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INCREASING DIVER EFFECTIVENESS WITH CARBON DIOXIDE ABSORBERS AND MICROPROCESSOR DECOMPRESSION COMPUTERS

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ABSTRACT

Laboratory experiments were set up to determine the effects of inlet velocity, gas mixture, and initial CO_2 concentration on the absorption effectiveness of a cylindrical bed of barium hydroxide. A breadboard of an Intel 8085 microcomputer was built to allow a laboratory demonstration of a microprocessor based decompression computer.

Advances in either or both of these areas would permit divers to work more effectively and safely.

Both projects were run down to a simulated depth of 200 feet in a small pressure chamber. Data from the CO_2 absorption experiment consists of the raw experimental data as well as plots of CO_2 concentration versus time.

INTRODUCTION

TWO OF THE MAJOR RESTRICTIONS ON A DIVER'S BOTTOM TIME ARE THE SIZE AND WEIGHT OF THE REQUIRED CO_2 ABSORBERS AND THE TIME SPENT DECOMPRESSING UPON RETURN TO THE SURFACE. EXISTING ABSORBERS TEND TO BE LARGE AND HEAVY. A QUANTITATIVE UNDERSTANDING OF THE CO_2 ABSORBTION PROCESS WOULD PERMIT THE DESIGN OF MORE EFFICIENT ABSORBERS. THE PROPOSED PROGRAM STUDIED THE EXPERIMENTAL EFFECTS OF INLET VELOGICTY, GAS MIXTURE, AND CO_2 CONCENTRATION AT A SIMULATED DEPTH OF 200 FEET.

CURRENT DECOMPRESSION PRACTICE USES A STAGED ASCENT RATHER THAN A CONTINUOUS ASCENT. THE LATTER APPROACH IS BASED ON THE ACTUAL TISSUE PARTIAL PRESSURE OF THE ABSORBED DILUENT GAS AND FREQUENTLY RESULTS IN A SHORTER DECOMPRESSION TIME. A REAL TIME MICROPROCESSOR CAN BE PROGRAMMED TO CALCULATE THE ACTUAL TISSUE PARTIAL PRESSURES BASED ON A TISSUE MODEL AND DISPLAY THE MINIMUM SAFE ASCENT DEPTH TO THE DIVER. FOR THIS PROJECT THE ASSEMBLY LANGUAGE COMPUTER PROGARM, AND THE MICROPROCESSOR HARDWARE WILL BE DESIGNED AND BUILT.

Carbon Dioxide Absorption Experiments

The experiments were designed to simulate conditions at an ocean depth of 200 feet. The oxygen partial pressure was varied between the limits of anoxia and oxygen toxicity for a depth of 200 feet. The carbon dioxide partial pressure was varied over a range that would be typical for a diver's exhalation. The flow rates were varied over a range of rest to strenuous exertion. The following parameters were fixed: pressure, inlet temperature, moisture content of inlet gas (essentially bone dry for all mixtures), absorption chemical (barium hydroxide), quantity of absorbent, mesh size of absorbent, bed size, and bed geometry.

A typical experiment consisted of a flow of regulated, premixed gas into the cylindrical pressure vessel that housed the barium hydroxide. After leaving the reaction chamber the gas would flow through a rotameter which controlled the flow rate. A small quantity of this gas would pass through a two stage dehumidification column and a magnesium perchlorate dessicant bed before it was sampled by an infra red carbon dioxide analyzer. The rest of the gas was dumped to the atmosphere. Data taken consisted of: upstream pressure, pressure drop through the bed, inlet dry bulb temperature (T_1), inlet wet bulb temperature (T_2), outlet dry bulb temperature (T_3), rotameter setting, carbon dioxide analyzer reading, and the weight of the absorbent before and after the experiment.

Three sets of five experiments each were planned. One set was for each of the three variables. The midrange experiment for each set used the same gas mixture and operating conditions and was performed only once. The actual experiments differed somewhat from the original plan. Experiment # 1 was not conducted because the rotameter could not be used at a flow

RATE OF .25 FT^3/ MIN. EXPERIMENTS # 8, AND 13 WERE NOT CONDUCTED. THESE TWO WERE PLANNED TO BE IDENTICAL TO EXPERIMENT # 3 SO THAT ONE EXPERIMENT WOULD GIVE THE MIDRANGE DATA FOR ALL THREE SETS OF EXPERIMENTS. BECAUSE OF A BLOW THROUGH PROBLEM THE FLOW RATE WAS REDUCED FOR BOTH THE OXYGEN AND CARBON DIOXIDE PARTIAL PRESSURE VARIATION SETS.

INCREASING THE FLOWRATE DECREASED THE TIME REQUIRED FOR THE CARBON DIOXIDE TO ATTAIN A STEADY STATE VALUE EQUAL TO THAT OF THE INCOMING GAS. THIS CONDITION IS CALLED BREAK THROUGH. A SMALL VOLUME ABSORBENT BED WAS USED TO MINIMIZE THE REQUIRED AMOUNT OF VERY EXPENSIVE PREMIXED GAS. THIS SMALL BED VOLUME CAUSED SOME BLOW THROUGH PROBLEMS DUE TO THE VERY SHORT RESIDENCE TIMES IN EXPERIMENTS # 4, AND 5. AT HIGH FLOW RATES AND THEREFORE LOW RESIDENCE TIMES, THE GAS IS EXPOSED TO THE ABSORBENT CHEMICAL FOR LESS TIME THAN IS REQUIRED FOR THE CHEMICAL REACTION TO COMPLETELY OCCUR.

VARYING THE PARTIAL PRESSURE OF OXYGEN HAD NO APPRECIABLE EFFECT ON THE BREAKTHROUGH TIME. VARYING THE PARTIAL PRESSURE OF CARBON DIOXIDE DID NOT HAVE ANY EFFECT ON THE BREAKTHROUGH TIME ALTHOUGH AN INCREASED INPUT OF CARBON DIOXIDE PRODUCED A CORRESPONDINGLY HIGHER STEADY STATE OUTPUT LEVEL OF CARBON DIOXIDE.

TRANSIENT CARBON DIOXIDE READINGS DURING THE FIRST MINUTE OF ALL EXPERIMENTS WERE DUE TO GAS FROM THE PREVIOUS EXPERIMENT RETAINED IN SOME OF THE LINES, AND AIR INTRODUCED INTO THE REACTION CHAMBER WHEN IT WAS FILLED WITH FRESH BARIUM HYDROXIDE. DATA FROM THE FIRST MINUTE FOR ALL EXPERIMENTS SHOULD BE DISREGARDED.

Microprocessor Decompression Computer

Decompression of a diver refers to the relatively slow, and controlled process of reducing the diver's ambient pressure at a rate that will prohibit the formation of bubbles in any of his body tissues.

The following equation is used to predict the partial pressure of the dissolved diluent gas, nitrogen, in seven types of body tissues.

$$P_{N+1} = P_N + K(P_1 - P_N)$$

P_{N+1}, P_N: partial pressure of diluent gas dissolved in tissue, in s.w.

P_1: ambient partial pressure of diluent gas, inches sea water

K: rate constant for a tissue = Ln $2/T_2$, 1/min

T_2: tissue half time, min

This equation was used in this system and is accurate for descents, and time at depth. It is only an approximation for ascents. Several additional relationships are presented in Jennings (8) which more accurately deal with the tissue partial pressure profile during ascents.

A flow chart for the assembly language computer program is in the appendix of this report. The program operates in the following manner.

1. store maximum allowable partial pressure for each tissue at the seven decompression stops, M values
2. store the seven tissue constants
3. set initial conditions, P_N = 12 psi
4. read P_1 from a pressure transducer and analog to digital converter
5. calculate and store seven values for P_{N+1}
6. compare these seven values with the M values for each tissue
7. select the minimum safe ascent depth for each tissue and store

8. DETERMINE THE MAXIMUM OF THESE SEVEN VALUES AND DISPLAY THIS DEPTH

9. SET $P_N = P_{N+1}$

10. REPEAT EVERY TWO SECONDS, GO BACK TO STEP FOUR

THE COMPUTER PROGRAM CONSISTS OF THE FOLLOWING SUBROUTINES WHICH ARE LISTED IN THE ORDER OF EXECUTION. EIGHT BIT ANALOG TO DIGITAL(A/D) CONVERSION ROUTINE. SIXTEEN BIT A/D CORRECTION ROUTINE FOR AUTO-ZERO AND AUTO-FULL-SCALE ERRORS. ARITHMETIC CONTROL ROUTINE THAT CALLS THE SPECIFIC ARITHMETIC SUBROUTINES TO SOLVE THE PARTIAL PRESSURE EQUATION. MULTIPLE PRECISION COMPARE SUBROUTINE WHICH COMPARES THE TWENTY FOUR BIT CALCULATED PARTIAL PRESSURES WITH THE TWENTY FOUR BIT STORED M VALUES. SUBROUTINE TO SOLVE FOR THE MAXIMUM VALUE OF THE SEVEN STORED ASCENT DEPTHS. A MULTIPLE PRECISION ADDITION AND SUBTRACTION SUBROUTINE. A TWENTY FOUR BIT MULTIPLY ROUTINE WHICH GIVES A FORTY EIGHT BIT RESULT AND A FORTY EIGHT BIT DIVIDE ROUTINE WHICH GIVES UP TO A FORTY EIGHT BIT QUOTIENT. A TIME DELAY ROUTINE TO SET THE SAMPLE RATE AT 0.5 Hz. AND FINALLY THE ROM AND RAM DATA. ALL SUB-ROUTINES WORK INDEPENDENTLY AND IN CONJUNCTION WITH EACH OTHER. WITH THE EXCEPTION OF THE ARITHMETIC CONTROL ROUTINE WHICH WAS NOT COMPLETED DUE TO A LACK OF TIME.

THE PROTOTYPE WAS BUILT ON AN INTEL SDK-85 DEVELOPMENT SYSTEM WHICH UTILIZES THE 8085 MICROPROCESSOR AND ITS MEMORY CHIPS; 8155 RAM, AND 8755 EPROM. EXPANSION RAM WAS ADDED TO ALLOW EASIER PROGRAM DEVELOPMENT. THE PRESSURE TRANSDUCER IS NATIONAL SEMICONDUCTOR LX-1620A. THE A/D CONVERTER IS A FAIRCHILD uA9708 EIGHT BIT CONVERTER. THE A/D CONVERTER IS CONTROLLED BY THE MICROPROCESSOR. THE DISPLAY CONSISTS OF TWO, SEVEN SEGMENT DISPLAY LIGHT EMITTING DIODES (LED) AND THEIR ASSOCIATED DECODER/DRIVERS. ALL OF THE HARDWARE FUNCTIONS PROPERLY.

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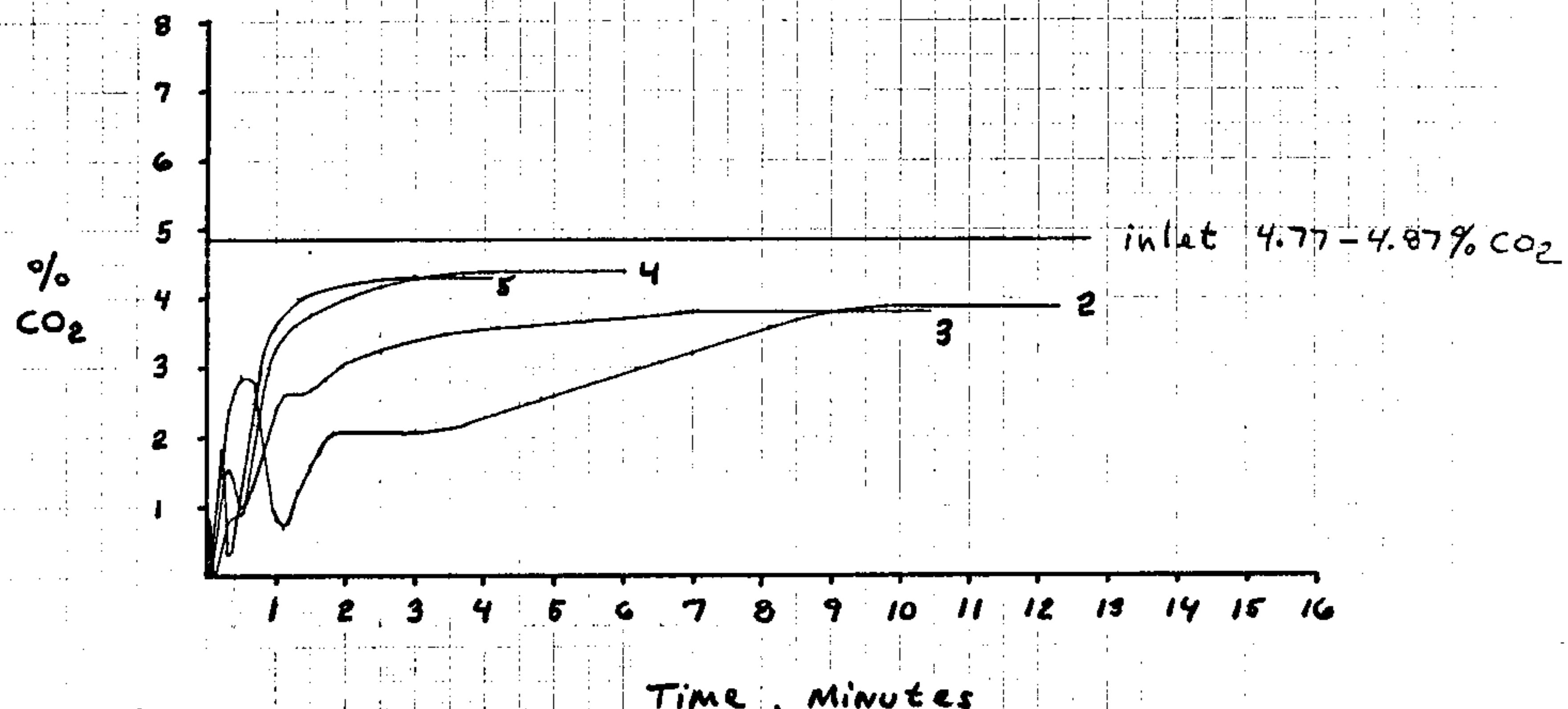
% CO_2 vs. Time
Variable Flow rate

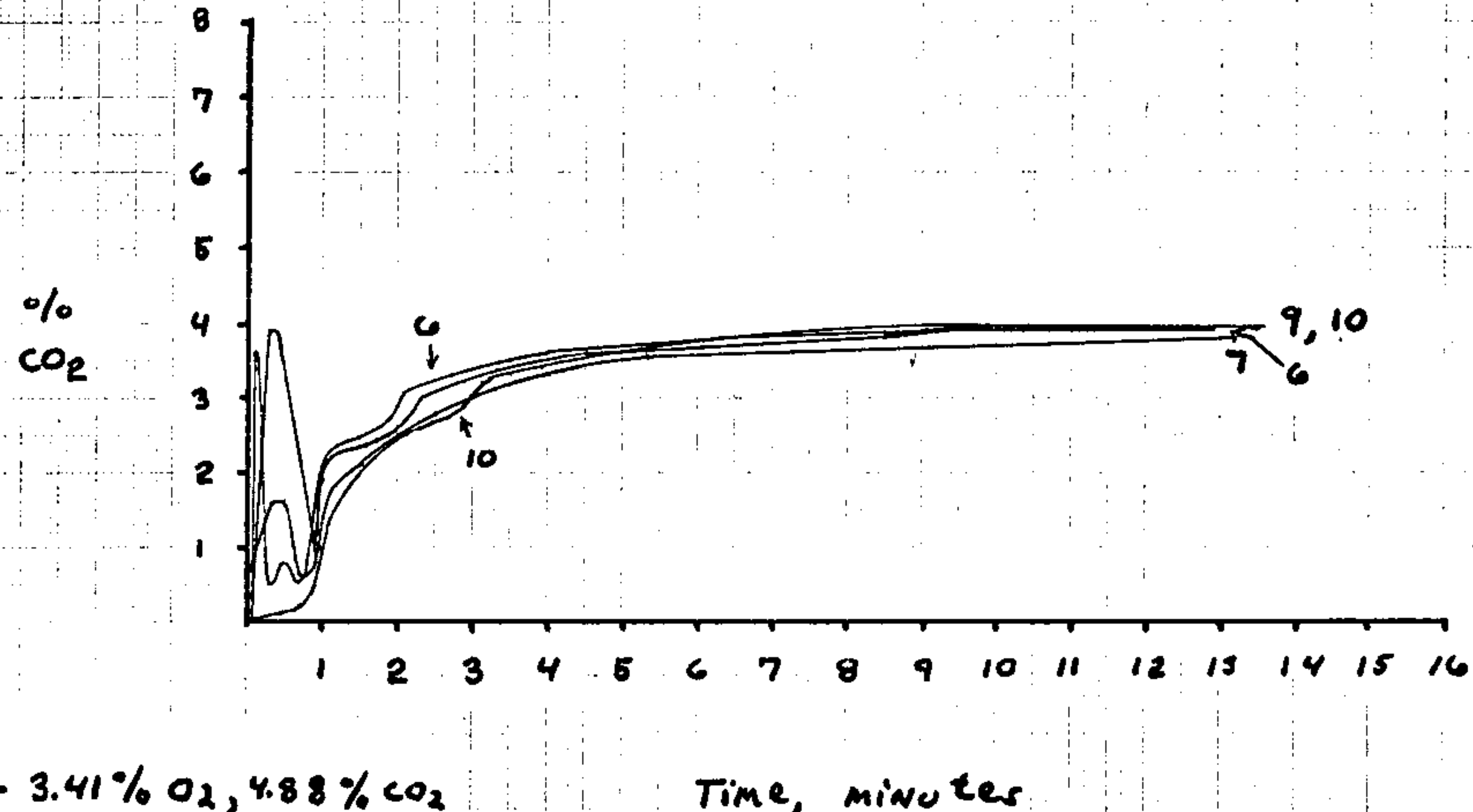


2 – .78 ft^3/min
3 – 1.15
4 – 1.50
5 – 2.25

4-8 Mesh – Barium Hydroxide

% CO_2 vs. Time

variable O_2 partial pressure

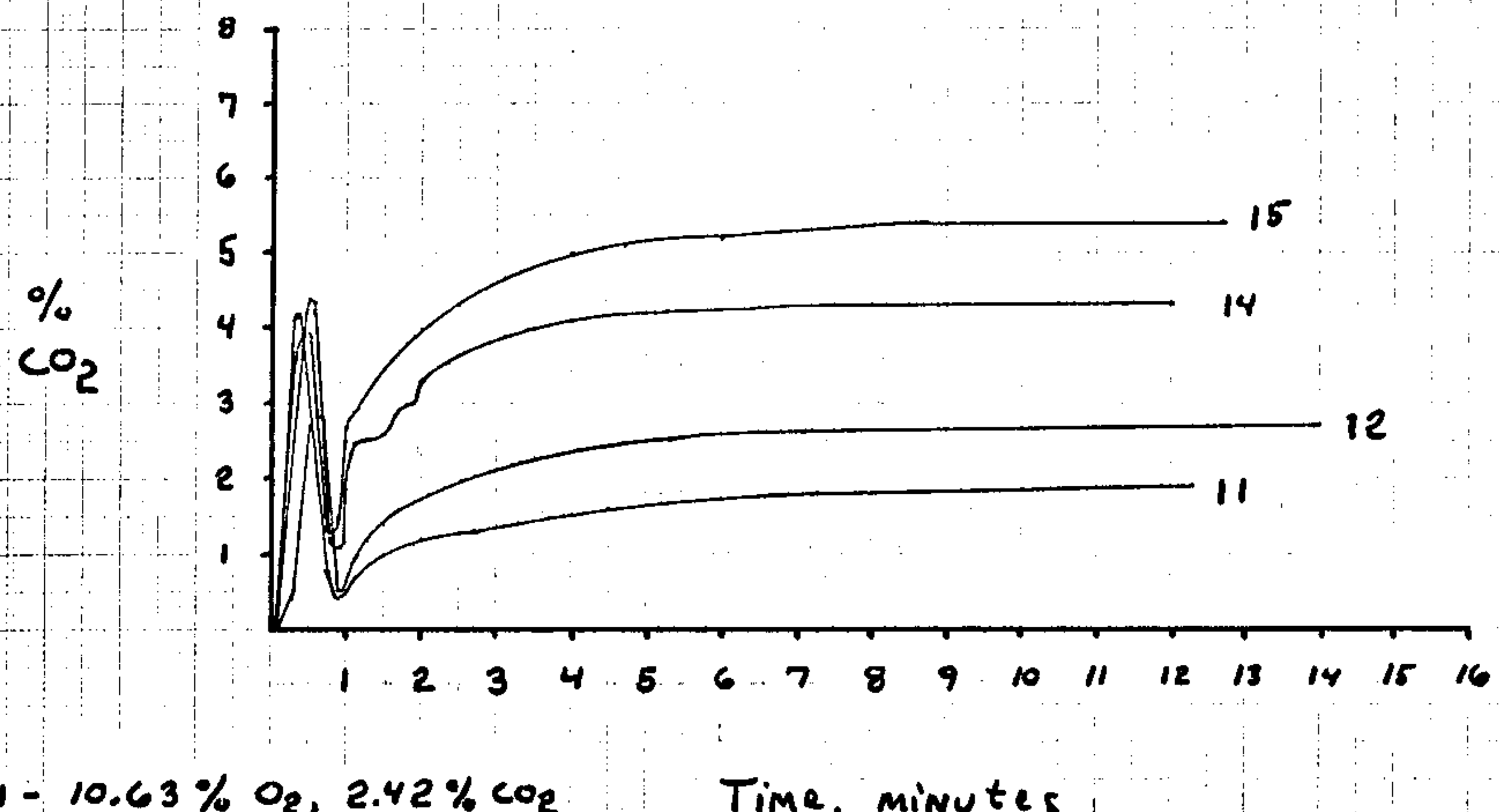


6 - 3.41% O_2, 4.88% CO_2
7 - 6.75 4.71
9 - 14.28 4.84
10 - 16.91 4.69

4-8 Mesh Barium Hydroxide

% CO_2 vs. Time

Variable CO_2 partial pressure



11 - 10.63 % O_2, 2.42 % CO_2
12 - 11.08 8.71
14 - 10.78 5.12
15 - 10.81 6.30

4-8 mesh Barium Hydroxide

Exp # 2
Cylinder # 94764

He - O_2 - CO_2
Nominal Gas Mix: 86-10-4
Actual Gas Mix: 11.06 - 4.87

P_{reg}: 100

Wgt. Baralyme Before: 225 g
Wgt. Baralyme After: 238.7 g

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	% CO_2	
1	88	.2	77.3	72.2	90.2				0	.78			flow thru center of bed
2	89	.2	75.7	69.5	103.1				0				
3	89	.2	75.9	68.9	100.0				0				
4	89.5	.2	75.9	68.8	96.5				0				
5	90	.2	76.0	68.7	95.6				0				
6	90	.2	76.0	68.7	94.5				0				
7	90	.2	75.9	68.6	93.3				0				
8	90	.2	75.8	68.4	91.1				0				
9	90	.2	75.6	68.3	90.1				0				
10	90	.2	75.4	68.0	88.5				0				
11	85	.2	74.8	67.4	87.6				0				
12	50	.2	74.5	64.5	86.0				0				
13													
14													
15													

full length dry

Exp # 3
Cylinder # 46086

$He-O_2-CO_2$
Nominal Gas Mix: 86-10-4
Actual Gas Mix: 10.6 - 4.77

P_{reg}: 100

Wgt Baralyme Before: 225.0
Wgt Baralyme After: 236.2

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	88	.4	76.8	71.2	94.5				3.6	1.15			
2	90	-.3	76.6	69.8	94.7				3.6				
3	90	.3	76.9	69.9	92.1				3.6				
4	91	.3	77.0	69.8	89.0				3.6				
5	91	-.3	76.9	69.7	87.7				3.6				
6	91	-.3	76.8	69.5	86.9				3.6				
7	91	.3	76.4	69.3	86.4				3.6				
8	91	.3	76.0	68.9	85.5				3.6				
9	91	.3	75.6	68.7	84.8				3.6				
10	91	.3	75.2	68.7	84.2				3.6				
11	91	.3	74.6	67.9	83.4				3.6				
12													
13													
14													
15													

full length dry

Exp # 4
Cylinder # 94764

He - O_2 - CO_2
Nominal Gas Mix: 86-10-4
Actual Gas Mix: 11.06 - 4.87

P_{reg}: 100

Wgt Baralyme Before: 225 g
Wgt Baralyme After: 235.2

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	85	.55	75.0	69.3	103				7.2	1.50			
2	87	.55	75.6	68.6	99.5				7.2				
3	87	.55	76.0	68.7	91.0				7.2				
4	88	.50	76.0	68.5	87.2				7.2				
5	88	.50	75.9	68.3	85.1				7.2				
6	88	.50	75.6	67.9	84.3				7.2				
7													
8													
9													
10													
11													
12													
13													
14													
15													

Exp # 5 — $He-O_2-CO_2$ Nominal Gas Mix: 86-10-4 — P_{reg}: 100 — Wgt. Bara lyme Before: 225 g

Cylinder # 94764 — Actual Gas Mix: 11.06 - 4.87 — Wgt. Bara lyme After: 233.8

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	75	1.1	76.2	69.6	99.9				14.8	2.25			down stream end, flow around outside only
2	79	1.0	74.9	67.4	90.4				14.8				
3	79	1.0	73.5	66.0	86.5				14.8				
4	79	1.0	72.1	64.8	84.1				14.8				
5	79.5	1.0	70.4	63.4	82.0				14.8				
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													

Exp # 6
Cylinder # 33801

$He - O_2 - CO_2$
Nominal Gas Mix: 93-3-4
Actual Gas Mix: 3.41- 4.88

P_{reg}: 100

Wgt. Bavalyme Before: 225 g
Wgt- Bavalyme After: 237.7 g

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	90	.25	74.0	69.3	87.4				1	.90			
2	91	.25	74.0	68.0	103.1				1				
3	91	.25	74.4	68.2	98.6				1				
4	91	.25	74.8	68.4	93.0				1				
5	91	.25	75.0	68.5	90.0				1				
6	91	.25	75.0	68.6	88.9				1				
7	91	.25	75.1	69.6	86.9				1				
8	91	.25	75.0	69.5	85.7				1				
9	91	.25	74.8	69.4	84.5				1				
10	91	.25	74.5	68.1	83.7				1				
11	91	.25	74.2	67.9	82.7				1				
12	91	.25	72.9	67.6	82.0				1				
13	91	.25	73.3	67.3	81.5				1				
14	91	.25	73.2	67.0	81.0				1				
15													

Exp # 7
Cylinder # 24708

$He-O_2-CO_2$
Nominal Gas Mix: 90-6-4
Actual Gas Mix: 6.75-4.71

P_{reg}: 100

Wgt. Baralyme Before: 225 g
Wgt. Baralyme After: 238.6 g

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	% CO_2	
1	90	.25	76.8	75.6	106.2				1	.90			
2	91	.25	77.1	74.6	120.0				1				
3	91	.25	77.4	74.6	107.8				1				
4	91	.25	77.7	74.9	101.8				1				
5	91	.25	77.9	75.2	78.8				1				
6	91	.25	77.9	75.3	95.9				1				
7	91	.25	77.8	75.4	94.1				1				
8	91	.25	77.7	75.5	91.8				1				
9	91	.25	77.5	75.5	90.4				1				
10	91	.25	77.2	75.5	89.2				1				
11	91	.25	77.0	75.3	88.2				1				
12	91	.25	76.5	75.2	87.3				1				
13	91	.25	76.2	74.9	86.4				1				
14	91	.25	75.8	74.6	85.6				1				
15													

Exp # 9 | He - O_2 - CO_2 Nominal Gas Mix: 83-13-4 | Preg: 100 | Wgt. Bara lyme Before: 225 g
Cylinder # 7515 | Actual Gas Mix: 14.28 - 4.84 | | Wgt. Bara lyme After: 234.1 g

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	90	.25	71.0	66.4	99.3				1	.90			
2	90	.25	71.4	65.9	111.9				1				
3	91	.25	71.9	66.2	101.1				1				
4	91	.25	72.6	66.6	96.7				1				
5	91	.25	72.7	66.9	92.0				1				
6	91	.25	72.2	67.1	87.6				1				
7	91	.25	73.5	67.2	88.0				1				
8	91	.25	73.5	67.3	86.9				1				
9	91	.25	73.6	67.4	85.8				1				
10	91	.25	73.5	67.4	84.7				1				
11	91	.25	72.4	67.2	83.4				1				
12	91	.25	73.2	67.1	82.6				1				
13	91	.25	73.1	67.0	82.0				1				
14													
15													

Exp # 10
Cylinder # 22439

He - O_2 - CO_2
Nominal Gas Mix: 80-16-4
Actual Gas Mix: 16.91 - 4.69

P_{reg}: 100

Wgt. Baralyme Before: 225 g
Wgt. Baralyme After: 237.5

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	% CO_2	
1	90	.25	74.3	70.3	83.0				1	.90			
2	90	.25	74.2	68.4	105.3				1				
3	90	.25	74.6	68.5	98.5				1				
4	90	.25	75.1	68.8	93.8				1				
5	90	.25	75.4	69.0	91.7				1				
6	90	.25	75.6	69.2	89.3				1				
7	90	.25	75.7	69.3	88.0				1				
8	90	.25	75.8	69.3	87.0				1				
9	90	.25	75.7	69.3	86.1				1				
10	91	.25	75.5	69.2	85.2				1				
11	91	.25	75.5	69.1	84.4				1				
12	91	.25	75.3	69.0	83.9				1				
13	91	.25	75.1	68.9	83.6				1				
14	91	.25	74.7	68.6	83.1				1				
15													

Exp # 11
Cylinder # 50541

$He-O_2-CO_2$
Nominal Gas Mix: 88-10-2 P_{reg}: 100
Actual Gas Mix: [illegible]3-2.9%

Wgt Bara lyme before: 225g
Wgt. Bara lyme After: 237.6g

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	$IR-CO_2$	$\%CO_2$	
1	90	.25	75.7	70.4	85.3				1	.90			downstream [illegible]
2	90	.25	76.0	68.9	97.8				1				mostly pink
3	91	.25	76.5	69.3	91.2				1				
4	91	.25	76.9	69.5	89.8				1				
5	91	.25	77.1	69.6	88.4				1				
6	91	.25	77.4	69.7	87.1				1				
7	91	.25	77.3	69.9	86.4				1				
8	91	.25	77.4	69.8	85.6				1				
9	91	.25	77.2	69.7	84.9				1				
10	91	.25	77.2	69.6	84.0				1				
11	91	.25	76.8	69.5	83.6				1				
12	91	.25	76.6	69.4	82.9				1				
13	91	.25	76.4	69.2	82.5								
14													
15													

Exp # 12
Cylinder # 34843

$He-O_2-CO_2$
Nominal Gas Mix: 87-10-3
Actual Gas Mix: 11.03- 3.71

P_{reg}: 100

Wgt. Bara lyme Before: 225g
Wgt. Bara lyme After: 236.80

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	90	.25	77.1	71.1	86.0				1	.90			
2	91	.25	76.7	69.5	104.8				1				
3	91	.25	77.1	69.7	99.5				1				
4	91	.25	77.4	69.7	97.5				1				
5	91	.25	77.5	69.7	92.8				1				
6	91	.25	77.5	69.7	91.3				1				
7	91	.25	77.5	69.7	89.5				1				
8	91	.25	77.4	69.6	88.2				1				
9	91	.25	77.3	69.5	87.1				1				
10	91	.25	77.0	69.3	86.6				1				
11	91	.25	76.8	69.2	85.7				1				
12	91	.25	76.4	69.0	85.2				1				
13	91	.25	76.1	68.7	84.1				1				
14	91	.25	75.7	68.6	83.7				1				
15	91	.25	75.5	68.4	82.9				1				

Exp # 14 $He-O_2-CO_2$
Nominal Gas Mix : 85-10-5 Preg : 100 Wgt. Bara lyme Before : 225 g
Cylinder # 50569 Actual Gas Mix : 10.78 - 5.12 Wgt. Bara lyme After : 239.1 g

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	90	.25	76.4	70.8	107.9				1	.90			all blue
2	90	.25	76.1	69.4	125.1				1				
3	91	.25	76.5	69.5	110.0				1				
4	91	.25	76.9	69.7	104.1				1				
5	91	.25	77.1	69.9	97.1				1				
6	91	.25	77.3	70.0	94.3				1				
7	91	.25	77.3	69.9	92.2				1				
8	91	.25	77.3	69.9	90.4				1				
9	91	.25	77.3	69.9	89.8				1				
10	91	.25	77.1	69.8	89.6				1				
11	91	.25	77.0	69.6	87.7				1				
12	91	.25	76.9	69.5	86.6				1				
13	91	.20	76.6	69.3	86.2				1				
14													
15													

Exp # 15
Cylinder # 14393

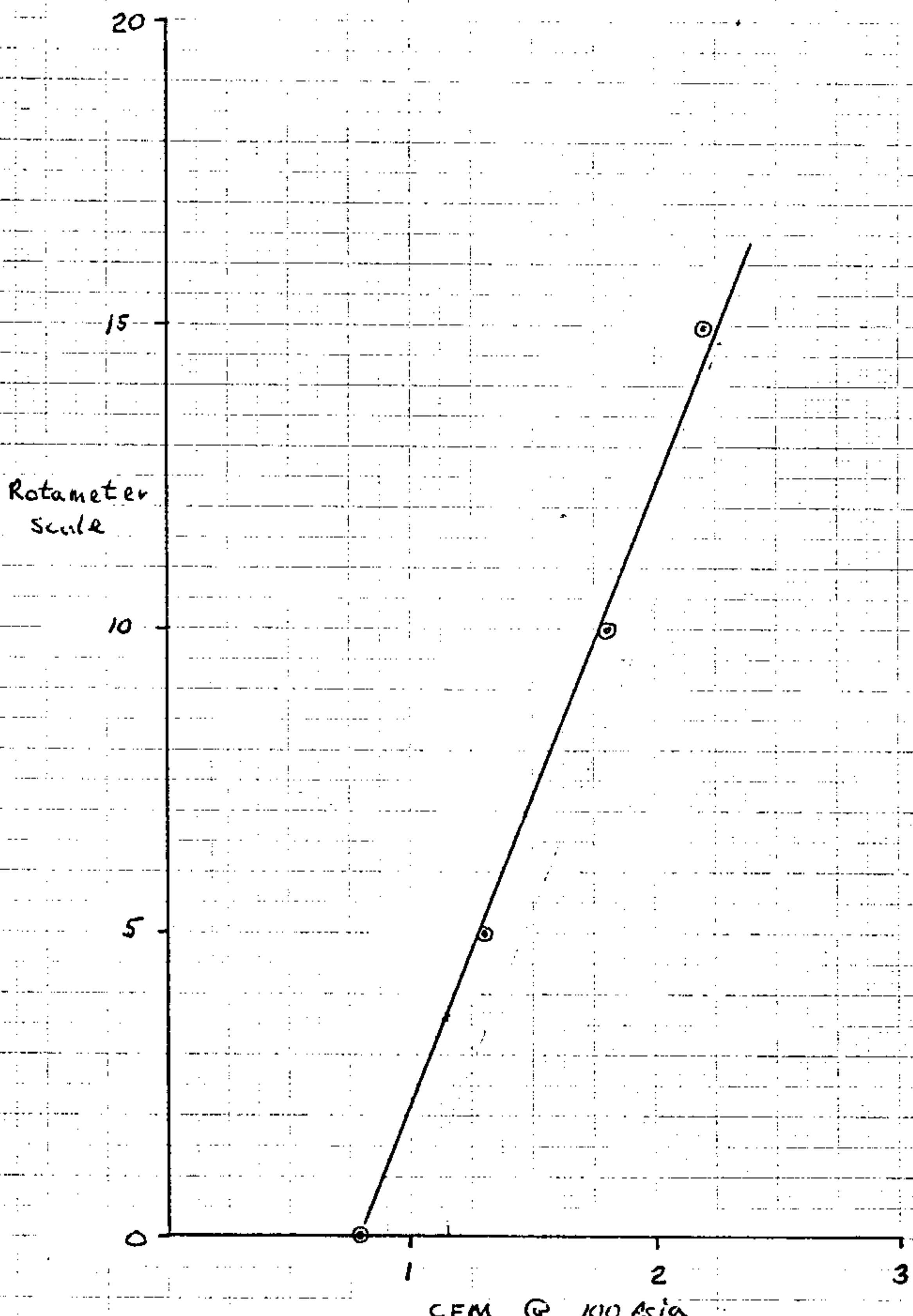
$He - O_2 - CO_2$
Nominal Gas Mix: 84-10-6
Actual Gas Mix: 10.01-6.30

Preg: 100

Wgt. Baralyme Before: 225g
Wgt. Baralyme After: 240.2

MIN	P	ΔP	T_1	T_2	T_3	T_4	T_5	T_6	Rot.	$\dot{V}$	IR-CO_2	%CO_2	
1	90	.25	77.2	72.1	108				1	.90			all blue
2	91	.25	76.7	69.9	127				1				
3	92	.25	77.2	70.0	111.8				1				
4	92	.25	77.4	70.2	104.2				1				
5	92	.25	77.8	70.4	100.0				1				
6	92	.25	78.0	70.6	95.7				1				
7	92	.25	78.2	70.6	93.4				1				
8	92	.25	78.0	70.6	92.1				1				
9	92	.25	78.0	70.5	90.3				1				
10	92	.25	78.0	70.4	89.2				1				
11	92	.25	77.8	70.3	88.7				1				
12	92	.25	77.7	70.2	87.8				1				
13	92	.25	77.3	70.0	87.2				1				
14													
15													

Rotameter Calibration $4.80\%\ CO_2$, $10.63\%\ O_2$ balance He
T = 75°F
P = 100 psia



1/10/80
TKF

BECKMAN

I. R. ANALYZER

CALIBRATION CURVE

Model 315

PO 296710

SO PI 27904

Customer University of California

Location Berkeley, California

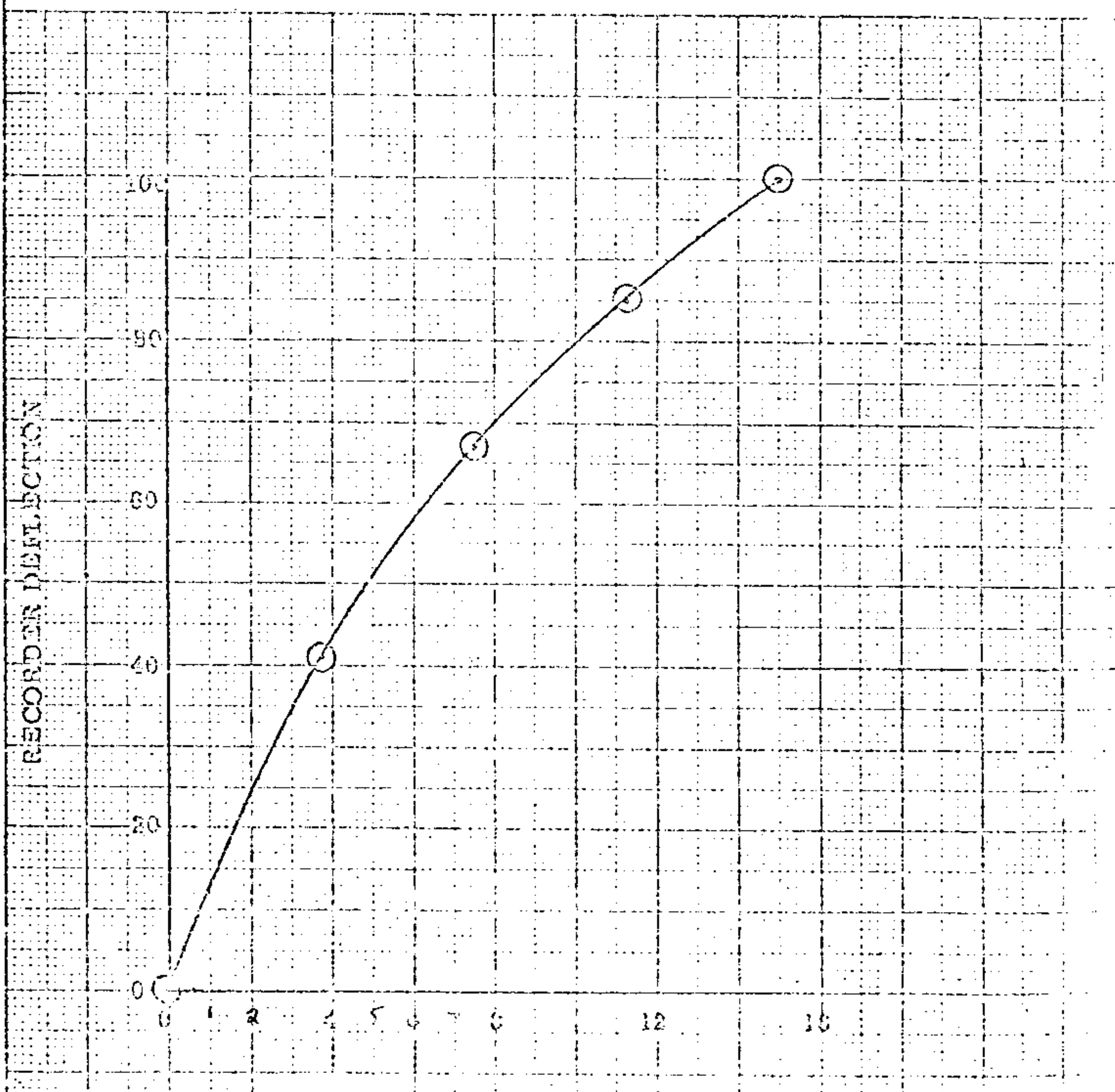
Application Carbon Dioxide Range 0-15% by volume

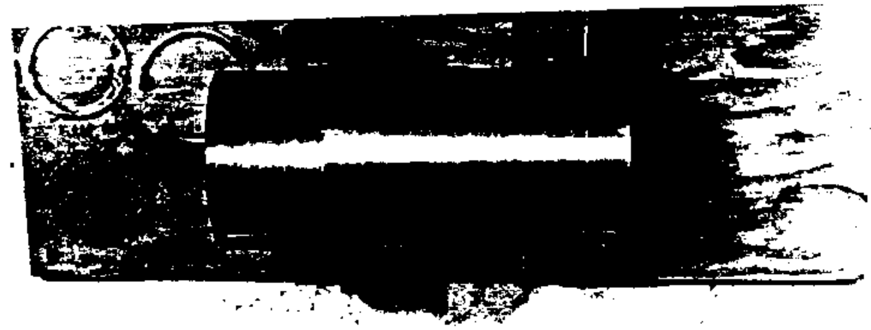
Amplifier No. 1000712 Pick-up No Detec. No. 5196 Tag

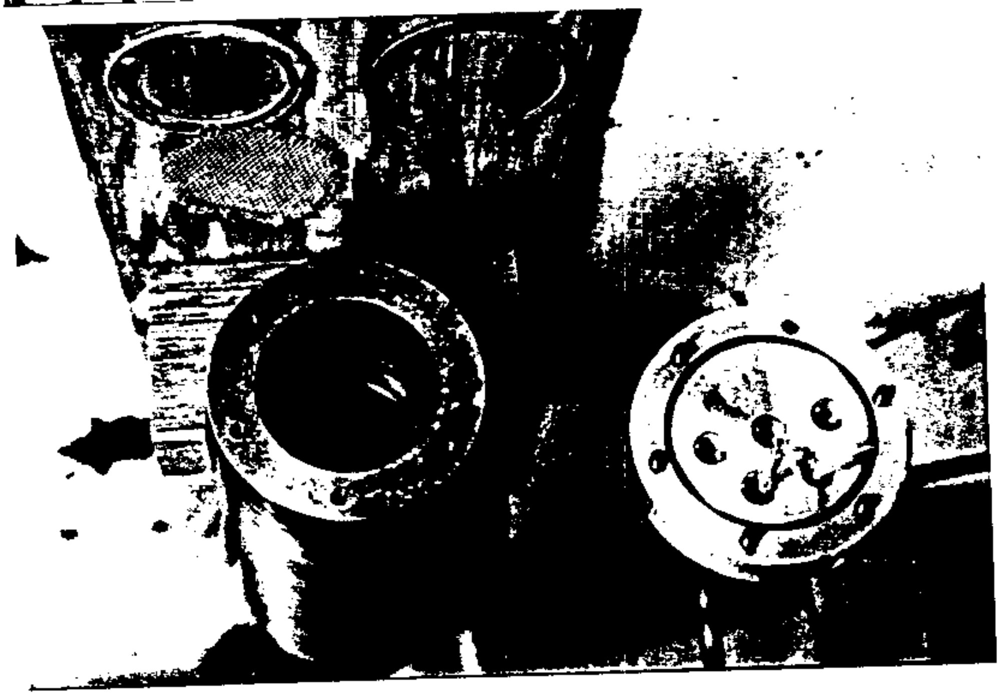
Zero Gas Nitrogen Calib. Press Atmospheric Cylinder No

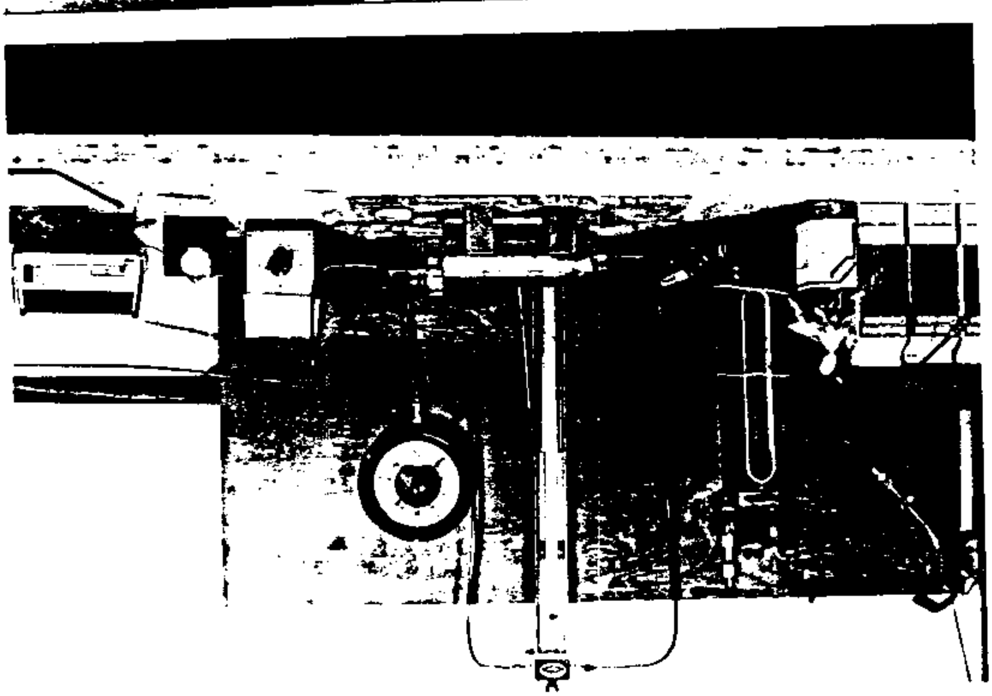
Upscale Gas See Manual Calib. Press Atmospheric Cylinder No

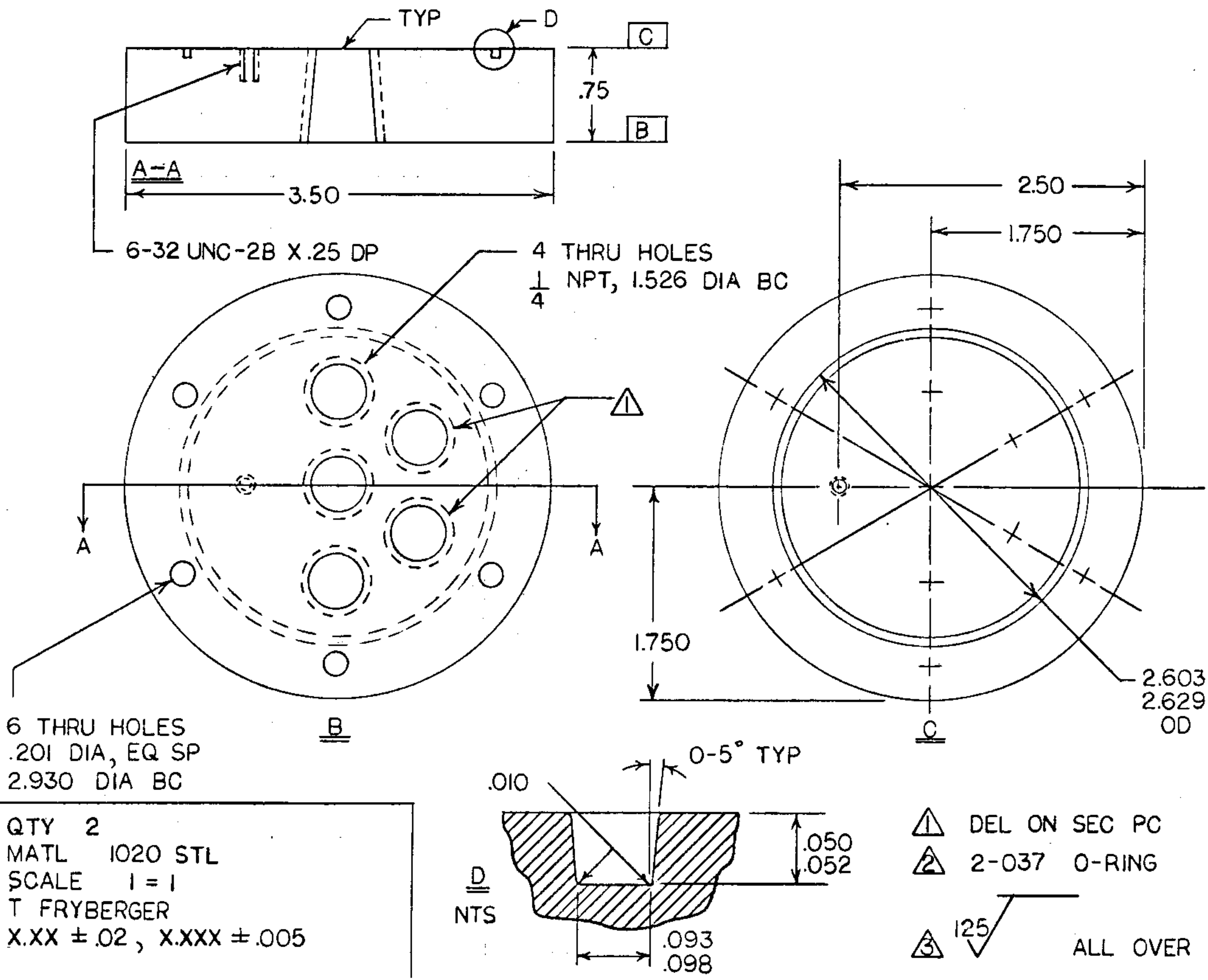
Stream Pressure Atmospheric





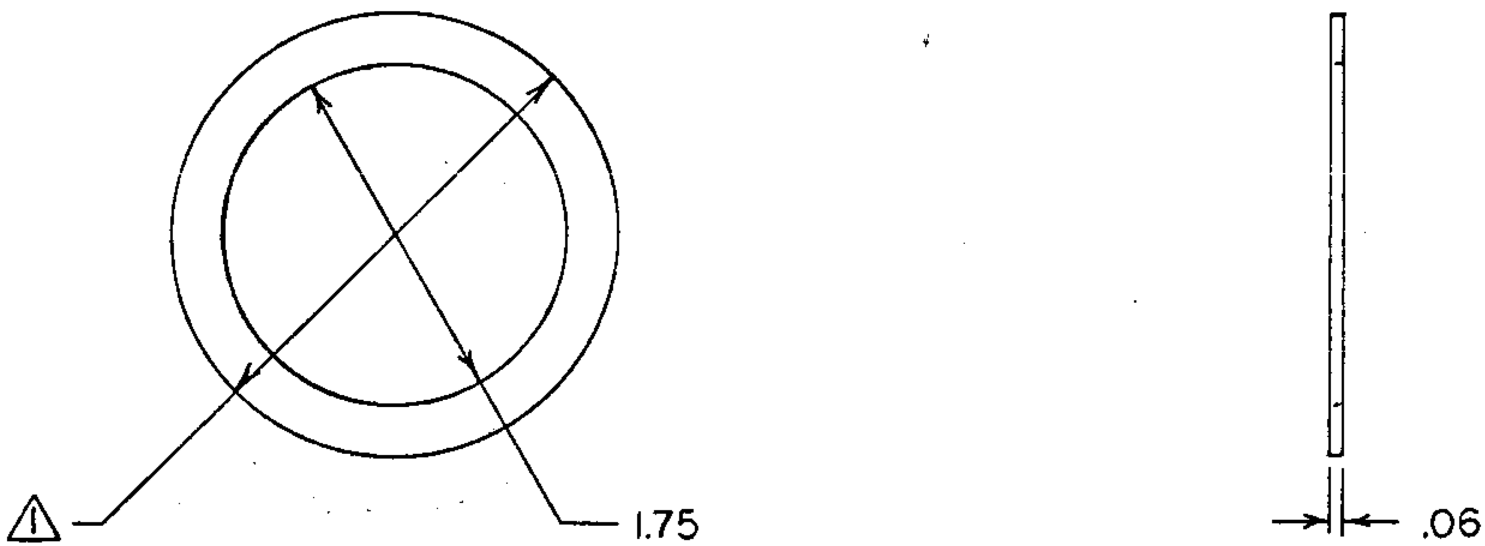






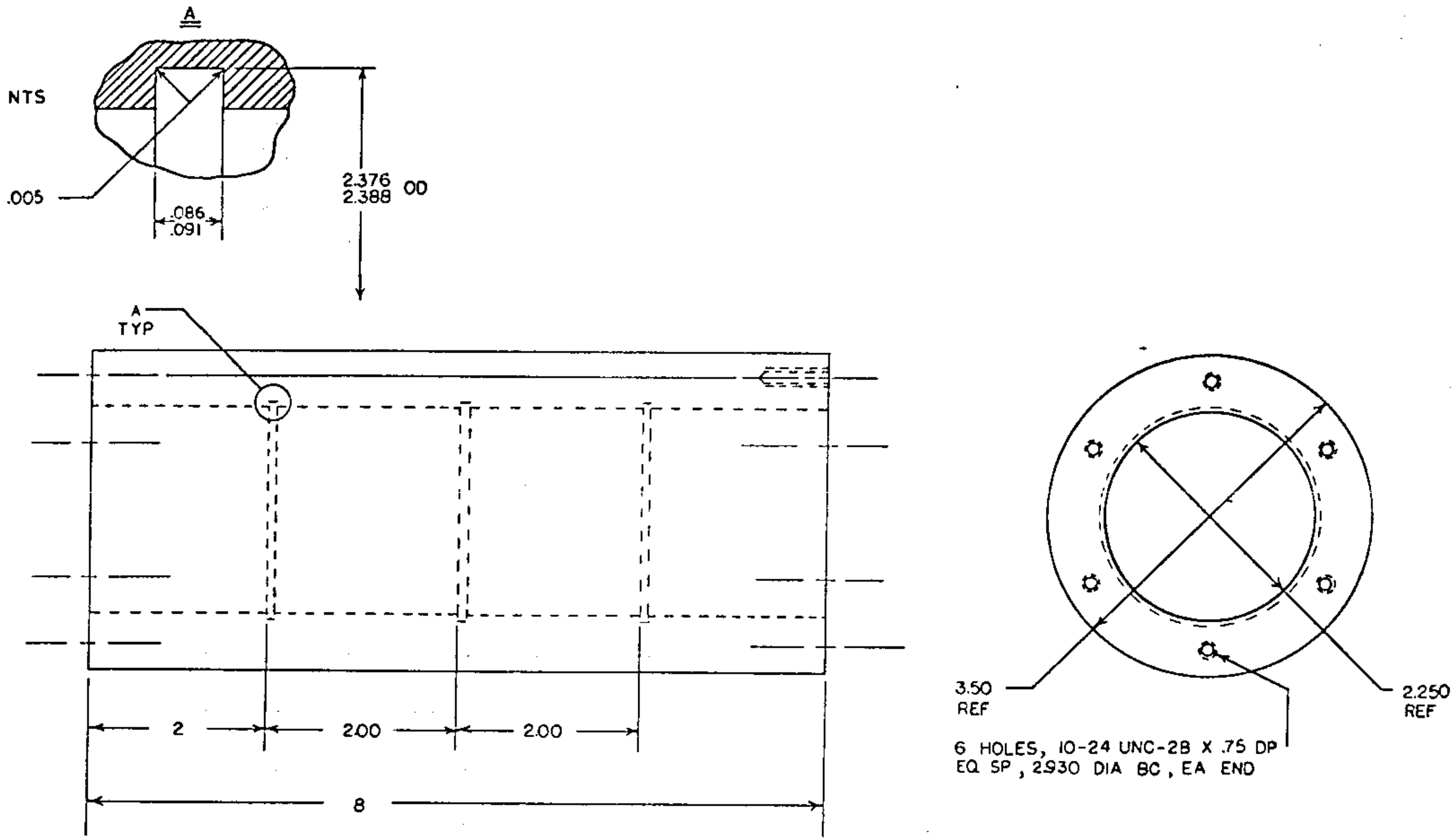
QTY 2
MATL 1020 STL
SCALE 1 = 1
T FRYBERGER
X.XX ± .02, X.XXX ± .005

△1 DEL ON SEC PC
△2 2-037 O-RING
△3 125 √ ALL OVER



1 .015 CL, 2250REF

QTY 3
MATL 1020 STL
SCALE 1 = 1
X.XX ± .02
T FRYBERGER

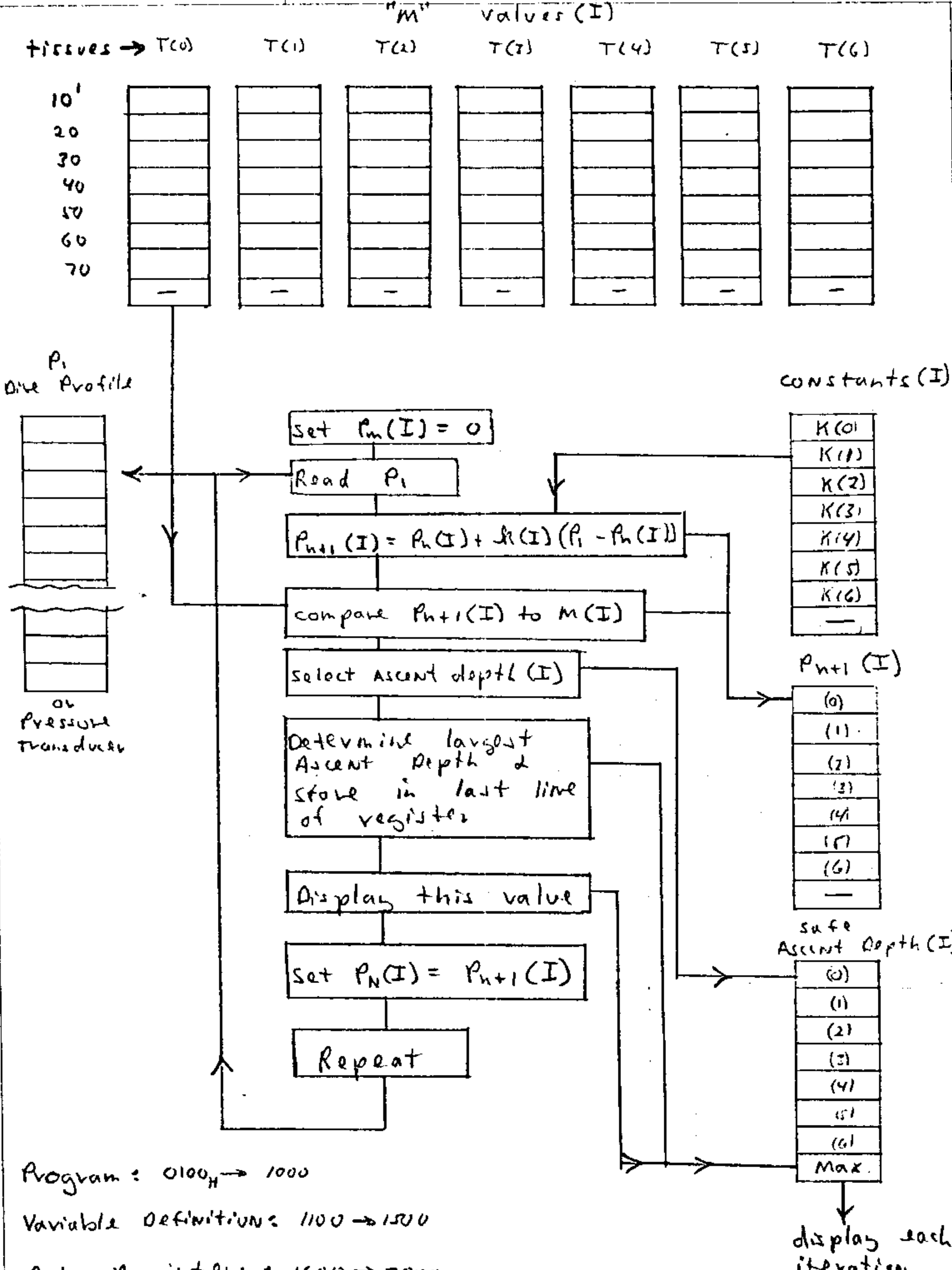


1. 125 ALL OVER
2. RING NO 3000-X225-SS2

QTY 1
MATL 1020 STL
SCALE 1 = 1
X ± .1, X.XX ± .02, X.XXX ± .005
T FRYBERGER

	#	% He	% O_2	% CO_2	$\dot{V}_{in}$ (ft^3/min)	P psia	$T_{upstream}$ °F	$\phi_{upstream}$ %	Residence Time s	ρ_{gas} @ depth lb/ft^3	$V_{required}$ @ depth ft^3	Weight used @ depth lb	$\Delta\rho_{tank}$ lb/ft^3	V_{tank} ft^3
	1	86	10	4	.25	104				.152	2.50	.38	2.70	.141
	2	"	"	"	.65	"				"	6.50	.99	"	.366
$\dot{V}$	3*	"	"	"	1.15	"				"	11.50	1.75	"	.647
	4	"	"	"	1.50	"				"	15.00	2.28	"	.844
	5	"	"	"	2.25	"				"	22.50	3.42	"	1.270
	6	93	3	"	1.15	"				.115	11.50	1.32	2.03	.650
	7	90	6	"	"	"				.131	"	1.51	2.32	"
pO_2	8*	86	10	"	"	"				.152	"	1.75	2.70	.647
	9	83	13	"	"	"				.168	"	1.94	2.98	.650
	10	80	16	"	"	"				.185	"	2.13	3.27	.650
	11	88	10	2	"	"				.142	"	1.63	2.51	.650
	12	87	"	3	"	"				.147	"	1.69	2.60	.649
pCO_2	13*	86	"	4	"	"				.152	"	1.75	2.70	.647
	14	85	"	5	"	"				.158	"	1.82	2.79	.650
	15	84	"	6	"	"				.163	"	1.87	2.89	.649

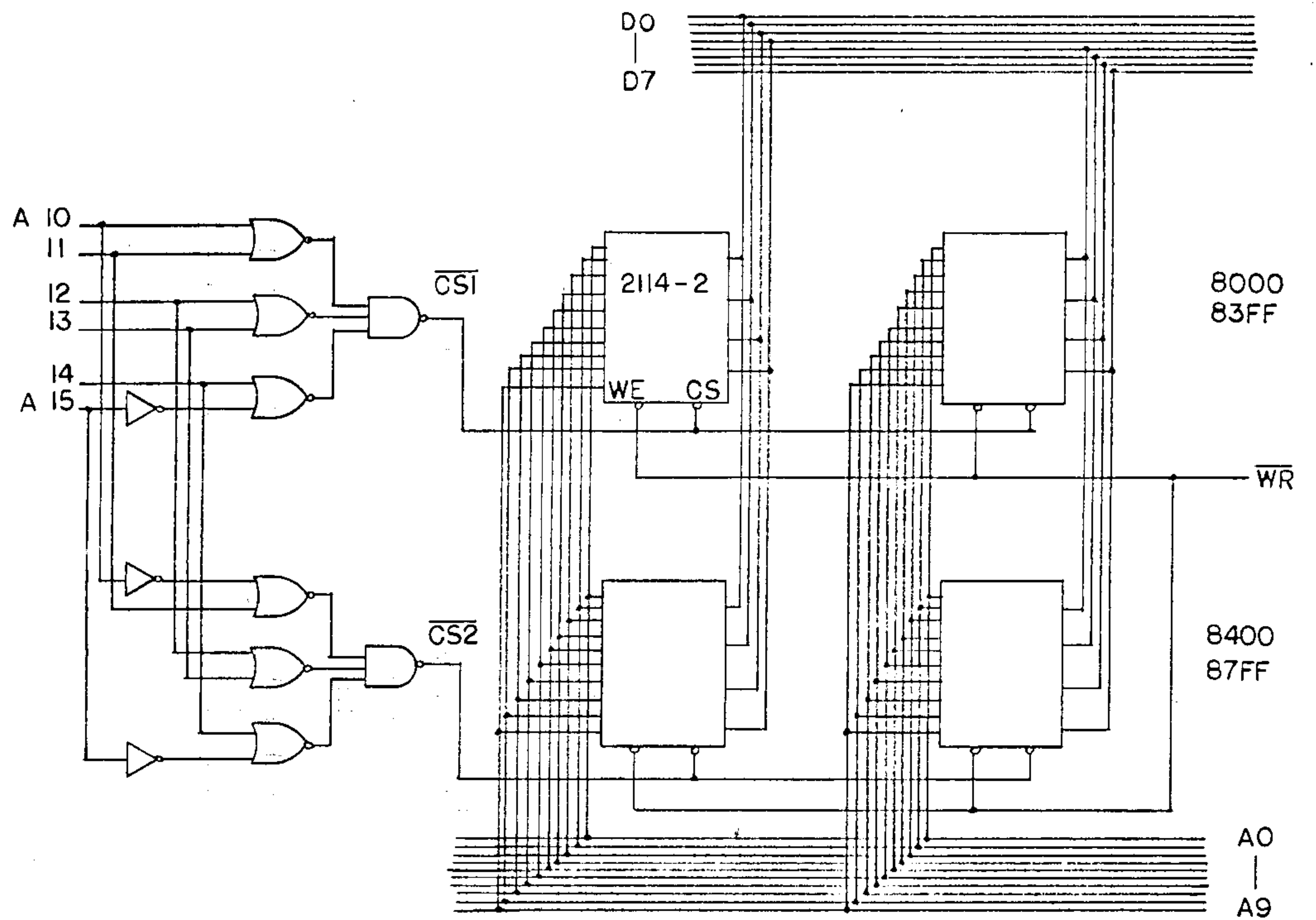
		V_{tank} SCF	
$\dot{V}$	1	21.25	
	2	55.25	
	3*	97.76	
	4	127.50	
	5	191.27	
pO_2	6	98.20	
	7	98.38	
	8*	97.76	
	9	98.17	
	10	98.22	
pCO_2	11	98.36	
	12	98.04	
	13*	97.76	
	14	98.23	
	15	97.95	



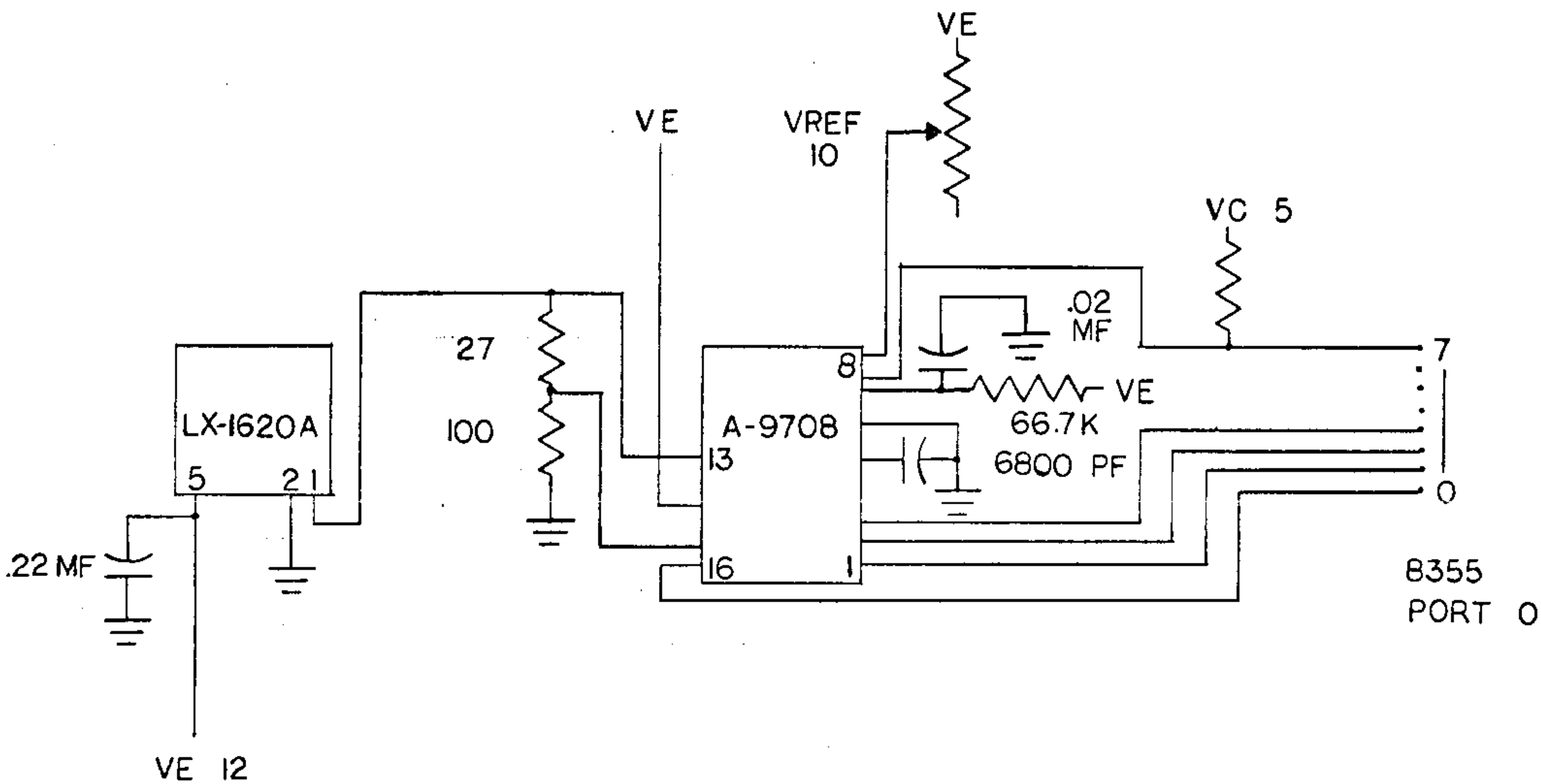
Program : $0100_H \rightarrow 1000$

Variable Definition : $1100 \rightarrow 1500$

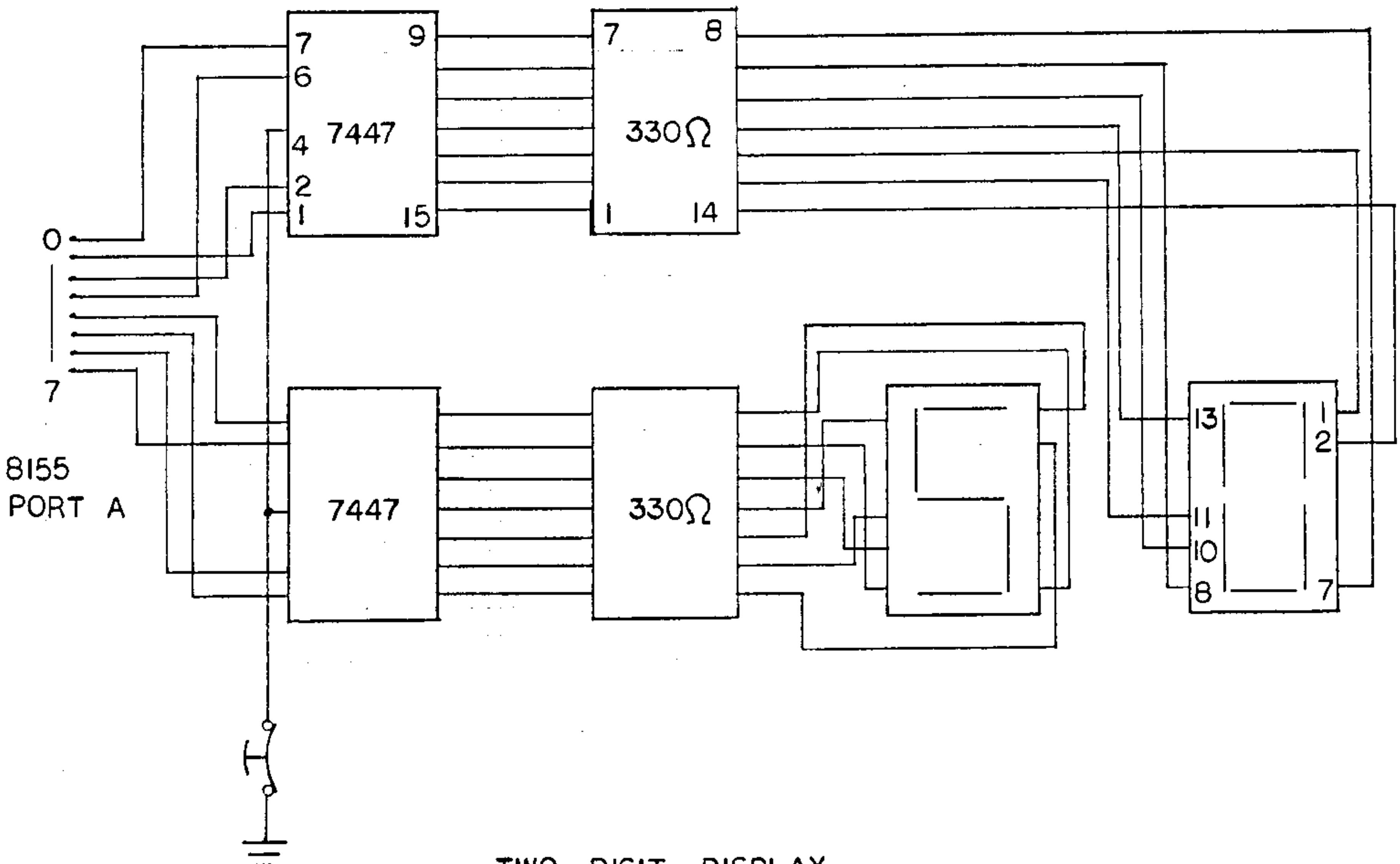
Data Registers : $1600 \rightarrow 2000$



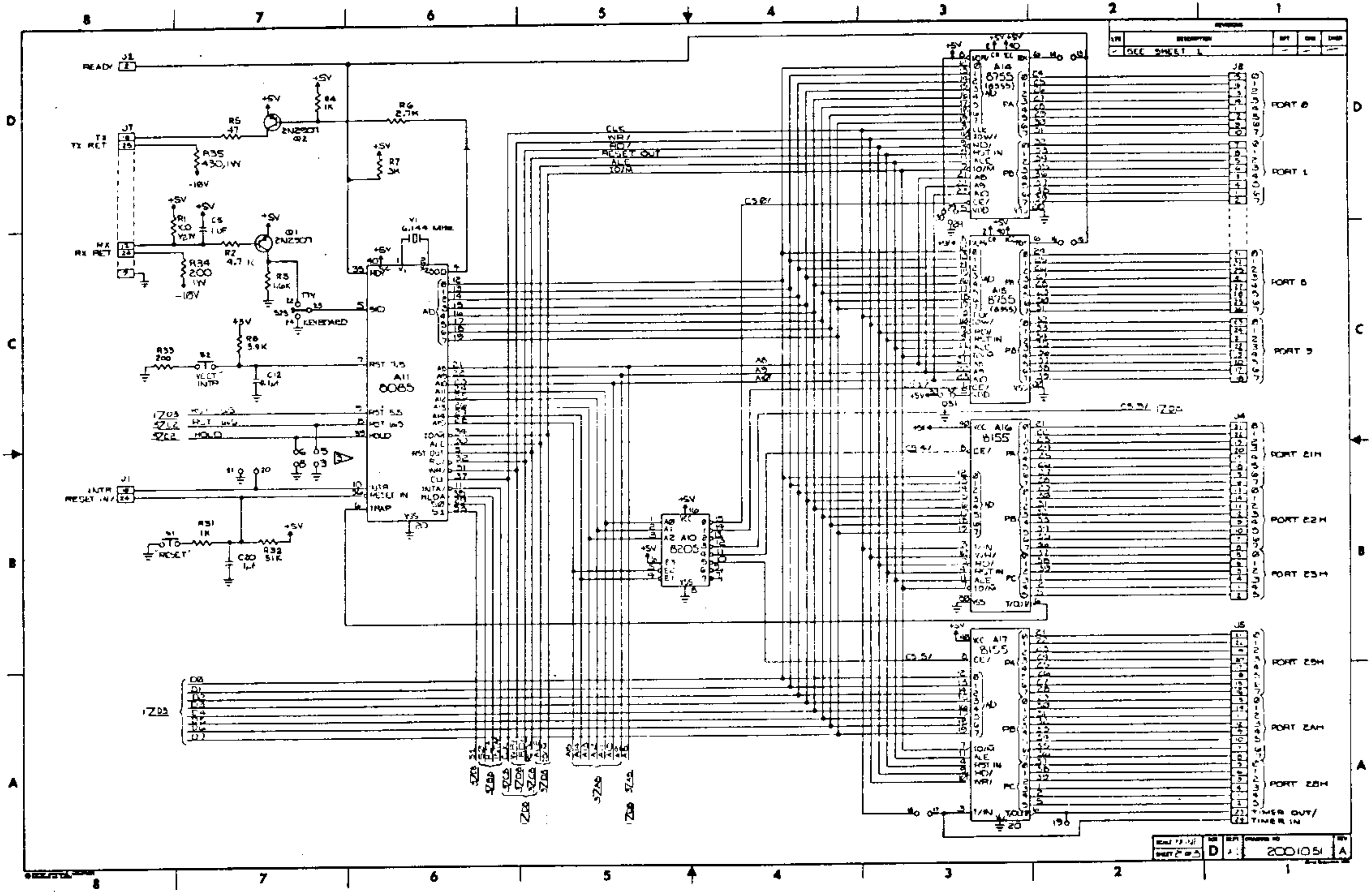
EXPANSION RAM 2K BYTES



PRESSURE TRANSDUCER AND A/D CONVERTER



TWO DIGIT DISPLAY



READY
TX RET
RX RET
R35 430,1W
R34 200 1W
R33 200
R31 1K
R32 51K
R6 2.7K
R7 3K
R8 3.9K
2N2907
Y1 6.144 MHz
A11 8085
A10 8205
A14 8755 (8355)
A15 8755 (8355)
A16 8155
A17 8155
CLK
WR/
RD/
RESET OUT
ALE
IO/M
CS 8/
CS 5/
CS 3/
VECT INTR
RESET
TTY
KEYBOARD
PORT 0
PORT 1
PORT 8
PORT 9
PORT 21H
PORT 22H
PORT 23H
PORT 25H
PORT 2AH
PORT 28H
TIMER OUT/
TIMER IN
SEE SHEET 1
2001051