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DISPOSAL OF

HYPERGOLIC PROPELLANTS

Final Report

Phase VI   Task 1

The Cryogenic Scrubber Prototype

August 1976

by

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prepared for

PREFACE

This study was conducted by Florida Institute of Technology under Contract NAS 10-8399, administered by the National Aeronautics and Space Administration, John F. Kennedy Space Center, Florida. The HASA Technical Representative for the contract was Mr. Harold H. Franks, DD-MDD, and the Alternate Technical Representative was Mr. Jimmy L. Dobson, DD-MDD. Florida Institute of Technology's study manager was Dr. Thomas E. Bowman, Mechanical Engineering Department.

THE CRYOGENIC SCRUBBER PROTOTYPE (CSP)

TABLE OF CONTENTS

1. <u>ABSTRACT</u>

A large part of the Phase VI effort has involved evaluation of a Cryogenic Scrubber Prototype (CSP) as a means of removing both Monomethylhydrazine (MMH) and Dinitrogen Tetroxide (NTO) from vent streams. This report concerns the concept, laboratory data, design, construction, experimentation and discussion involving the CSP as well as the final recommendations concerning its use in the Shuttle Program.

2. CONCEPT

The hypergols which will be utilized in the Shuttle Program are Monomethylhydrazine (MMH) and Dinitrogen Tetroxide (NTO). These materials must be removed from GHe and GN_2 vent streams at the pad, the HMF, and the OPF in order to prevent any possible health hazards and environmental pollution. Since the freezing points of these materials are considerably higher than those of the carrier gases, it was envisioned that cooling would cause condensation of the hypergols and facilitate their subsequent removal. Liquid nitrogen (LN_2) was proposed as the coolant since it is readily available at KSC and many workers are experienced in the necessary handling procedures. Also, because of its -198°C temperature, LN_2 should theoretically be able to condense out even relatively small concentrations of hypergol contaminants and thus the effluent discharges of GHe and GN_2 should theoretically approach undetectable limits.

3. LABORATORY DATA

Liquid Nitrogen (LN_2) traps were proposed, in the summer of 1975, to remove NO_2-N_2O_4 from GN_2 and GHe vent streams from the pad, the HMF, and the OPF facilities which will be constructed and utilized for the Shuttle Program. To investigate the feasibility of such systems, a laboratory model was constructed as shown in Figure 1. GHe was passed through latex rubber tubing, through a flow meter, and into a 3-necked, 500 ml. round bottom flask containing one drop (0.05 ml.) N_2O_4 at room temperature 23-25°C. From one of the necks, the NO_2 containing He stream was passed through an LN_2 trap and finally passed through rubber tubing into a water trap containing sulfanilic acid and N-(1-napthyl)-ethylenediamine to form a deep red color which was quantitated spectrophotometrically. (See Phase I-III, Final Report.)

Four complete experiments were run at different He flow rates: 30, 50, 75, and 100 cc/min. At 200 cc/min., plugging of the trap occurs. The results of these experiments are shown in Table 1. NO_2 determinations were conducted with and without the LN_2 trap inserted into the stream. The calculated surface area of those surfaces cooled by LN_2 and in contact with the NO_2 contaminated He stream is 144.6 sq. cm. When high concentrations of N_2O_4 in the 3-necked round bottom flask were used, the LN_2 trap would quickly plug with solidified N_2O_4 since most of the blue solid N_2O_4 is trapped inside the inner tube of the trap 1-2 cm. below the level of the LN_2. Very little was dispersed beyond this point. (see Figure 2.)

The effluent concentration assays were made by determining the amount of NO_2 contained in the water trap (Trap No. 2, Figure 1) that accumulated over an experimentally convenient period of time.

As can be seen, use of the LN_2 trap resulted in a drastic reduction of the NO_2 in the effluent He stream. Extrapolations to field conditions could not be made because the flow rates in this experiment were too low. However, LN_2 cooling at this point seemed to be an attractive method for removing NO_2 from the He vent streams. Although further experiments conducted with equipment designed to accomodate higher flow rates were deemed necessary before a final experimental judgement could be made.

On a theorectical basis, there are two very significant advantages of cryogenic trapping as compared to conventional scrubbing systems.

1. Cryogenic trapping avoids the problems associated with attempting to dissolve NO_2 in water while at the same time generating insoluble NO. This is the real limiting problem with conventional water scrubbers.

2. The vapor pressure of dissolved NO_2 inhibiting absorption of fresh NO_2 (Raoult's law) would not be applicable in the cryogenic system. This consideration would be even more important in the case of MMH vapor disposal.
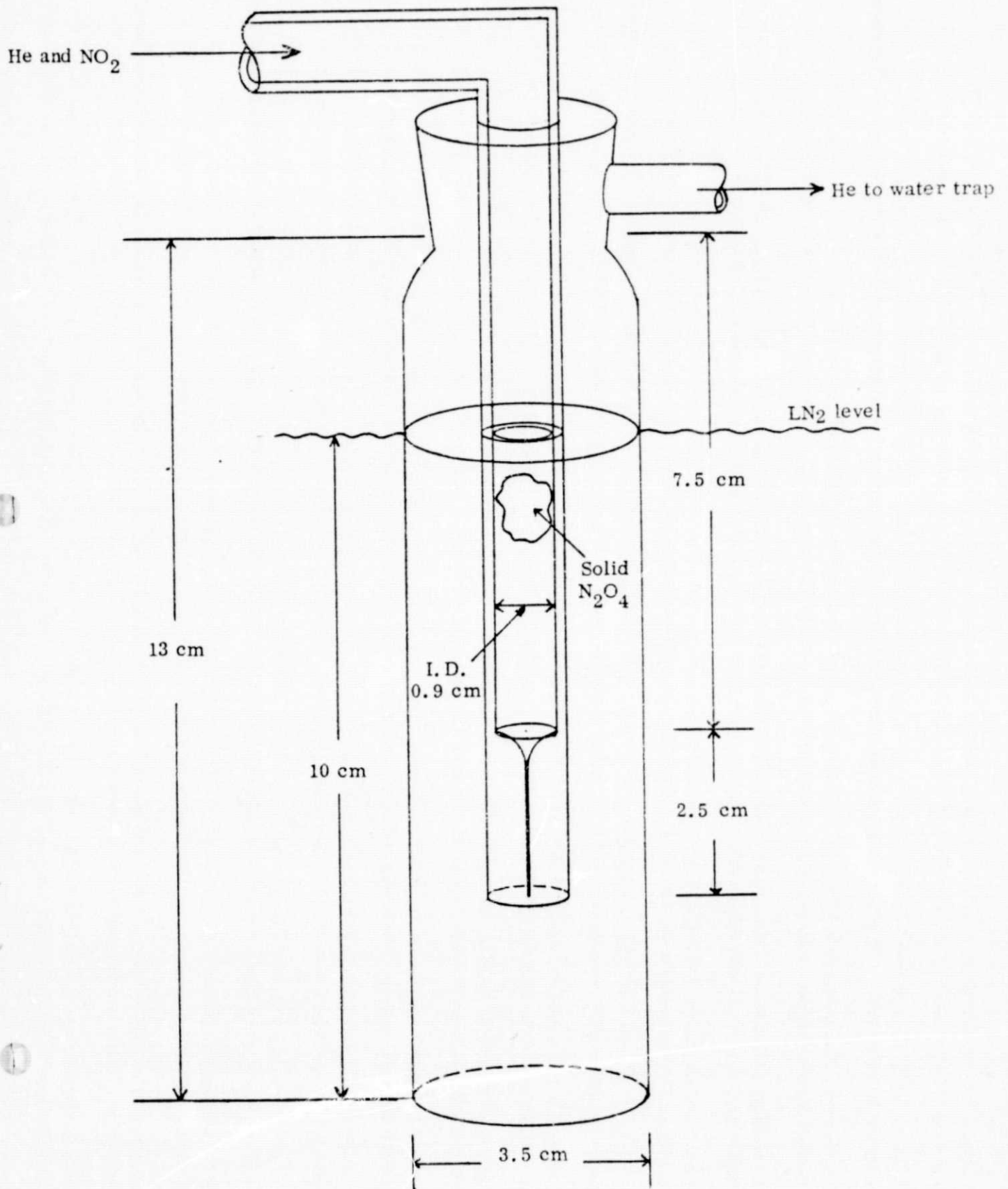
Figure 2. THE NO$_2$ TRAP IN LN$_2$

Figure 1. A LABORATORY MODEL FOR CRYOGENIC TRAPPING OF VENTED HELIUM STREAMS CONTAINING NITROGEN DIOXIDE
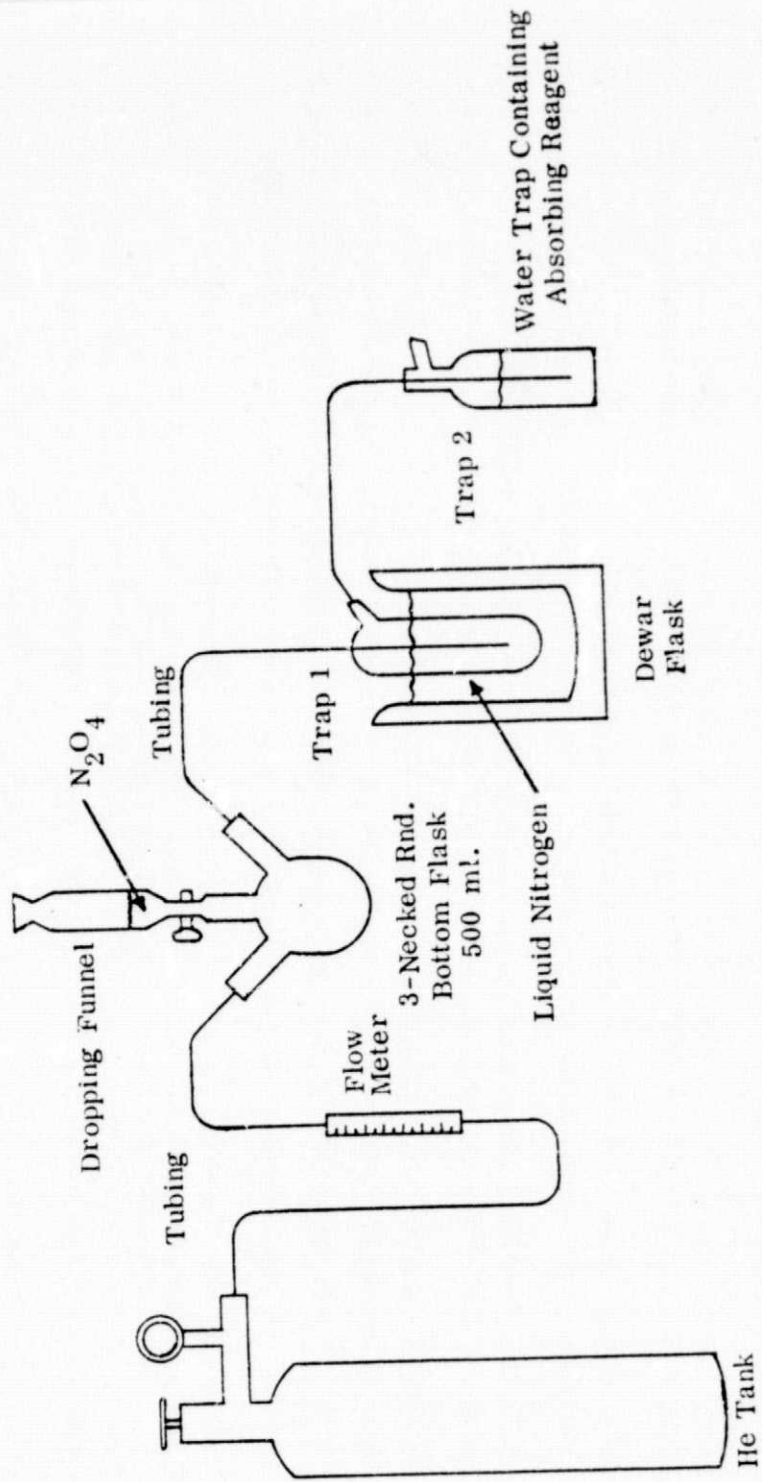
TABLE I - REMOVAL OF NO_2 FROM He VENT STREAMS

EXPERIMENT NUMBER	CONDITIONS	RATE He FLOW (cc/min., CF/min.) x 10^{-3}	EFFLUENT NO_2 CONCENTRATIONS (ul NO_2/1000 cc He gas)	TIME OF FLOW (Minutes)
1.	LN Trap	30, 1.06	26.3	33.3
	No LN_2 Trap	30, 1.06	42,300.	33.3
2.	LN_2 Trap	50, 1.77	61.0	20.0
	No LN_2 Trap	50, 1.77	42,300.	20.0
3.	LN Trap	75, 2.65	2.82	13.3
	No LN_2 Trap	75, 2.65	210,000.	13.3
4.	LN_2 Trap	100, 3.53	1.98	10.0
	No LN_2 Trap	100, 3.53	86,630.	10.0

4. DESIGN

In view of the apparently successful laboratory results, a Cryogenic Scrubber Prototype (CSP) was constructed. This unit was designed by E. Spearman P.E., of Canoga Park, California. The basic design of the CSP is illustrated in Figure 3. As is seen, the hypergol laden GN_2 stream enters at the top and passes over 40-1/2 inch coils containing either LN_2 or cold GN_2. The GN_2 stream exits from the bottom through a tube passing up through the center of the coils. The surface area of the coils is 40 sq. ft. There are substantial differences between CSP design and the laboratory design described earlier. First, there is no surrounding annulus containing LN_2 on the CSP. This feature would be analagous to the LN_2 containing dewar which was used in the laboratory. Lack of this design feature allows the outside walls to remain relatively warm although the inside coils become extremely cold. Secondly, there is no substantial baffling between the inlet port and the exit port of the CSP. Thirdly, the cold surfaces in the CSP are stainless steel whereas those in the laboratory model are glass.

The CSP was designed to handle a flow rate of 20 SCFM and thus the ratio of SCFM to cold surface area is:

$$\frac{20 \text{ SCFM}}{40 \text{ sq. ft.}} = 1/2$$

The laboratory model performed satisfactorily with the following ratios of flow rate to area:
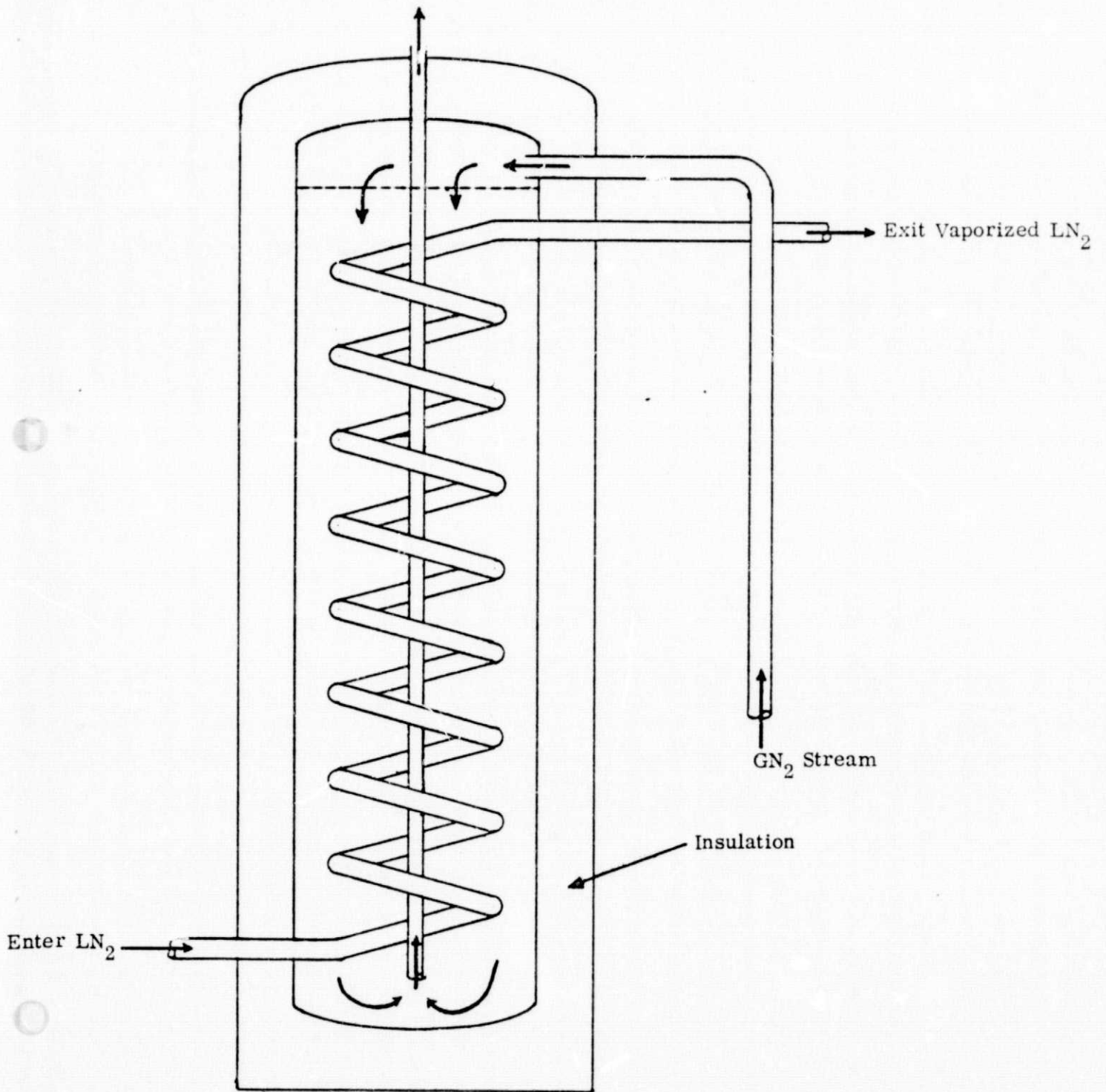
$$\frac{100 \text{ cc/min.}}{144 \text{ sq. cm.}} = \frac{1}{1.44}$$

$$\frac{74 \text{ cc/min.}}{144 \text{ sq. cm.}} = \frac{1}{1.92}$$

$$\frac{50 \text{ cc/min.}}{144 \text{ sq. cm.}} = \frac{1}{2.88}$$

$$\frac{30 \text{ cc/min.}}{144 \text{ sq. cm.}} = \frac{1}{4.80}$$

Figure 3: Design of the CSP

Exit Vaporized LN_2

GN_2 Stream

Insulation

Enter LN_2

Hence, it is seen that the laboratory model and the CSP have comparable ratios of flow rate to cold surface. Other calculations may be useful for design comparison. These include ratios of cold surface (in contact with LN_2) to relatively warm surfaces which are dependent on heat transfer through gases. In the laboratory model the ratio of cold surface area to warm surface area is 2.58 to 1. For the CSP the ratio is 40 sq. ft. to 37.4 sq. ft. or 1.07 to 1. Thus the laboratory ratio was approximately two and one-half times more favorable than the CSP. This situation may be one reason for the large difference in scrubbing efficiency between the laboratory model and the CSP.

Midway through the experimentation program, it was decided that filling the void volumes of the CSP might prove advantageous in increasing the efficiency of hypergol removal from the GN_2 stream. Although it was decided that stainless steel filler of some sort - nuts, bolts, fittings, etc. would be the ideal material, such material could not be found. Instead the CSP was filled to within 6" of the top with small 1" $CaCO_3$ stones. This design modification however, did not increase hypergol removal efficiency.

5. CONSTRUCTION

The CSP was fabricated by Cryogenic Experts Inc., CEXI of Canoga Park, California under the direction of Eugene Spearman, P.E., FIT Consultant. The basic element, a heat exchanger, was obtained from Rocketdyne and is numbered 303393.

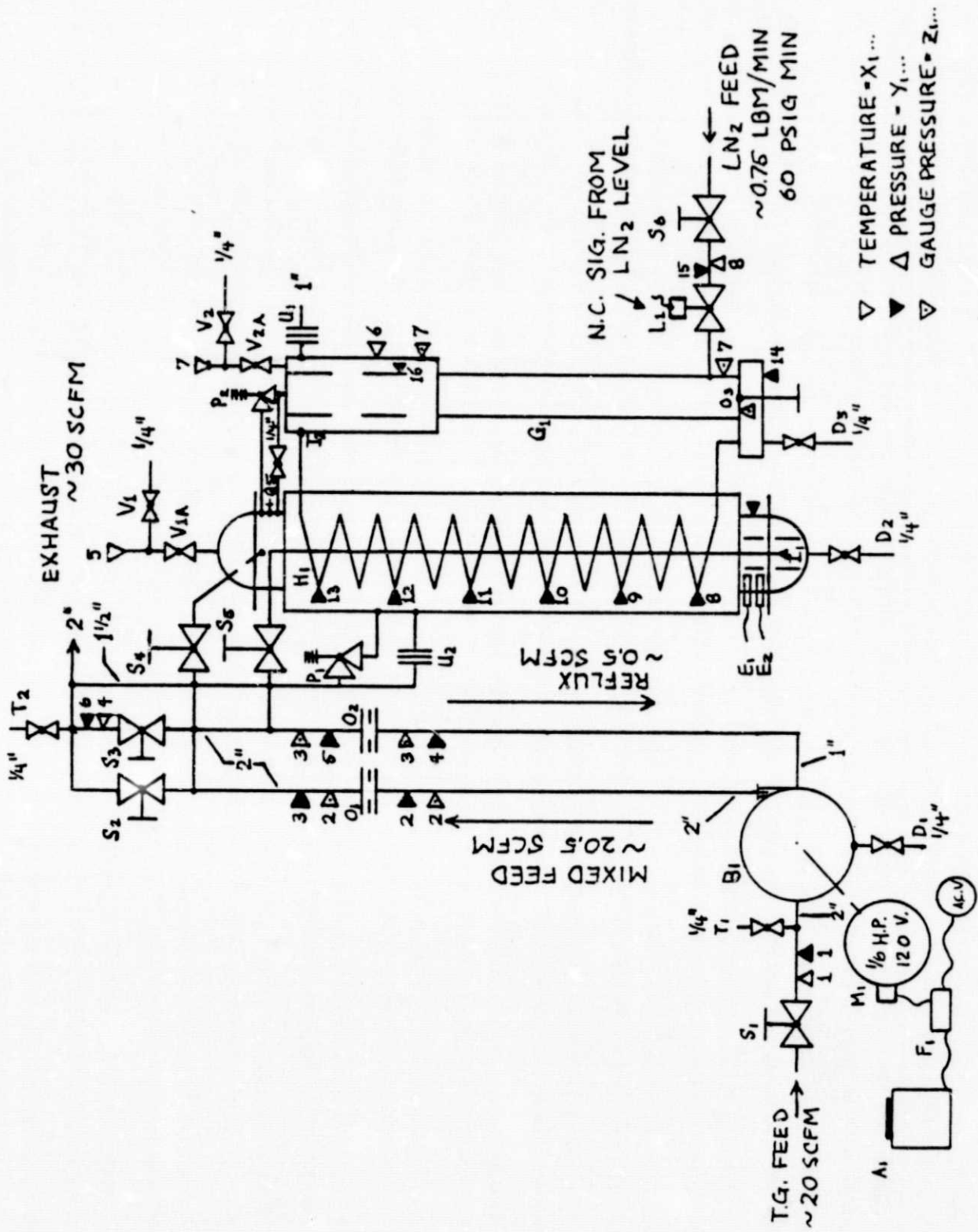Diagrams and photographs of the scrubber are shown in the following figures.

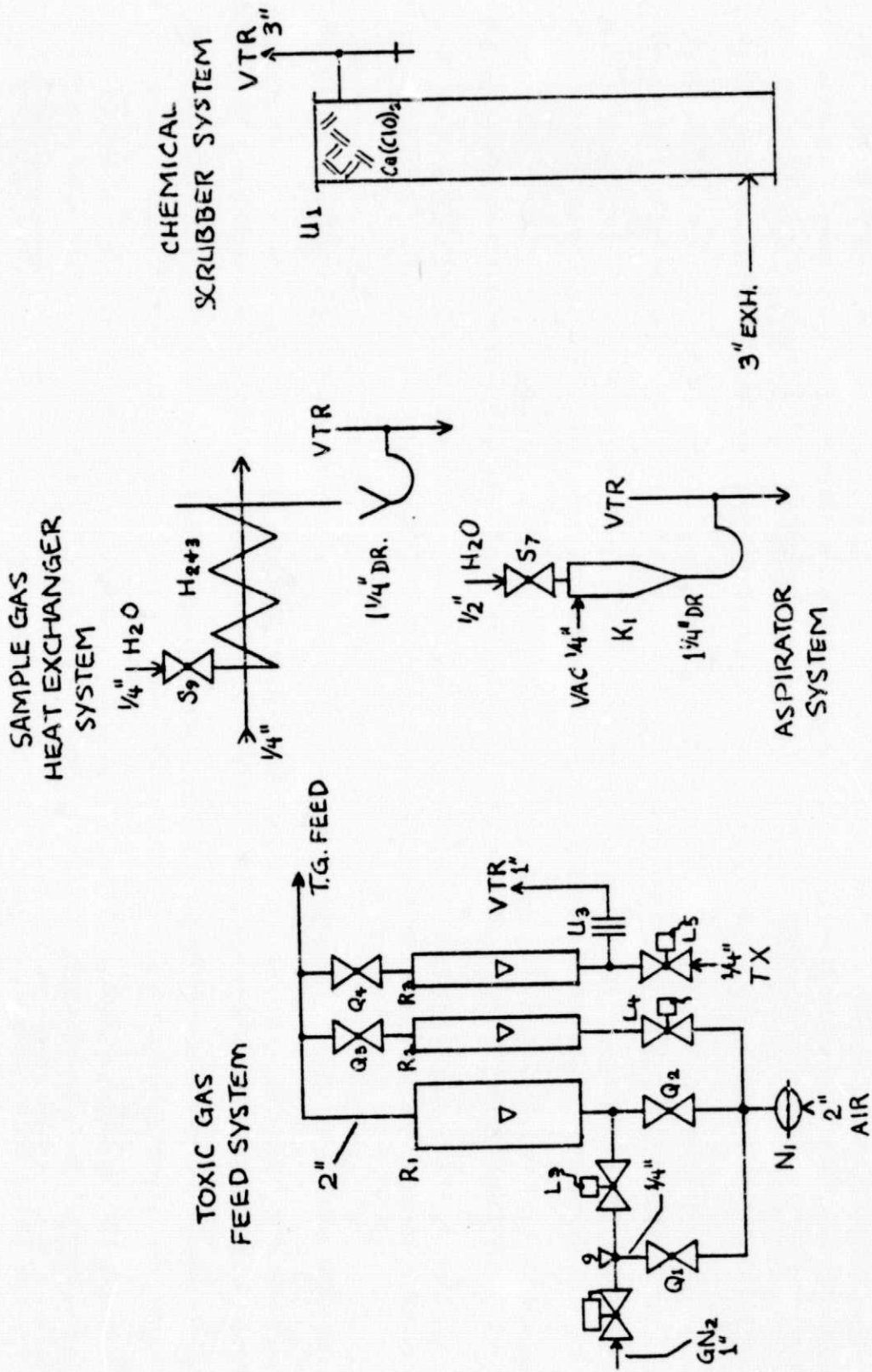Figure 4A: FLOW DIAGRAM, CRYOGENIC SCRUBBER

Figure 4B: FLOW DIAGRAM OF CRYOGENIC SCRUBBER ACCESSORY SYSTEMS

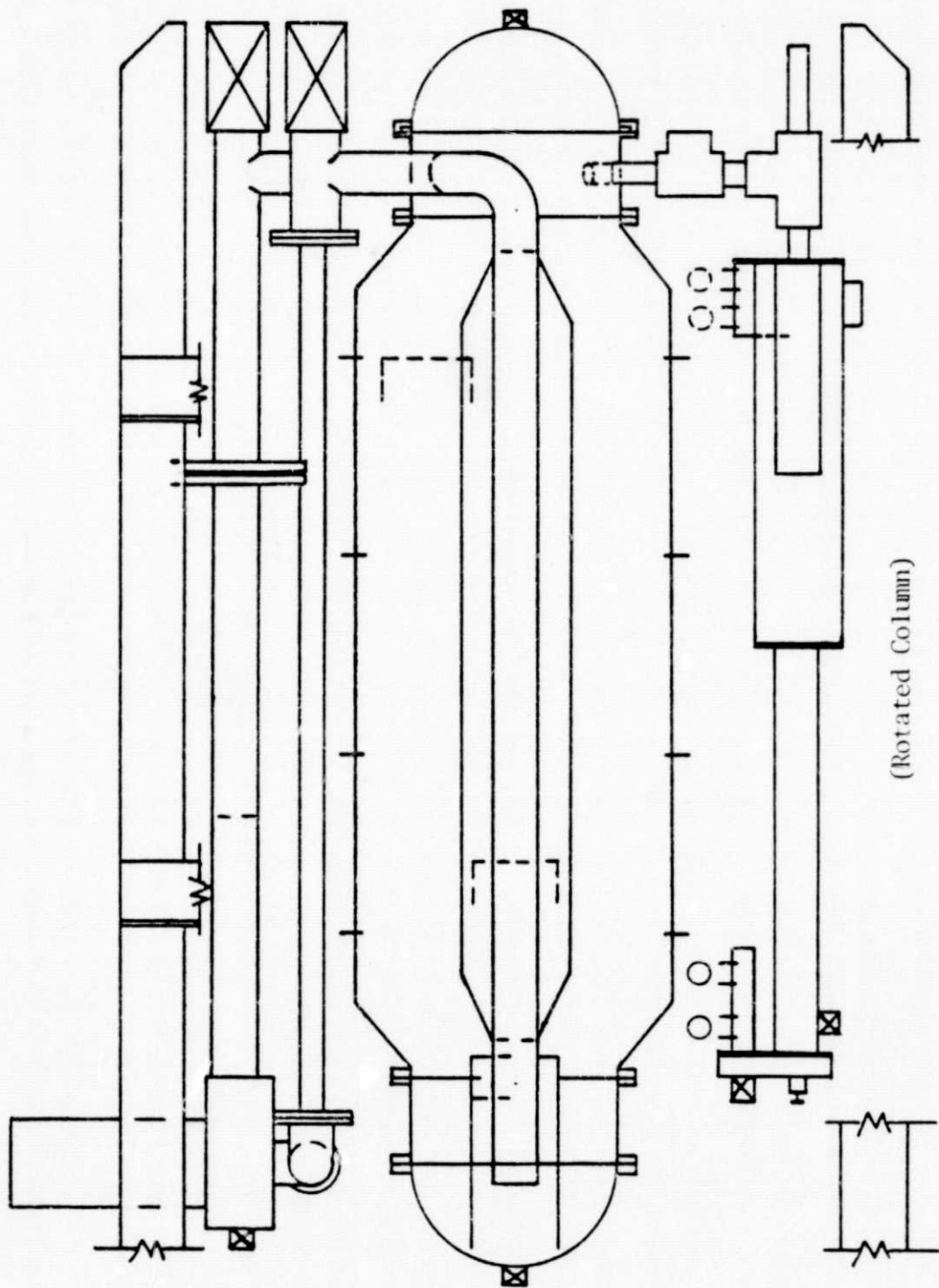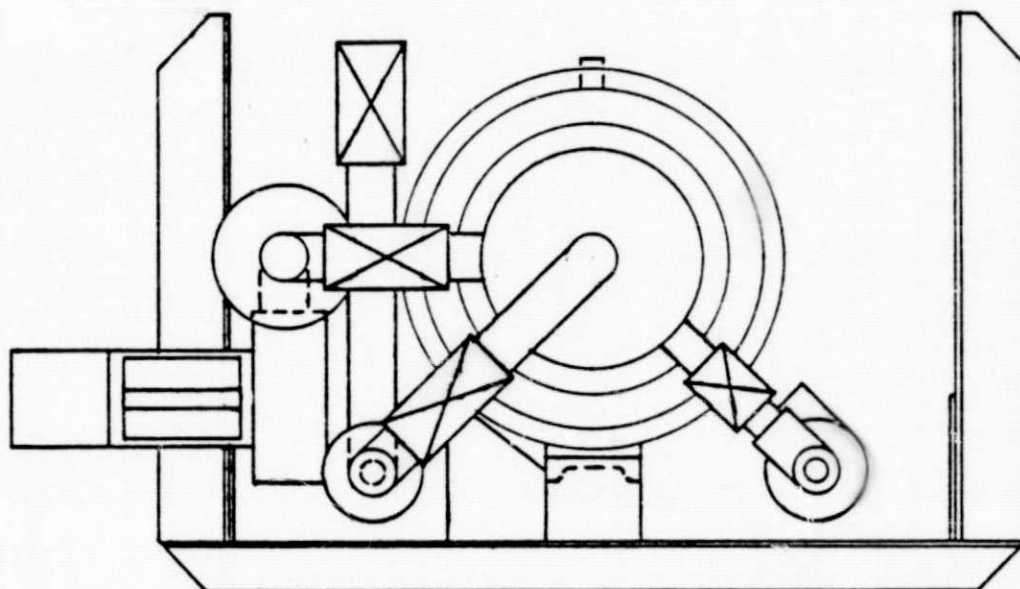Figure 5a.   PROTOTYPE SCRUBBER LAYOUT, FRONT VIEW (1/8 scale)
Per G. Spearman, P.E.

(Rotated Column)

Figure 5b.   PROTOTYPE SCRUBBER LAYOUT, TOP VIEW (1/8 scale)
Per G. Spearman, P.E.

A_1 Transformer, Variable Superior, Series 21 — 0-140 VAC, 4.5A., 1-ϕ, 60n, 16 lbs. open type

B_1 Blower, Mill type, 1/3 HP, Cadillac, Model F-10 — 95 CFM 18'WC.120V.3A, 60n, 12 lbs., plus modif.

C_1 Control Valve (if required)

D_1 Drain Valve ¼" NPT Mark Whitey IGM 4 316 SS Toggle

D_2 Drain Valve ¼" NPT Mark Whitey IGM4 316 SS Toggle

D_3 Drain Valve ¼" NPT Mrk Whitey I GM 4 316 SS Toggle

E_1 & E_2 Cartridge Heater 375W Chromolox — 120 Vac, 3.1A., 1-ϕ, 1000°F. 347 St. Stl.

F_1 Fusetron Dual Element & Base Buxx T-4 — 250 Vac., 4A., 1-ϕ

G_1 LN$_2$ Column - see detail Fab. by CFX1

H_1 LN$_2$ Heat Exchanger - Rocketdyne H-1 GG/LOX

H_2 Sample Gas Heat Exchanger ¼" 321 SS Tube in H$_2$O shell

H_3 Sample Gas Heat Exchanger ¼" 321 SS Tube in H$_2$O shell

I_1 Inertial Separator - see detail - Fab. by CFX1

I_2 Inertial Separator - see Detail - Fab, bt CFX1

J_1 EXH. Gas Scrubber - see Detail - Fab. by FIT

K_1 Test Gas Aspirator - from FIT

L_1 LN$_2$ Sol. Valve ¼" NPT, 120 Vac. N.C. Atromatic, 316 SS, BDGS3008G Cr=0.72

L_2 GN$_2$ Sol. Valve ½" NPT, 120 Vac. N.C. Atromatic, Bronze, AAD 3200 Cr = 0.72

L_3 GN$_2$ Sol. Valve 1/8" NPT, 120 Va. N.C. Atromatic 316 SS, SBTD 1002, CR=.093

L_4 Toxic Gas Sol. Valve 1/8" NPT Atromatic 316 SS, GBTD 1002, CR=.093

M_1	Blower Motor (see B_1 above)
N_1	Air Filter 3/8" SAE Flare 0.3u D.O.P. MSA 78606 with 95302 Element
O_1	Mixed Feed Flow Orifice 3/4" Bno.45 316 SS x 0.50" Plate - CEX1
O_2	Reflux Flow Orifice 1/8" Bno.15 316 SS x 0.50 Plate - CDX1
O_3	LN_2 RGSTR. FLOW Orifice - 5/32" DIA See detail - Fab by CEX1
P_1	Back Pressure Relief Valve 3/4" x 1" NPT.F. Sage Model 433413 50 PSIG Back Pressure, $0.015\frac{-2}{IN}$
P_2	Pressure Safety Relief Valve 3/4" x 1" NPT, F. Sage Model 433413 30 PSIG Back Pressure, $0.015\frac{-2}{IN}$
Q_1	GN_2 Trim Control Valve ½"
Q_2	Air Trim Control Valve ½"
Q_3	GN_2 Mixing Flow Valve ¼" - 316 SS
Q_4	Toxic Gas Mixing Flow Valve ¼" - 316 SS
Q_5	GN_2 Reflux Flow Valve ¼" AN $\quad\quad\quad\quad C_V=0.019.$ NUPRO SS-4BMW
R_1	Make VP Gas Flow Meter, 2" - 44SCFM @ 9" W.C. Fischer & Porter 10 A 3500 Brass Low△P.
R_2	Diluent Gas Flow Meter, 1.3 5o 23,000 cc/min.set Century Triflat, Fischer & Porter # 80A451
R_3	Toxic Gas Flow Meter, 1.3 to 23,000 cc/min. set Century Triflat, Fischer & Porter #80A451
S_1	Toxic Gas Feed Throttle Valve 2" - 316 SS
S_2	Heat Exchanger Bypass Valve 2" - 316 SS
S_3	Exhaust Gas Blocking Valve 2" - 316 SS
S_4	Heat Exch. Isolation Supply Valve 2" - 316 SS
S_5	Heat Exch. Isolation Exh. Valve 2" - 316 SS

T_1	Toxic Gas Feed Sample Valve ¼" NPT Mark Whitey IGM4 316 SS Toggle	
T_2	Toxic Gas Exh. Sample Valve ¼" NPT Mark Whitey IGM4 316 SS Toggle	
U_1	Rupture Disk 1" Aluminum - BS&B BV1" 60 PSIG Ambient	
U_2	Rupture Disk 1½" TFE/Halon - BS&B DV 1½" 40 PSIG Ambient	
U_3	Rupture Disk 1" TFE/Halon, BS &B DV 1" 50 PSIG Ambient	
V_1	Vent Valve ½" N.P.T., Mark Nupro 316-4P-4M	C_V=0.043, 1/16" Port
V_2	Vent Valve ¼" N.P.T., Mark Nupro 316-4P-4M	C_V=0.043, 1/16" Port
V_3	Vent Valve ¼" N.P.T., Mark Nupro 316-4P-4M	C_V=0.043, 1/16" Port

SEALANT - Silastic - Gen. Elec. $108

INSULATION - Polyurethane "INSTAFOAM" - ½ Cu. Ft. Spray Cans

BIGHAM INSULATION (Bob Bryant) (305) 522-2887
P.O. Box 22146
Fort Lauderdale, Florida 33315

TEMPERATURE PROBES   (D = Probe immersion, inches)

X_1 - Toxic gas feed, ± 50°C Base, 1" D, Model 78 H 09, CAL A-C (TYP) with ¼" NPT. Comp. fitting (TYP).

X_2 - Mixed Feed, - 200°C Base, 1" D.

X_3 - Mixed Feed, ± 50°C Base, 1" D.

X_4 - Reflux, -200°C Base, ½" D.

X_5 - Reflux, ± 50°C Base, ½" D.

X_6 - EXN.1, -200°C Base, 1" D.

X_7 - Exch. Sump, -200°C, 3" D.

X_8 - Exch. Coil, -200°C, Base, 2½" D (200 r @ 0°C)

X_9 -   "   "   "   "   "   "

X_{10} - "   "   "   "   "   "

X_{11} - "   "   "   "   "   "

X_{12} - "   "   "   "   "   "

X_{13} - "   "   "   "   "   "

X_{14} - LN$_2$ sump, -200°C Base, ½" D.

X_{15} - LN$_2$ Feed, -200°C Base, ½" D (may use T.C.)

X_{16} - GN$_2$ Exh., -200°C Base, 3" D.

CEXI - F.I.T. FURNISH

Rosemount series 78, Platinum resistance, 316 SS Capsule sensor, Comp. Loop lead wires with Model 442 A Alpha line temperature transmitter: RTD to 4-20 mA outputs.

13 x MTRS - 442 A RG A 200C M200 NIN

x x MTRS - 442 A RG A 200C M50 NIN

DELTA PRESSURE PROBES   (D = Nom. mid range, inch)

$\frac{1}{2}$ - Mixed Feed Flow - Model 1151 DP 3 A 22 5 M (TYP) with 2-$\frac{1}{4}$" NPT 2 1/8" D.C. (TYP)

    D = 2$\frac{1}{2}$" @ AMB. Temp.

    B $\sim$ 0.45 on 2" DIA. (0_1)

1/3 - Reflux Flow

    D = 2$\frac{1}{2}$" @ AMB. Temp.

    B $\sim$ 0.15 on 1" DIAM. (0_2)

1/7 - LN_2 Level - Model 1151 DP 3 A 22 LM with 2-$\frac{1}{4}$" NPT 2 1/8" D.C.

    D = 15" @ LN_2 Temp. Orifice DM 3/32" (0_3)
    (Furnish ADV. Sol. V_{alve} sig.)

3 - Rosemount Model 1151DP Alphal line pressure XMTDS.

GAGE PRESSURE PROBES   (D = Nom mid range, as noted)

Z_1 - Toxic Gas Feed $\frac{1}{4}$" NPT, 0-10" V.W.C. Vert. Manometer, DWYER $104.

Z_4 - Exhaust Gas $\frac{1}{4}$" NPT. 0-7" P.W.C. included Manometer, Dwyer $26.

Z_5, 7 & 8 - HT. XCH'R $\frac{1}{4}$" NPT 0-60 PSIG 3$\frac{1}{2}$" Bourdon Gage w/Diaph.
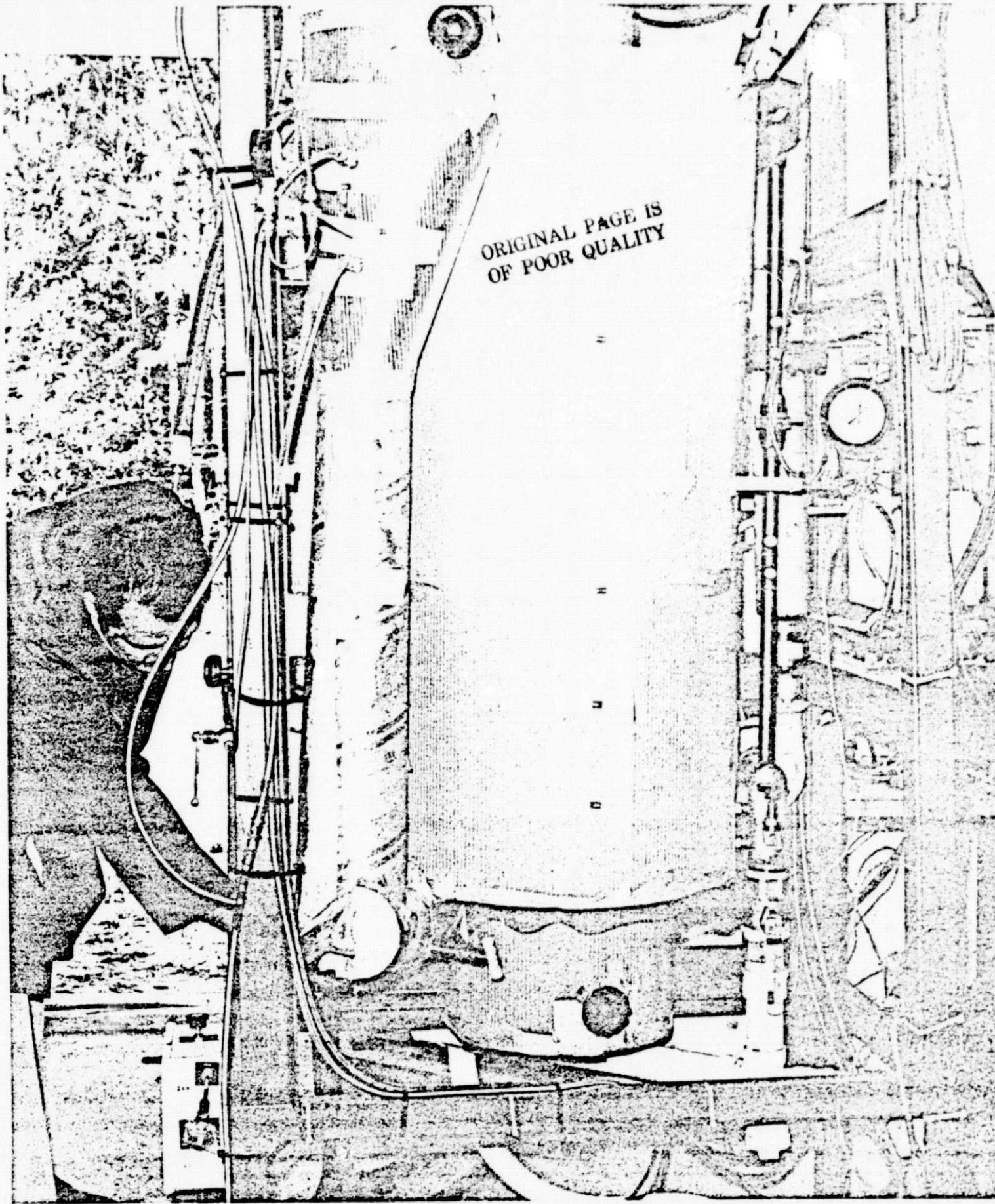
Z_6 - GN_2 col. Model 1144 G 0120 A 22 LM with 1-$\frac{1}{4}$" NPT.

        D = 15 PSIG @ LN_2 Temp.

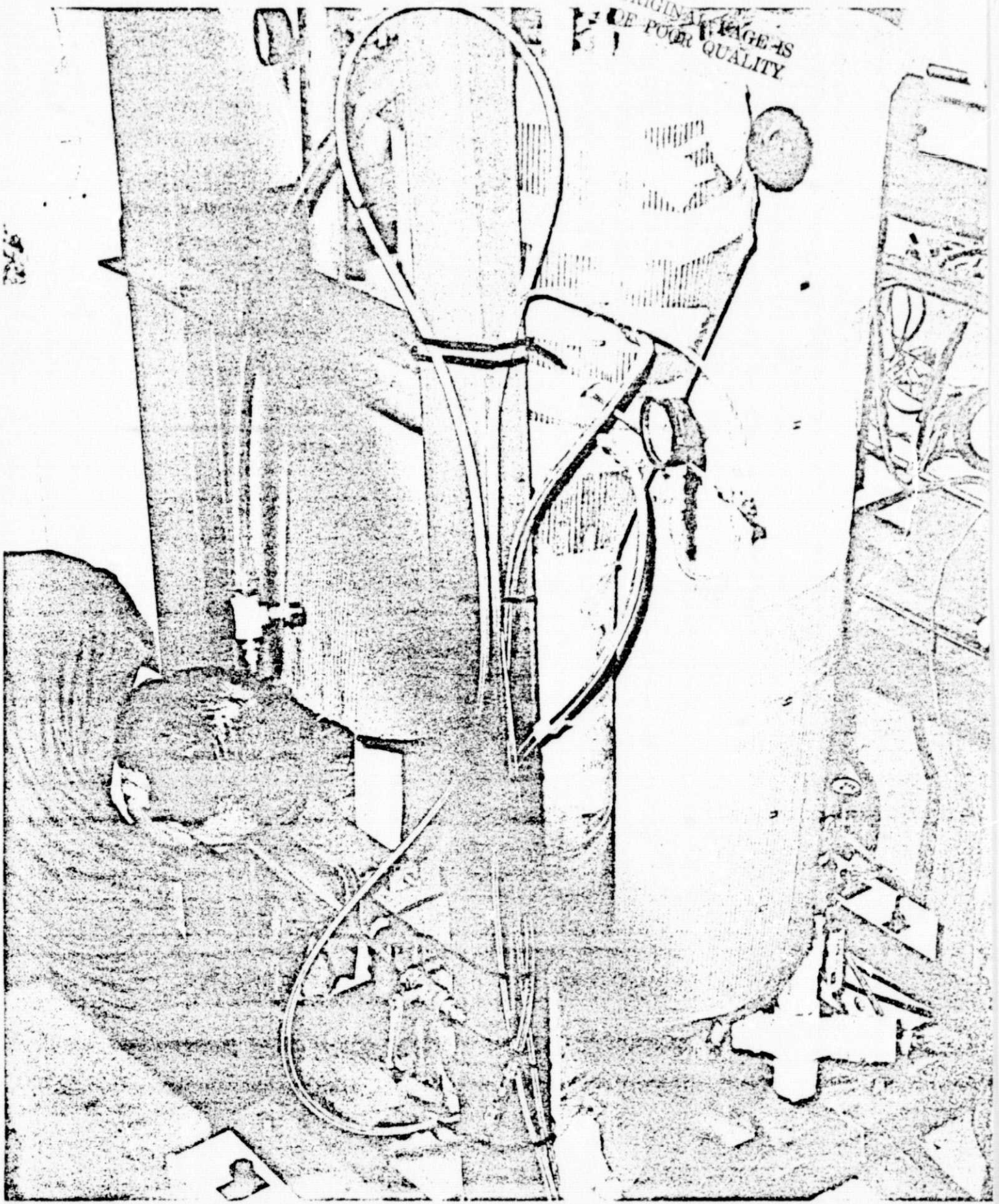1 - Rosemount Model 1144 G Alpha line Pressure XMTR.

ORIGINAL PAGE IS
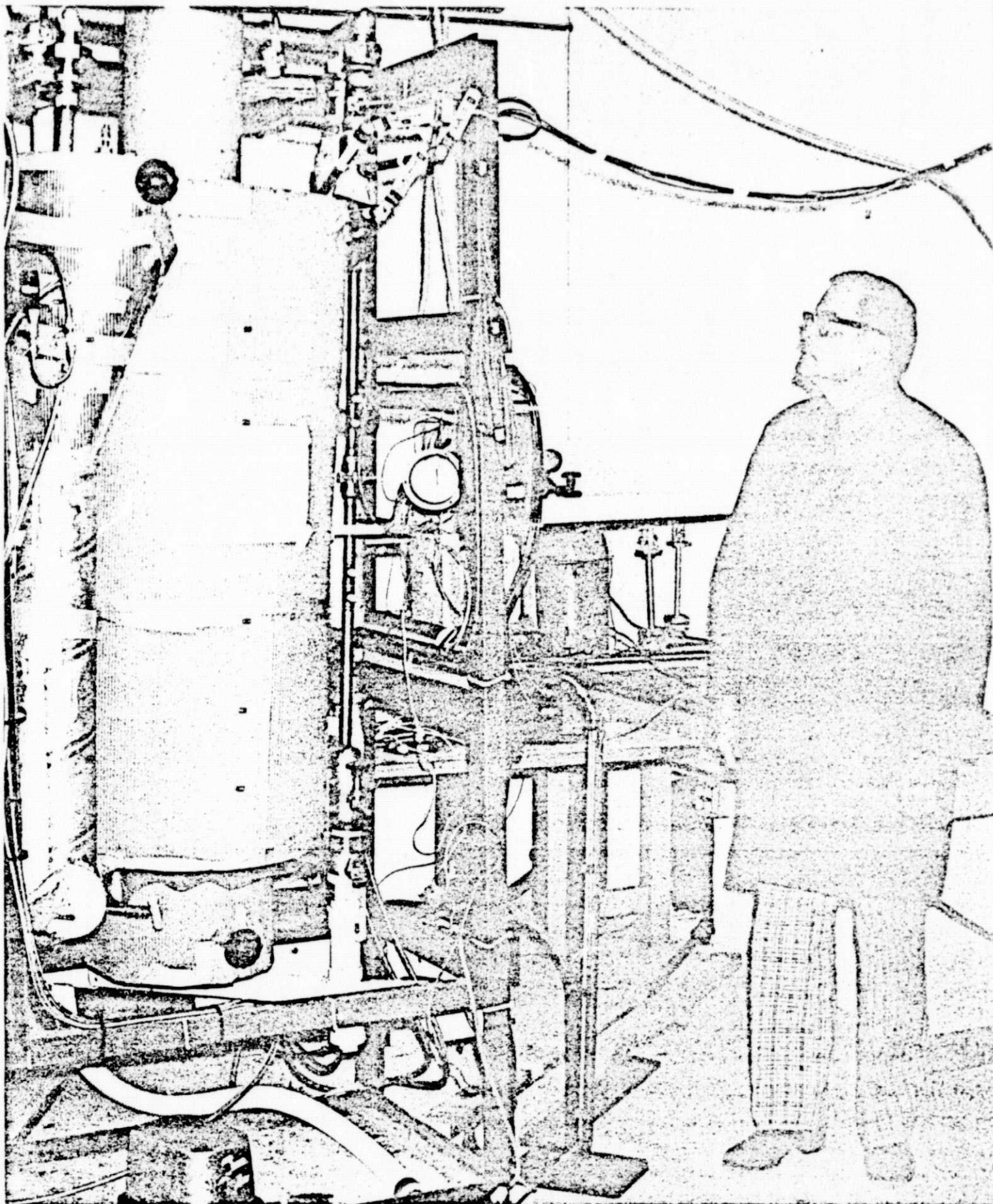OF POOR QUALITY

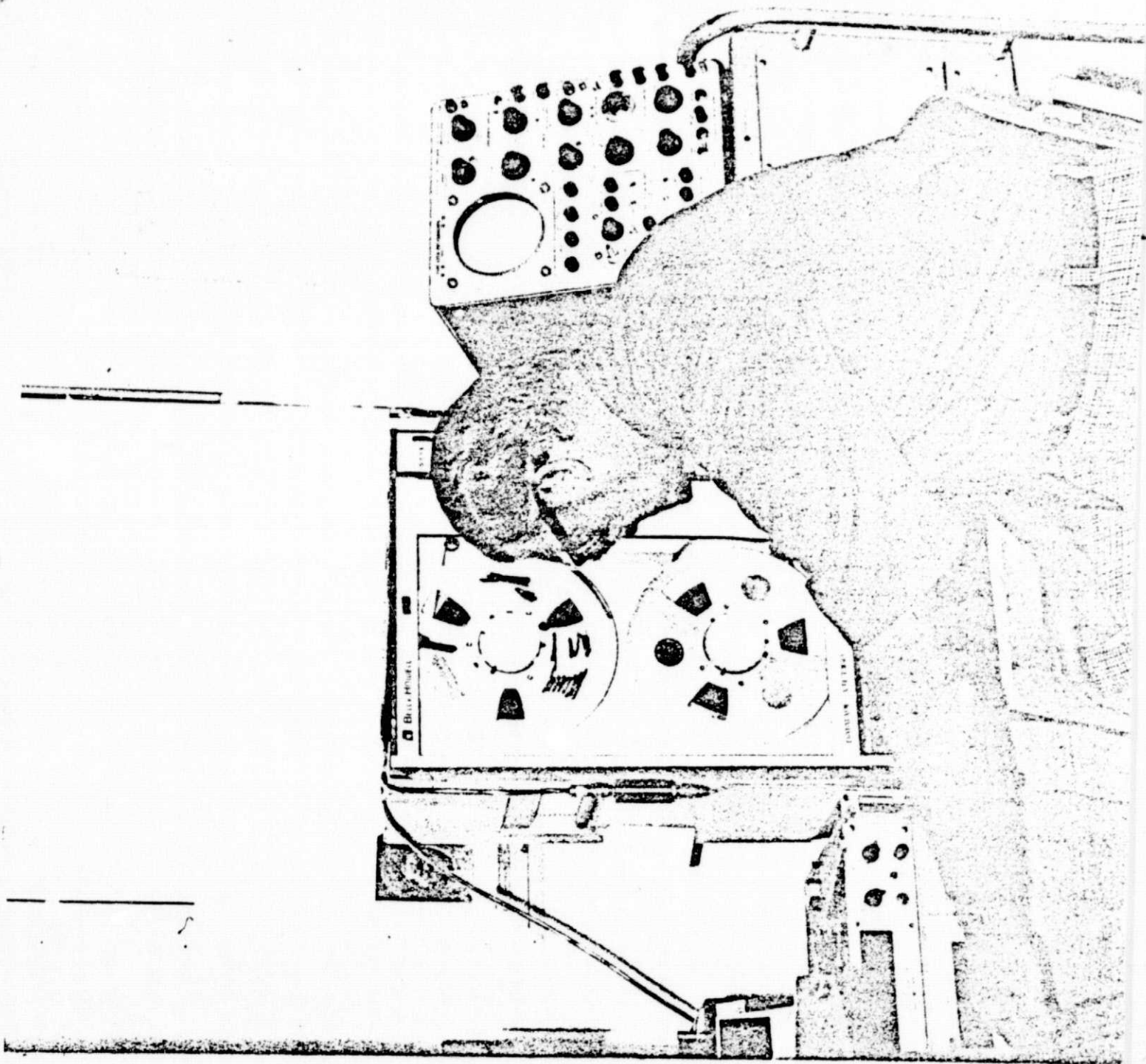*OPENING THE LN$_2$ VALVE ON THE CSP*

Figure 6

LOOKING DOWN ON THE CSP

Figure 7

THE CSP JUST PRIOR TO OPERATION
Figure 8

THE TAPE RECORDER FOR THE CSP

Figure 9

6. EXPERIMENTATION

The ability of the CSP to condense atmospheric water from air was the first project undertaken (Experiments 1-2-10-76 to 1-2-19-76) (see Table 2). The blower was used to force air through the CSP which was cooled to about -150°C. The theoretical total amount of moisture condensed was determined from the dew point and the SCF of air put through the system. The actual amount of water condensed was measured by heating the CSP, opening the drain valve D_2, and measuring the amount of water released. The per cent efficiency is determined by the following simple formula:

$$\frac{Trapped\ and\ measured\ H_2O\ x\ 100}{Theoretical\ total\ amount\ H_2O \atop entering\ CSP} = Efficiency\ (\%)$$

As is seen, the results are erratic and the efficiencies are poor. They range from 21 to 71% with an average of 55%.

In order to check the validity of these calculations slight modifications of the above experiments were carried out (Experiments 1-2-20-76 to 1-2-24-76 and 1-3-3-76 to 1-3-5-76). A measured amount of water was converted to steam and merged with a 5-20 SCFM GN_2 stream which was supplied from a portable LN_2 tanker supplied by Union Carbide of Mims, Florida. Using this method the entering quantity of water can be measured directly. However, the efficiencies decreased even more when this method was used. They ranged from 11 to 47% with a mean of 30%. Two values of greater than 100% were discarded due to experimental error caused by failure to completely purge the CSP before initiating experiments.

Experiments 1-2-25-76 and 1-2-26-76 measured the efficiency of MMH condensation from a GN_2 stream. As can be seen from the Table, the efficiencies

ranged from 0 to 33%. The input measurement was taken just prior to entry into the scrubber sytem at T_1. The output measurements were taken at a point just before exiting to the outisde scrubber. P.P.M. concentrations of MMH were made using Drager tubes obtained from KSC. These results only served to substantiate the initial findings with water and thus further experimentation with MMH became unjustifiable. However, experiments using NO_2-N_2O_4 seemed warranted since our initial laboratory data was obtained on this material. The initial experiment (1-3-1-76) with NO_2-N_2O_4 is shown in Table 2. Again the results were unpromising.

The remaining experiments were conducted using N_2O_4 and are listed in the Table as Experiments 1-3-30-76 and 1-4-1-76. Both of these experiments were concerned with determining the effects of CSP temperature on the scrubbing efficiency. Again, the measurements were made using Drager tubes. As is seen, no experiments resulted in scrubbing efficiencies greater than 0. These results were clearly unpromising and experimentation on the CSP was discontinued.

The LN_2 usage for each experiment is delineated in Table 2. Each experiment required on the average 1.0 *P.S.I.* per hour run. A *P.S.I.* unit is equivalent to 2857 SCF of GN_2, which in turn is equivalent to 100 K of LN_2, which equals 220 lbs. Thus, scaling up the CSP for the full-size unit would require apporximately 26,400 lbs. of LN_2 for one 6-hour run. This is 13.25 tons which at present prices of $80.00/ton amounts to $1,060. If we assume that 110 lbs. of N_2O_4 will be vented during the loading process, this means that each lb. of N_2O_4 removed from the vent stream will cost $9.64. This is clearly unacceptable.

The calculated input concentration column in Table 2 was determined from flow rate data of the GN_2 stream and the hypergol stream. The large differences between the calculated input concentration and the experimental input concentration is due to hypergol condensation in the feed lines. This was qualitatively confirmed several times.

The following experiment was conducted in an attempt to minimize LN_2 usage. The CSP was cooled down to $-190^{\circ}C$ and a small bleed into the CSP was allowed overnight. However, the CSP did not remain cool overnight using this technique and by morning of the following day, the temperature of the CSP was ambient. Therefore, a basic design modification of the CSP appears necessary if only to control LN_2 usage.

TABLE 2

THE CRYOGENIC SCRUBBER PROTOTYPE EXPERIMENTATION

Experiment Number	Time of Run (Hours)	CSP Fan Voltage	Flow Rate SCFM	Input Material (carrier gas)	Total Input H_2O (ml)	Calculated Input Concentration (ppm)	Experiment Input Concentration (ppm)
1-2-10-76	1.5	30	3*	H_2O, Air	63*		6,556
1-2-11-76	1,5	60	6*	H_2O, Air	127*		6,556
1-2-13-76	1.5	60	6*	H_2O, Air	205*		11,076
1-2-16-76	1.4	30-90	10-30	H_2O, Air			
1-2-19-76	1.1	60	6*	H_2O, Air	128*		9,312
1-2-20-76	4.3	60	20	H_2O, GN_2	10		
1-2-23-76	3.9	60	20	H_2O, GN_2	150		
1-2-24-76	3.9	60	20	H_2O, GN_2	30		
1-2-25-76	3.0	40	20	MMH, GN_2		1,776	6
						1,776	30
1-2-26-76	3.7	60	20	MMH, GN_2		12,302	20
1-3-1-76	1.2	60	20	N_2O_4, GN_2		1,783	60±10
						892	60±10
1-3-3-76	2.0	45	10	H_2O, GN_2	8.0		
1-3-4-76	2.0	45	10	H_2O, GN_2	28.0		
1-3-5-76	2.0	45	5	H_2O, GN_2	35.0		
1-3-30-76	1.0	60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10
1 1-76	1.0	60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10
		60	5	N_2O_4, GN_2		3,600	75±10

TABLE 2

continued

Experiment Number	Lowest Temperature	Effluent Concentration (ppm)	Time of Assay (Hours)	Total Amount Recovered From CSP (ml)	% Efficiency	Amount LN₂ Used (P.S.I.)
1-2-10-76	-150			40	63*	0.5
1-2-11-76	-150			90	71*	1.3
1-2-13-76	-165			44	21*	1.3
1-2-16-76	-160					1.6
1-2-19-76	-137			80	63*	1.0
1-2-20-76	-160			10	100[a]	2.6
1-2-23-76	-160			70	47	2.5
1-2-24-76	-155			12	40	3.0
1-2-25-76	-150	0.5	1.9		92[b]	Gauge malfunction
		20	3.0		33	
1-2-26-76	-25	20	3.7		0	1.5
1-3-1-76	-165	60±10	0.5		0	1.75
		60±10	0.6		0	
1-3-3-76				10.0	>100[a]	2.0
1-3-4-76				3.0	11	4.5
1-3-5-76				8.0	23	1.5
1-3-30-76	-178	75±10	0.00		0	0.5
	-168	75±10	0.25		0	
	-164	75±10	0.50		0	
	-158	75±10	0.75		0	
	-153	75±10	1.00		0	
1-4-1-76	-5	75±10	0.00		0	
	-27	75±10	0.25		0	
	-53	75±10	0.50		0	
	-77	75±10	0.75		0	
	-107	75±10	1.00		0	

* High Estimate.   [a]Result due to experimental error.   [b]Early in MMI run.

7. DISCUSSION

As mentioned earlier in the design section of this report, there are several significant differences between the CSP and the laboratory model. Whether any of these is significant in terms of performance can only be determined by further experimentation. However, there was one phenomenon observed which is worthy of mention and may eventually lead to some concrete answers.

In the laboratory experiments, the bright blue frozen NO_2 collected in one place to such an extent that blockage became a significant problem. However, the CSP presented the opposite problem. In spite of the fact that the effluent gas from the CSP was extremely cold ($-87^{\circ}C$), large amounts of NO_2, MMH and H_2O would not collect inside the CSP. Also, the amounts of LN_2 used in these experiments would be prohibitive if scaled up to the amounts required in the Shuttle program. Since most of the LN_2 is utilized in the initial chilldown, and very little is used during the "scrubbing" process, any practical design using the cryogenic principle must be analogous to that shown in Figure 1. This type of design will allow the cryogenic scrubber (CS) to remain cold at all times and thus utilize a minimum of LN_2. Using this design, once the LN_2 has been depleted to a certain level all that is required is for the vessel to be refilled. The technology of maintaining LN_2 in closed vessels with small bleeds has been well established, therefore such designs should be no real problem, particularly if the "footprint" in which the system must sit is not too restrictive.

8. FINAL RECOMMENDATIONS

The CSP did not yield any sort of results which could be called encouraging enough to yield design criteria within the currently established time frame. However, the sound theorectical concepts and the highly promising laboratory date seem to indicate that the inability of the CSP to function is related to basic design and/or materials problems. Thus, it is recommended, before any construction of a new CSP is undertaken, that basic design and materials specifications be decided upon as a consensus of experts from KSC, FIT, industry and academia in general, and that laboratory scale experiments be resumed. These experiments should be on a scale of 1/10 to 1/4 of the current CSP.