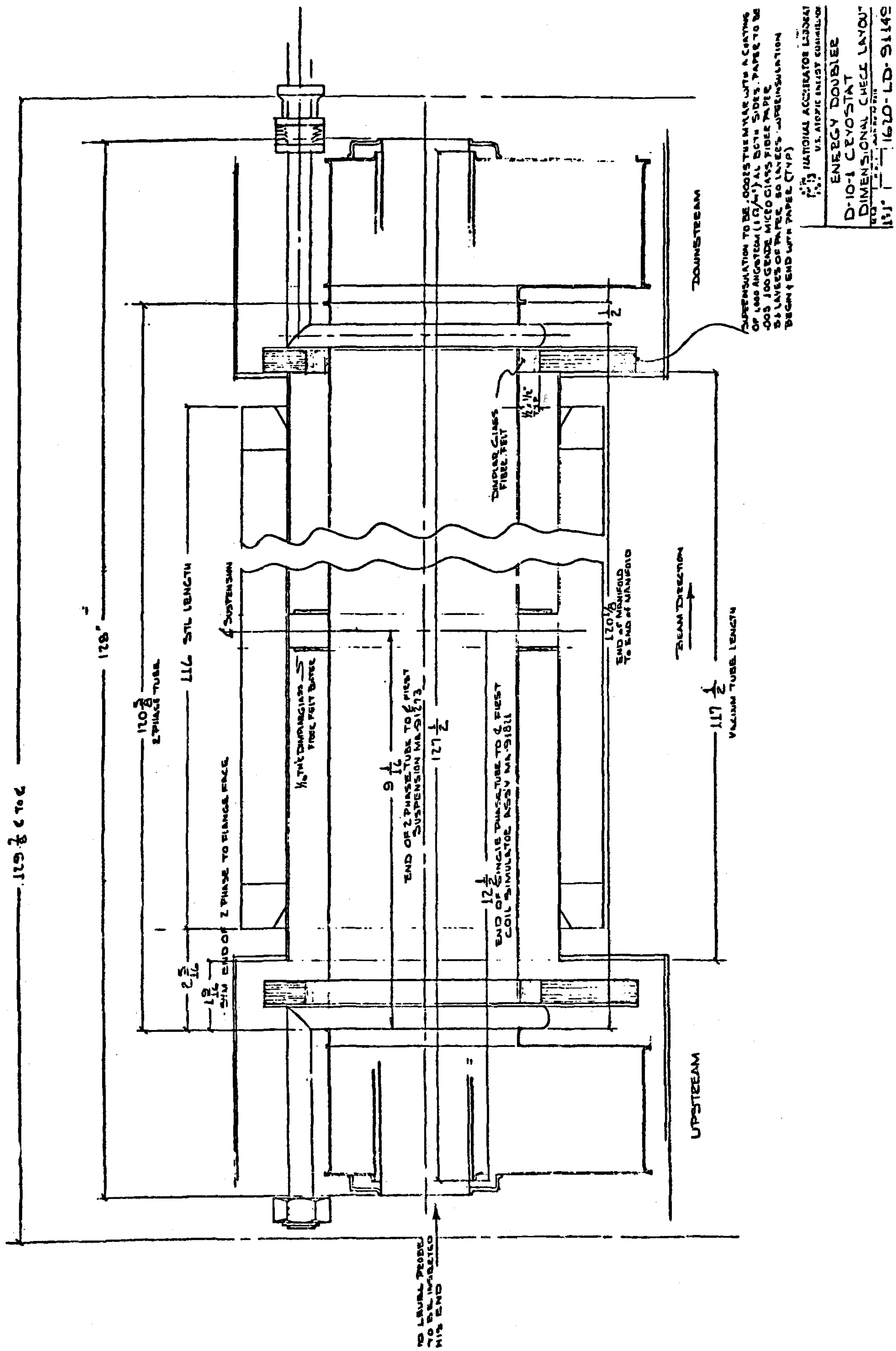
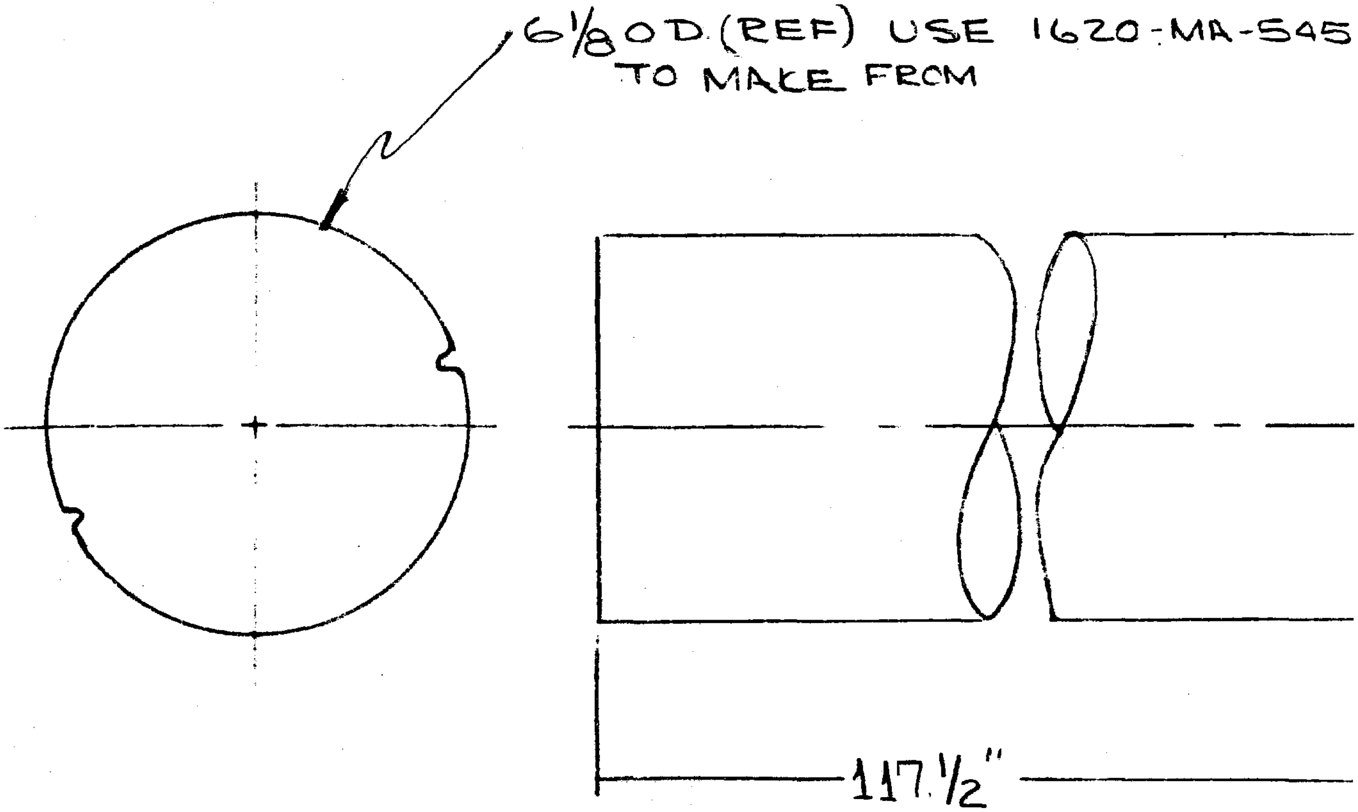
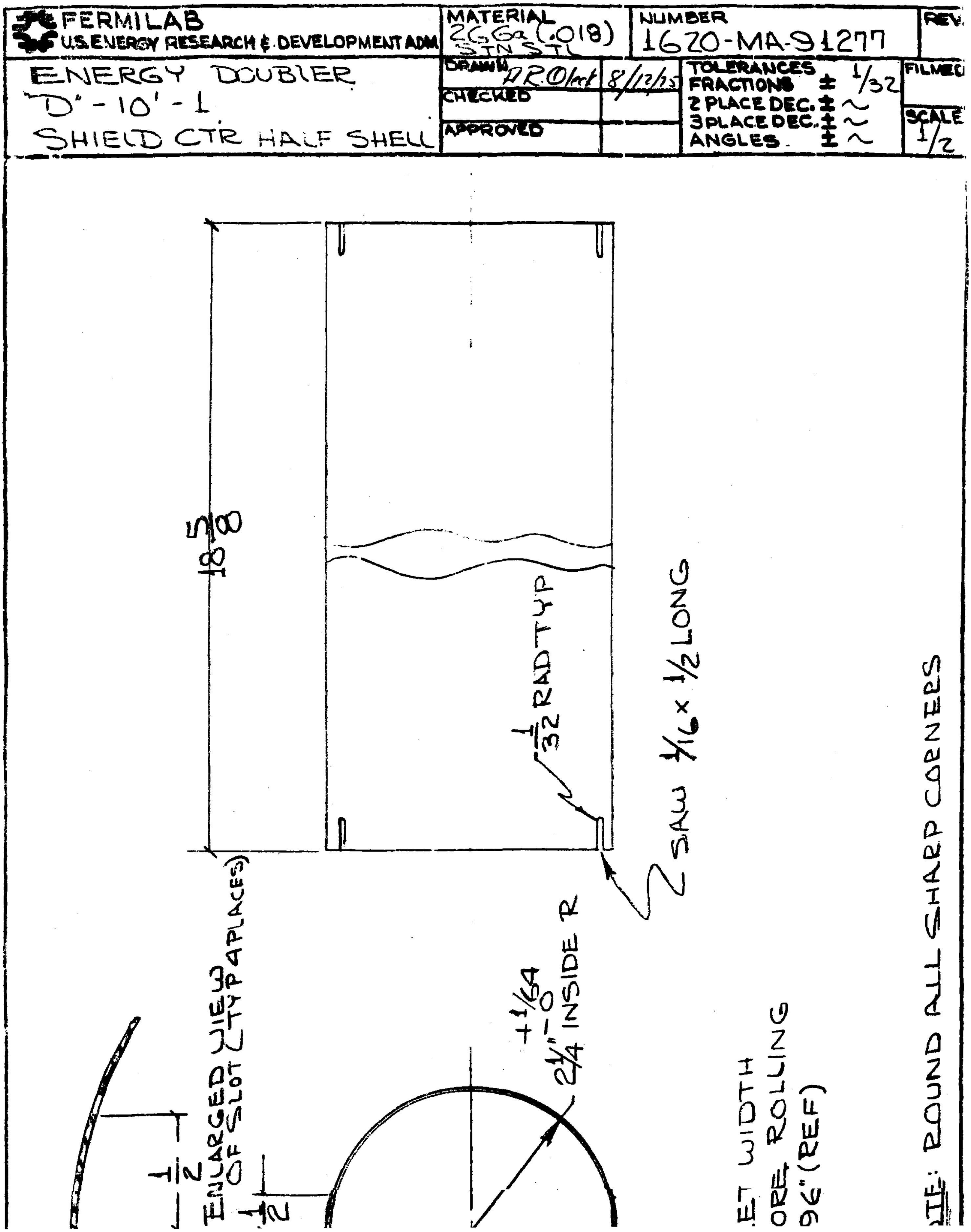
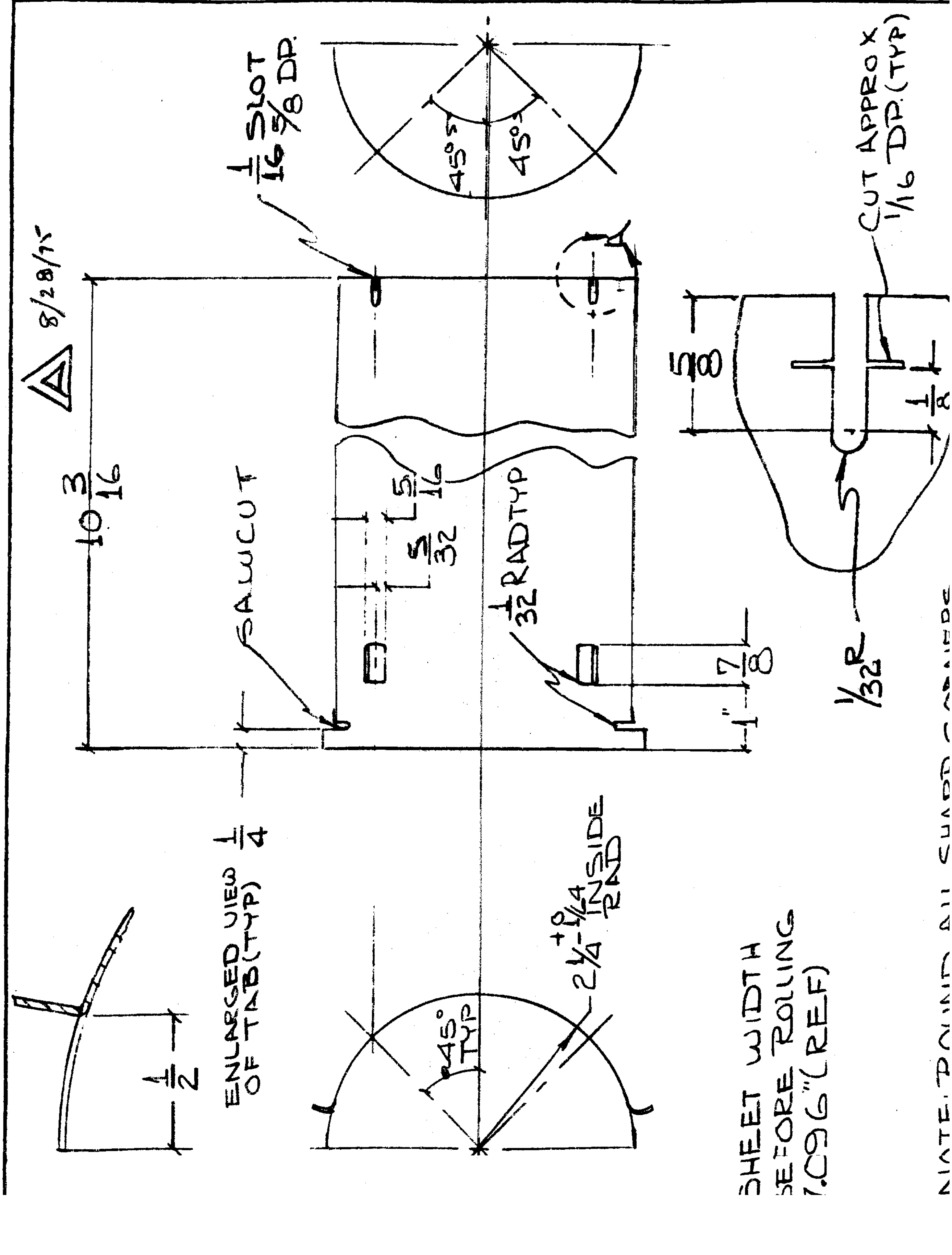

ENERGY DOUBLER
D-10-1 CRYOSTAT
DIMENSIONAL CHECK LAYOUT
1620-LD-91149
DOWNSTREAM
UPSTREAM
BEAM DIRECTION
116 STL LENGTH
128"
117 1/2
VACUUM TUBE LENGTH
120 1/8
END of MANIFOLD TO END of MANIFOLD
127 1/2
DIMPLAR GLASS FIBER FELT
SUSPENSION
TO LEVEL PROBE TO BE INSERTED HIS END

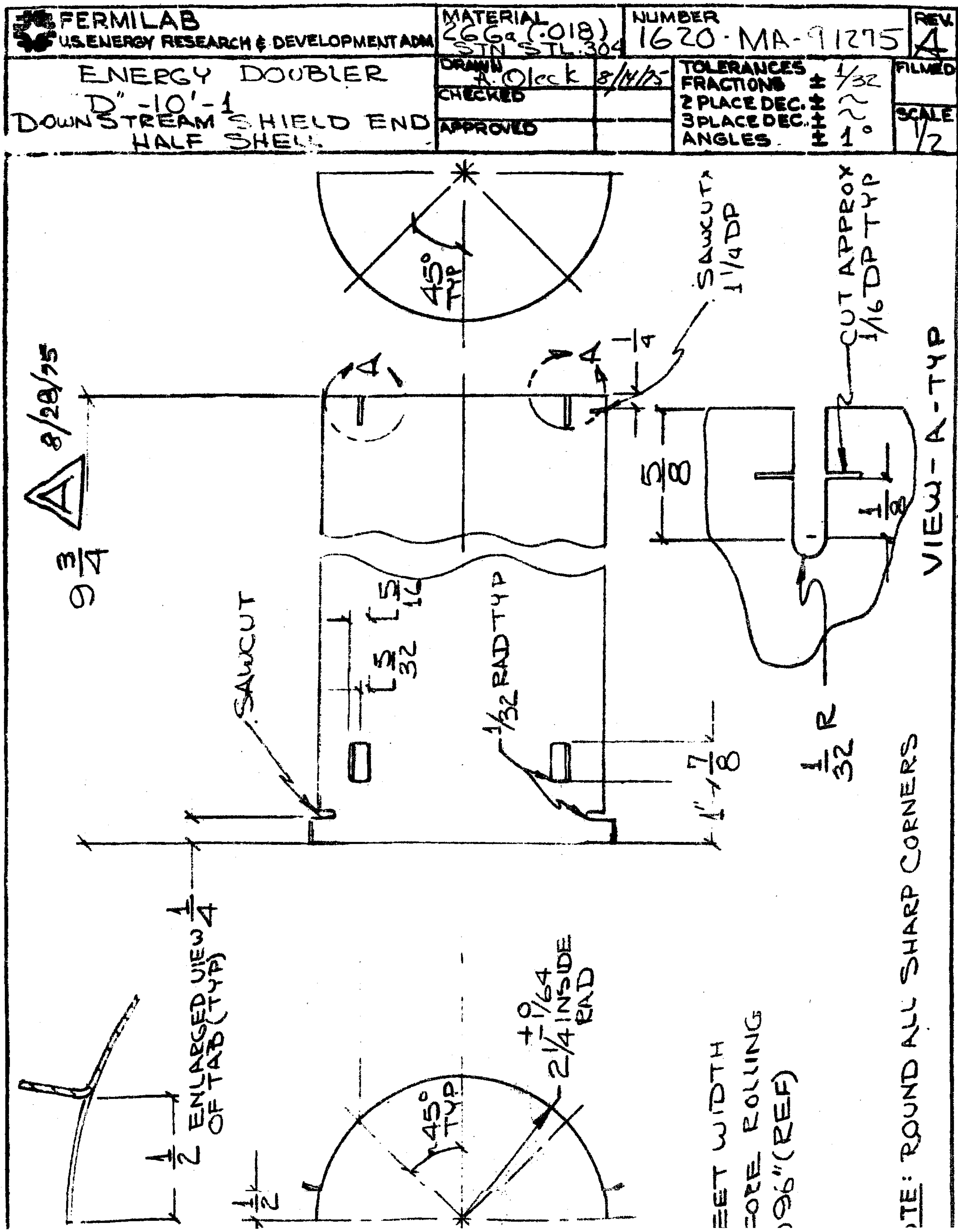
FERMILAB US ENERGY RESEARCH & DEVELOPMENT ADM	MATERIAL ~	NUMBER 1620-MA-91700
ENERGY DOUBLER 'D'-10'-1 OUTER VACUUM TUBE	DRAWN AROlick 8/25/?? CHECKED APPROVED	TOLERANCES FRACTIONS ± 1/32 2 PLACE DEC. ± 3 PLACE DEC. ± ANGLES ±

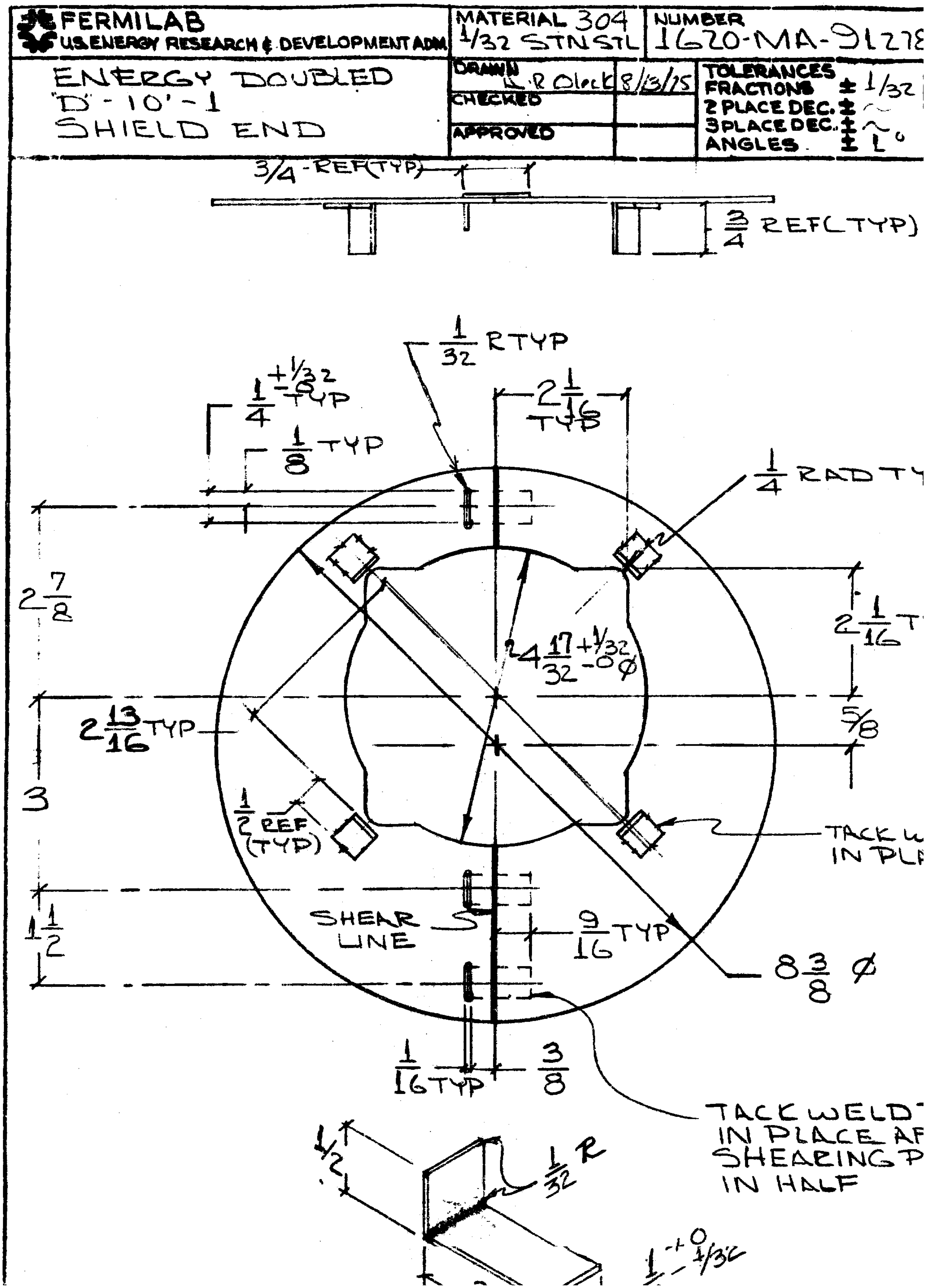


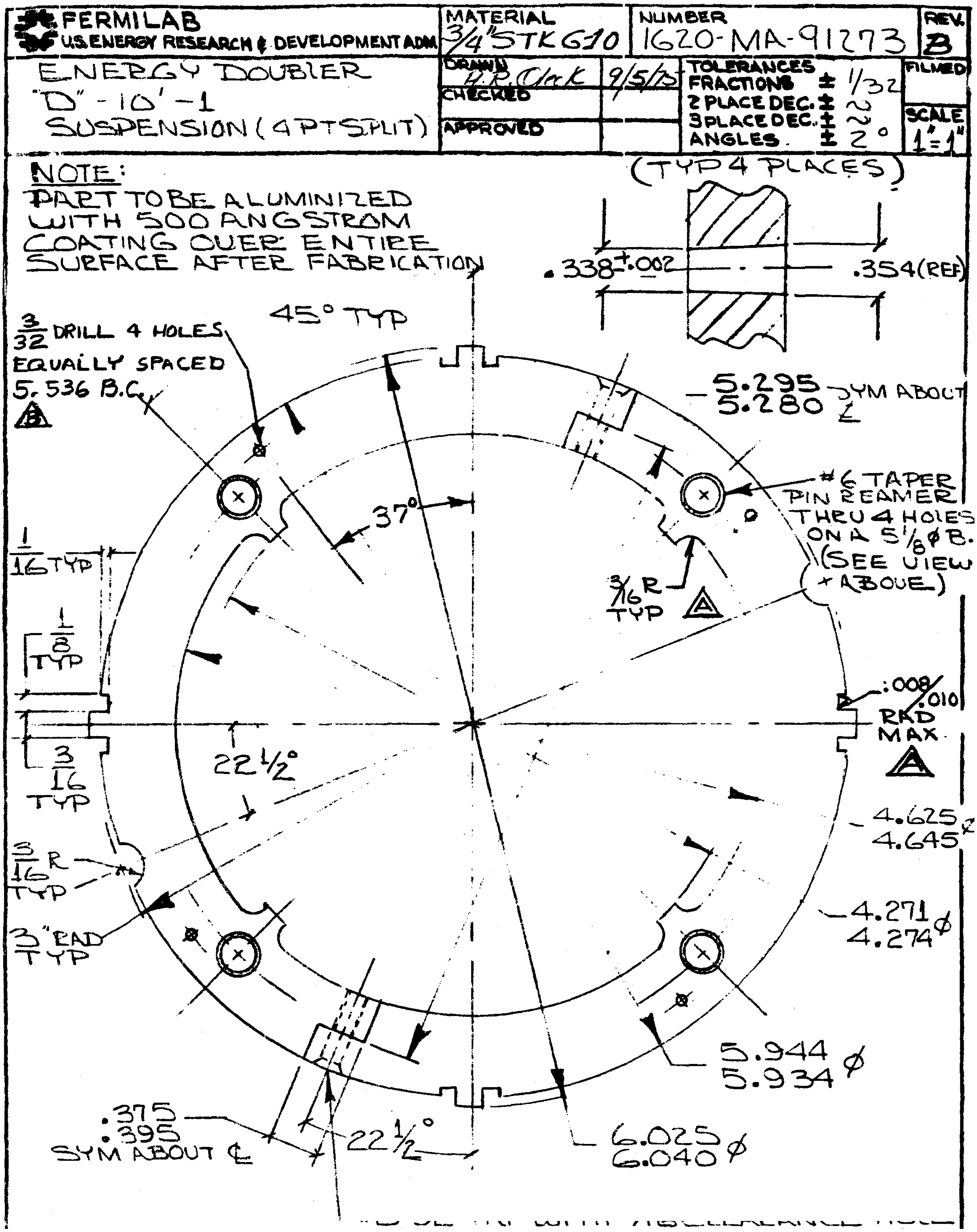

FERMILAB
U.S. ENERGY RESEARCH & DEVELOPMENT ADM
MATERIAL 26 Ga (.018) STN STL
NUMBER 1620-MA-91277
REV.
ENERGY DOUBLER
"D"-10'-1
SHIELD CTR HALF SHELL
DRAWN PRO/ark 8/12/75
CHECKED
APPROVED
TOLERANCES
FRACTIONS ± 1/32
2 PLACE DEC. ± ~
3 PLACE DEC. ± ~
ANGLES ± ~
FILMED
SCALE 1/2
18 5/8
1/32 RAD TYP
SAW 1/16 × 1/2 LONG
ROUND ALL SHARP CORNERS
ENLARGED VIEW OF SLOT (TYP 4 PLACES)
2 1/4" +1/64 −0 INSIDE R
96" (REF)

U.S. ENERGY RESEARCH & DEVELOPMENT ADM	STN STL 304		
ENERGY DOUBLER 'D-10'-1 UPSTREAM SHIELD END HALF SHELL	DRAWN A R Oleck	8/14/75	TOLERANCES FRACTIONS ± 1/32
	CHECKED		2 PLACE DEC. ± ~
			3 PLACE DEC. ± ~
	APPROVED		ANGLES ± 1°



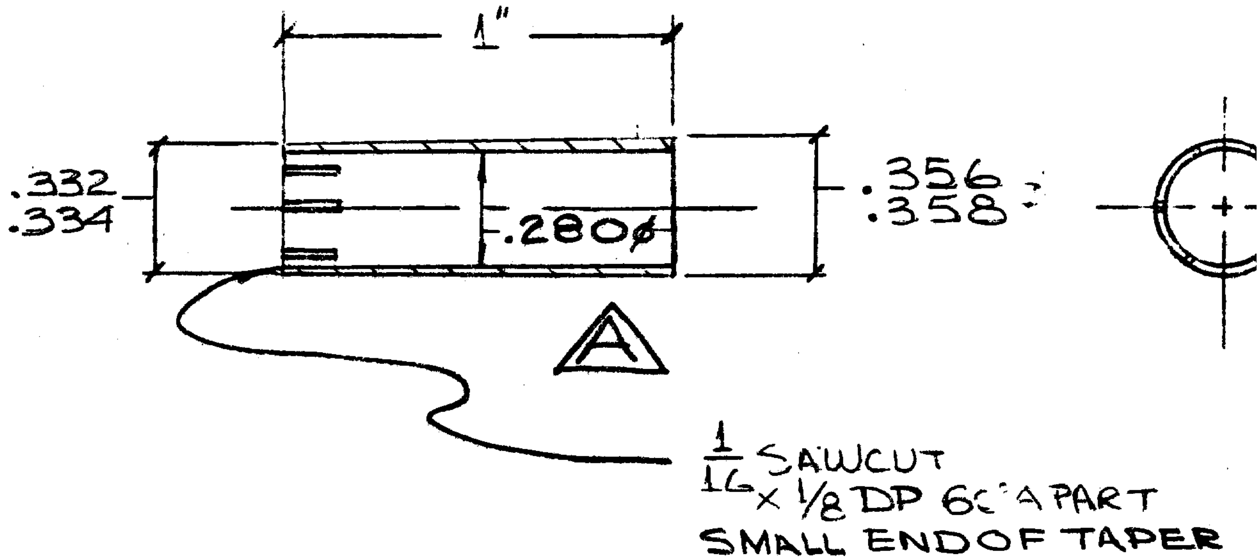

FERMILAB
U.S. ENERGY RESEARCH & DEVELOPMENT ADM.
ENERGY DOUBLER
"D" -10'-1
DOWNSTREAM SHIELD END
HALF SHELL
MATERIAL
26 Ga (.018)
STN STL. 304
DRAWN
A. Oleck
8/14/75
CHECKED
APPROVED
NUMBER
1620-MA-91275
REV.
A
TOLERANCES
FRACTIONS ± 1/32
2 PLACE DEC. ±
3 PLACE DEC. ±
ANGLES ± 1°
FILMED
SCALE
1/2
8/28/75
SAWCUT
1 1/4 DP
CUT APPROX
1/16 DP TYP
VIEW - A - TYP
4 x SIZE
45° TYP
9 3/4
5/8
1/8
1/4
5/32
5/16
1/32 RAD TYP
1/32 R
1 7/8
SAWCUT
ENLARGED VIEW OF TAB (TYP)
1/4
1/2
2 1/4 INSIDE RAD
NOTE: ROUND ALL SHARP CORNERS


FERMILAB
U.S. ENERGY RESEARCH & DEVELOPMENT ADM.
MATERIAL 304
1/32 STN STL
NUMBER
1620-MA-91278
ENERGY DOUBLED
"D"-10'-1
SHIELD END
DRAWN
8/13/75
CHECKED
APPROVED
TOLERANCES
FRACTIONS ± 1/32
2 PLACE DEC. ±
3 PLACE DEC. ±
ANGLES ± 1°
3/4 - REF (TYP)
3/4 REF (TYP)
1/32 R TYP
1/4 +1/32 -0 TYP
1/8 TYP
2 1/16 TYP
1/4 RAD TY
2 7/8
2 1/16 T
4 17/32 +1/32 -0 ⌀
2 13/16 TYP
5/8
3
1/2 REF (TYP)
TACK W
IN PL
1 1/2
SHEAR LINE
9/16 TYP
8 3/8 ⌀
1/16 TYP
3/8
TACK WELD
IN PLACE AF
SHEARING P
IN HALF
1/2
1/32 R
1 +0 -1/32


FERMILAB
U.S. ENERGY RESEARCH & DEVELOPMENT ADM.
MATERIAL 3/4" STK G10
NUMBER 1620-MA-91273
REV. B
ENERGY DOUBLER
"D"-10'-1
SUSPENSION (4 PT SPLIT)
DRAWN H.R. Clark 9/5/75
CHECKED
APPROVED
TOLERANCES
FRACTIONS ± 1/32
2 PLACE DEC. ± ~
3 PLACE DEC. ± ~
ANGLES ± 2°
FILMED
SCALE 1" = 1"
NOTE:
PART TO BE ALUMINIZED
WITH 500 ANGSTROM
COATING OVER ENTIRE
SURFACE AFTER FABRICATION
(TYP 4 PLACES)
.338 ±.002
.354 (REF)
45° TYP
3/32 DRILL 4 HOLES
EQUALLY SPACED
5.536 B.C.
B
5.295
5.280
SYM ABOUT ℄
37°
#6 TAPER
PIN REAMER
THRU 4 HOLES
ON A 5 1/8 Ø B.C.
(SEE VIEW ABOVE)
3/16 R TYP
A
1/16 TYP
1/8 TYP
.008/.010 RAD MAX
A
3/16 TYP
22 1/2°
4.625
4.645
3/16 R TYP
4.271
4.274 Ø
3" RAD TYP
5.944
5.934 Ø
.375
.395
SYM ABOUT ℄
22 1/2°
6.025
6.040 Ø

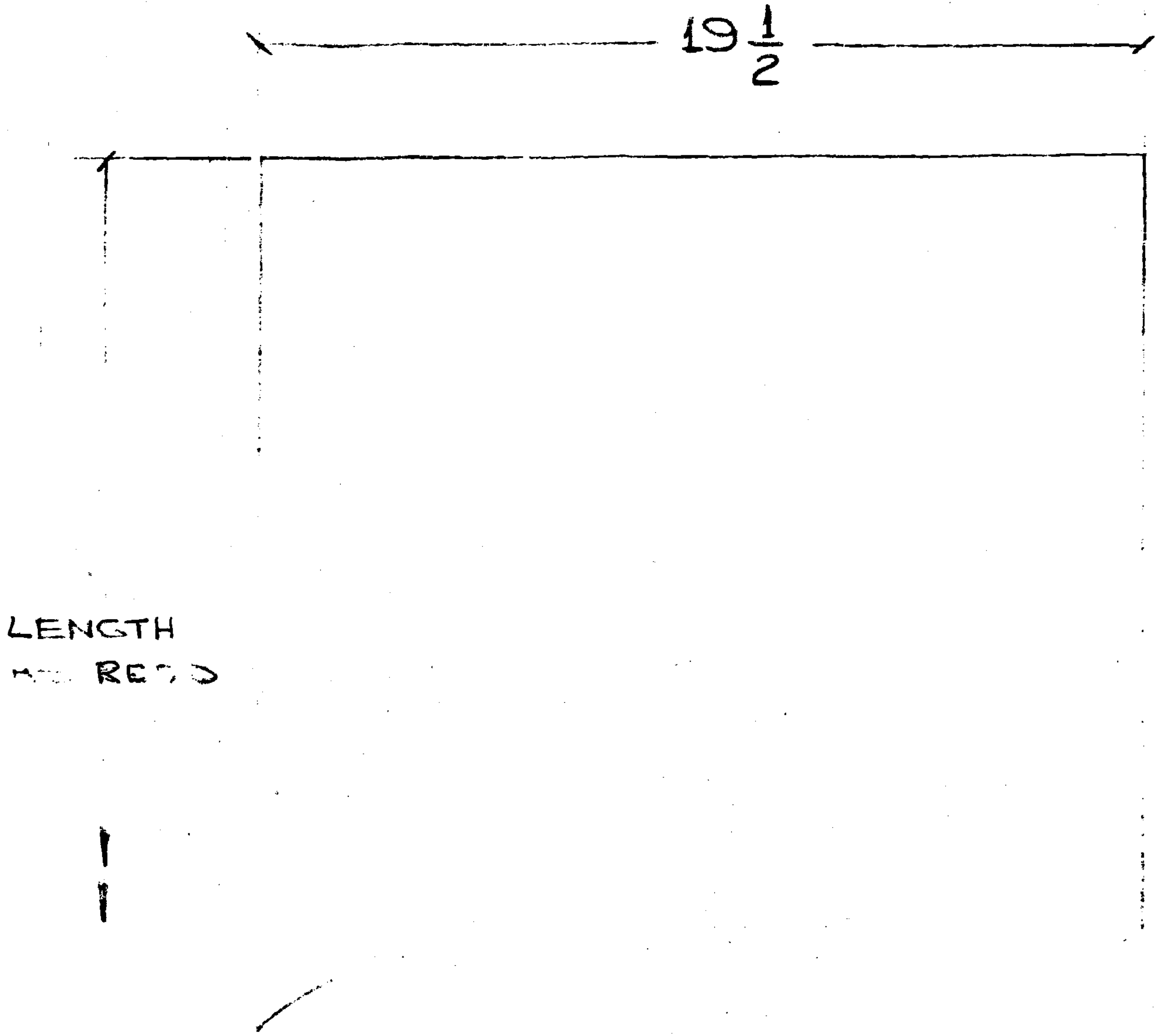
FERMILAB US ENERGY RESEARCH & DEVELOPMENT ADM	MATERIAL OFHC COPPER		NUMBER 1620-MA-91269
ENERGY DOUBLER "D"-10'-1 SUSPENSION TAPER SLEEVE	DRAWN H.P. Clack	9/5/75	TOLERANCES FRACTIONS ± 1/32
	CHECKED		2 PLACE DEC. ± ~
	APPROVED		3 PLACE DEC. ± .010
			ANGLES ± ~

A REV 9/15/75

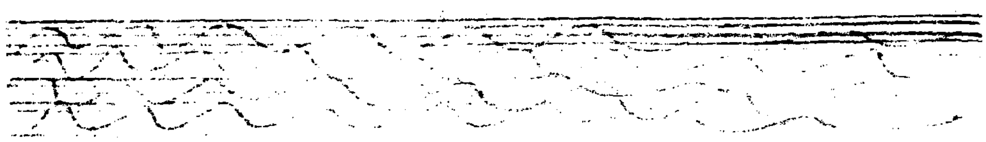


TM-6

U.S. ENERGY RESEARCH & DEVELOPMENT ADM.	NOTED		1620-MA-91702	
ENERGY DOUBLER "D" - 10'-1 SUPERINSULATION BATT	DRAWN A.R.Clark	9/23/75	TOLERANCES FRACTIONS ± 1/16	FILMED
	CHECKED		2 PLACE DEC. ±	
	APPROVED		3 PLACE DEC. ± ANGLES ±	SCALE ~



SUPERINSULATION TO BE 10CCLS THICK MYLAR WITH A COATING OF 1,000 ANGSTROM (1 Ω/IN²) ALUMINUM BOTH SIDES. PAPER TO BE .003 100 GRADE, MICRO GLASS FIBER PAPER



31 LAYERS OF PAPER - 30 LAYERS

FERMILAB U.S. ENERGY RESEARCH & DEVELOPMENT ADM	MATERIAL		NUMBER 1620 MA 91821
ENERGY DOUBLER "D" SERIES LEAK TEST MEASURE COIL SIMULATOR ASSY	DRAWN R. R. Black	10/15/75	TOLERANCES FRACTIONS ± 2 PLACE DEC. ± 3 PLACE DEC. ± ANGLES ±
	CHECKED		
	APPROVED