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MECHANICAL ENGINEERING SAFETY NOTE

Gas Delivery System and Reclamation Cylinders for Gamma Ray Imager

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Description of the System:

This safety note covers the gas delivery system and the gas reclamation cylinders used in a full volume gamma ray imager located in Building 132S, Room 2723. There are three parts to the imager. The first part is the gas delivery system built commercially by Insync Systems. It is used to purify and deliver electronegative free (99.9999999%) gas at an MOP of 135 psig. The second part of the system consists of two time projection chambers (TPC) where the experiments will be performed. The TPCs will nominally operate at 300psig but one has been designed for 400 and the other for 980 psig MAWP. They are covered by a separate safety note titled Time Projection Chamber, MESN99-020-0A. The third part of the system uses cryogenic reclamation cylinders to reclaim the purified gas. These cylinders have been fabricated by Acme Cryogenics and are rated by Acme to 2200 psig MAWP. The system layout is seen in Fig. 1. Gas will be transferred in the system by thermal cycles, using LN2 to create the temperature gradient via conduction through the walls of the reclamation cylinders. A certain percentage of alcohol may be used in the LN2 bath to raise the temperature of the bath above 77K. The asphyxiation hazard associated with the evaporation of LN2 and alcohol is dealt with in OSP 132S.31.

Note that there are four MAWPs in this system. They are MAWP0 for the input to the Supply Panel, MAWP1 for the Gas Delivery portion, MAWP2 for TPCs and MAWP3 for the Gas Reclamation portion.

The Gas Delivery System purifies research grade gas to an ultraclean gas that is free of electronegative materials. It consists of a Control Panel plus 4 secondary panels and connecting plumbing . A schematic is shown in Fig. 2. All of the process valves on the secondary panels are all metal, bellows sealed valves actuated with 50 psig house air with manual switches controlling the air. The switches are on the Control Panel. The secondary panels are designated as: Supply, Fig. 3, Purification, Fig. 4, Chamber, Fig. 5 and Reclamation, Fig. 6.

The Supply Panel has connections for three gas cylinders of research grade (99.999%) gas. The gas cylinders will contain Ar, Xe and CO2. (There may be interest in using combustible gases in later stages of this research. A revision of this note would be written to cover such work.) The pressure output of the cylinders is limited by a regulator to 135 psig MOP and protected by a 157 psig rupture disc. It is connected to the Purification and Reclamation panels as shown in Fig.2.

The Purification Panel includes a room temperature getter (Oxisorb Model S511-HV) followed by a hot getter (SAES Phase 1 MonoTorr). The Oxisorb and the MonoTorr

both have a manufacturer's MOP of 150 psig. The material in the getters can be returned to the manufacturer, after being saturated, for regeneration or disposal. There is a mass flow controller and a 157 psig rupture disk following the MonoTorr. The output of the Purification Panel flows to 3 places: 1) the Chamber Panel which leads to the TPC's, 2) the recirculation pump (which is currently replaced by a jumper) and 3) the Reclamation Panel, again as shown in Fig. 2.

The Chamber Panel provides gas flow to the TPCs, the turbomolecular pump (TMP) and system vent. The gas flow/pressure from the chamber into the rest of the system is restricted operationally by pressure regulators at the outlet of the chambers. Intermediate pressure gas is prevented from pressuring the purification panel above the MOP of 135 psig by both purification system operating procedures and a 157 psig rupture disk.

The rupture disc reliability is closely regulated by the manufacturer to the requirement that 2 discs from the involved lot rupture at the lot pressure plus or minus 5%. The lot pressure is the average of the two test disc rupture pressures and it must fall into the manufacturing range of -4 / +7 % of the pressure that is ordered by the customer. The lot pressure is stamped on a tag attached to the disc body. It is 157 psig. This means that MAWP1 could be as high as 168 psig for the low pressure portion of the the system. We designate MAWP1 at the lot pressure of 157 psig.

Overpressuring the TPCs will be prevented in final operations by: 1- monitoring and controlling gas flow into the chamber with the Mass Flow Controller, 2- using a load cell with 50 gm resolution interlocked to the valve allowing flow into the chamber, 3- having 402 psig rupture disks on the chambers. In preliminary operations the mass flow controller will be used under 2-man operator control to limit the amounts of Xe to 840 gm and Ar to 250 gm as measured by a Data Instruments load cell with a resolution of 200 gm. This would limit the TPC pressure to <3/8 the MAWP2 or ~150 psig as shown in Tables 1 and 2 respectively. The operators will have pressure readings on the TPCs to confirm the control and can revert to LN2 cooling and venting to limit the pressure. There is inherent safety in gas transfer from a TPC to a reclamation cylinder in that the volume ratio, TPC to RC, is ~3 but the MAWP ratio is 400/2200 or ~1/5.

The Reclamation Panel allows for gas to be transferred into or out of the reclamation cylinders. These cylinders attach to the reclamation panel with a VCR fitting (for cleanliness) immediately followed by a rupture disc set at 2230 psig and a pressure transducer. They each have a volume of 5.36 liter. Gas is drawn into a reclamation cylinder by dipping it in a surrounding cryogenic bath of LN2 or LN2/alcohol mix. In preliminary operations the mass of Xe in a reclamation cylinder will be limited by 2-man operator control to 8 kg and Ar in a separate cylinder to 650 gm as measured by a Data Instruments load cell with a resolution of 200 gm. This will limit the pressure to <1/2 of MAWP3 or ~1000 psig as shown in Tables 1 and 2 respectively. The associated pressure transducer reading will confirm the 2-man operator control. Above these masses the

cylinder will be weighed with a load cell from Data Instruments to measure the amount of gas in the cylinder. As above, in final configuration the load cell will be interlocked to the inlet flow valve,

The characteristics of the gases of interest are given in the following table:

Table 1. Process Gas Characteristics

Gas	Mol.Wt. grams	Melting Point °C	Boiling Point °C	Critical Temp °C	Critical Pressure psia	Critical Density g/ml
Ar	39.95	-189.4	-185.9	-122.4	705.4	0.531
Xe	131.1	-111.9	-108.1	16.6	846.7	1.155
CO_2	44.01	-56.6	-78.4*	16.6	1070.6	0.460

* Sublimation Temperature

Tables 2 and 3 respectively show that <10.6 kg of Xe and <1.3 kg of Ar will limit the cylinder pressures to less than the 2200psig MAWP3. The reclamation cylinders themselves weigh about 75 lbs. The present load cells have a 300 lb capacity, a 0.5 lb resolution and a tare weight removal feature on the readout.

Table 2. Pressure vs Mass of Argon in a Reclamation Cylinder or a TPC

reclaim cyl (liters)=		5.4				
T=294K			Reclaim		TPC	
p(atm)	p(psi)	moles/liter	V Ar@1atr	mass(kg)	V Ar@1atr	mass(kg)
1	14.7	0.0	5.4	0.01	15.04	0.02
1.5	22.05	0.1	8.1	0.01	22.57	0.04
2	29.4	0.1	10.8	0.02	30.10	0.05
3	44.1	0.1	16.2	0.03	45.34	0.08
4	58.8	0.2	21.5	0.04	60.28	0.10
5	73.5	0.2	26.9	0.04	75.40	0.12
6	88.2	0.2	32.4	0.05	90.55	0.15
7	102.9	0.3	37.8	0.06	105.71	0.18
8	117.6	0.3	43.2	0.07	120.89	0.20
9	132.3	0.4	48.6	0.08	136.09	0.23
10	147	0.4	54.1	0.09	151.31	0.25
15	220.5	0.6	81.4	0.13	227.70	0.38
20	294	0.8	108.8	0.18	304.56	0.50
25	367.5	1.1	136.5	0.23	381.89	0.63
30	441	1.3	164.3	0.27	459.66	0.76
35	514.5	1.5	192.2	0.32	537.87	0.89
40	588	1.7	220.3	0.37	616.50	1.02
45	661.5	1.9	248.5	0.41	695.52	1.15
50	735	2.1	276.9	0.46	774.91	1.28
60	882	2.6	334.0	0.55	934.73	1.55
70	1029	3.0	391.6	0.65	1095.77	1.82
80	1176	3.5	449.5	0.74	1257.79	2.08
90	1323	3.9	507.6	0.84	1420.57	2.35
100	1470	4.4	566.0	0.94	1583.82	2.62
120	1764	5.3	682.7	1.13	1910.65	3.17
140	2058	6.2	799.0	1.32	2235.95	3.71
160	2352	7.1	913.8	1.51	2557.34	4.24
180	2646	7.9	1026.5	1.70	2872.59	4.76
200	2940	8.8	1136.2	1.88	3179.75	5.27
220	3234	9.6	1242.5	2.06	3477.20	5.76
240	3528	10.4	1344.9	2.23	3763.74	6.24
260	3822	11.1	1443.1	2.39	4038.63	6.69
280	4116	11.9	1537.0	2.55	4301.43	7.13
300	4410	12.6	1626.6	2.70	4551.99	7.54
from Thermodynamic Properties od Argon from the Triple Point to 300 K At						
Pressures to 1000 Atmospheres QD 162 G1 1969B A.L.Gosman						

Table3. Pressure vs Mass of Xenon in a Reclamation Cylinder or a TPC

	reclaim cyl (liters)=		5.36				
	T=295K			Reclaim (Liters)		TPC (Liters)	
m^3/kg	p(atm)	p(psi)	moles/liter	V Xe@1at	mass(kg)	V Xe@1at	mass(kg)
185.80	1.0	14.5	0.0	5.3	0.03	14.91	0.08
36.33	4.9	72.4	0.2	27.3	0.15	76.27	0.41
17.63	9.9	144.9	0.4	56.2	0.30	157.17	0.85
11.38	14.8	217.3	0.7	87.0	0.47	243.50	1.31
8.24	19.7	289.8	0.9	120.2	0.65	336.36	1.81
6.34	24.7	362.2	1.2	156.1	0.84	436.92	2.35
5.07	29.6	434.7	1.5	195.5	1.05	547.08	2.94
4.14	34.5	507.1	1.8	239.3	1.29	669.64	3.60
3.43	39.5	579.6	2.2	289.0	1.56	808.81	4.35
2.85	44.4	652.0	2.7	347.1	1.87	971.25	5.23
2.37	49.3	724.5	3.2	418.1	2.25	1170.17	6.30
1.93	54.3	796.9	3.9	512.2	2.76	1433.51	7.72
1.50	59.2	869.4	5.1	662.3	3.56	1853.49	9.98
0.86	64.2	941.8	8.8	1147.7	6.18	3211.98	17.29
0.67	69.1	1014.3	11.4	1483.2	7.98	4150.65	22.34
0.62	74.0	1086.7	12.3	1594.5	8.58	4462.12	24.02
0.60	79.0	1159.2	12.8	1664.1	8.96	4657.10	25.07
0.58	83.9	1231.6	13.2	1715.5	9.23	4800.72	25.84
0.56	88.8	1304.1	13.5	1756.9	9.46	4916.56	26.46
0.55	93.8	1376.5	13.8	1791.5	9.64	5013.52	26.98
0.54	98.7	1449.0	14.0	1821.5	9.80	5097.45	27.44
0.53	108.6	1593.9	14.4	1871.8	10.07	5238.14	28.19
0.52	118.4	1738.8	14.7	1913.0	10.30	5353.50	28.81
0.51	128.3	1883.7	15.0	1949.1	10.49	5454.67	29.36
0.50	138.2	2028.6	15.2	1980.3	10.66	5541.95	29.83
0.49	148.0	2173.5	15.5	2008.8	10.81	5621.78	30.26
0.49	157.9	2318.4	15.7	2034.9	10.95	5694.56	30.65
0.48	167.8	2463.3	15.8	2058.5	11.08	5760.86	31.01
0.48	177.6	2608.2	16.0	2081.0	11.20	5823.82	31.34
0.47	187.5	2753.1	16.2	2100.5	11.31	5878.18	31.64
0.47	197.4	2897.9	16.3	2119.8	11.41	5932.29	31.93
0.46	217.1	3187.7	16.6	2153.9	11.59	6027.79	32.44
0.45	236.9	3477.5	16.8	2185.8	11.76	6116.94	32.92
7.19	79.0	1159.2	3.5	452.6	0.75	<- Ar for comparison	

Once the gas has been condensed in the bottom of the reclamation cylinders, pressure is built in the reclamation cylinders by removing the cryogenic bath. Gas is introduced into the low pressure loop of the system through a regulator as shown in Fig. 2. The pressure of the gas is monitored with a pressure transducer and is physically limited by a 157 psig rupture disk. Normal gas flow is into the Gas Purification System from the reclamation cylinders.

InSync Systems certifies the tubing, fittings and weldments as shown in Appendices D-G. Copies of all Insync certification documents are attached in AppendixD.

Hazards:

The LLNL safety guidance is to calculate the isentropic energy release associated with the expansion of the contained gas from MAWP3 to the local atmospheric pressure. The pertinent equation is

$$E = kRT/(k-1)\left((p_2/p_1)\exp((k-1)/k)-1\right), \quad \text{ftlb/lb}$$

Using values as follows

> k = 1.67 for Ar and Xe, 1.3 for CO2, T = 530R, p_1= 2244.3 psia, p_2= 14.3 psia, R = 1545/MW ft lb / lb F, MW for Ar = 39.9, for Xe = 131.3, for CO2 = 44, storage masses for Ar and Xe from Tables 1 and 2 and for CO2 from 5.36 liter and perfect gas density

gives the greatest total delta energy for Xe of 3.26E5 ft lb / cylinder equivalent to 97.8 gm of TNT. The total is over the 7.5E4 ft lb level prescribed as the lower limit for requiring a safety note for manned area equipment. A lower total delta energy value results for CO2 because its three atom molecule lowers k from 1.67 to 1.30 and for Ar because of its greater departure from a perfect gas.

The operational pressure hazards are tempered by the use of rupture discs to limit the service pressures to the MAWPs. These discs are closely controlled by their manufacturers as discussed earlier.

Two-man operator judgment is required to limit the fill gas weights in initial runs to give pressures of ~ half MAWP3. There will be interlocks on the TPC and reclamation cylinder fill levels to prevent over charging before going on to higher fill weights and pressures.

There is a slight potential for asphyxiation associated with the free evaporation of LN2 and for excessive noise associated with valve venting. These hazards are discussed in OSP 132S.31.

Pressure Safety Assessment:

Acme designed the reclamation cylinders in accordance with ASME Boiler and Pressure Vessel Code, Section 8, Division 1, 1998. These calculations are shown in Appendix B. They did not Code stamp the vessels for reasons that are not clear at this juncture. The fabrication drawing is shown in Appendix C. As shown the cylindrical portion is 4-in. Schedule 160 pipe with an OD of 4.50 in. and an ID of 3.44 in. The heads are 4-in Schedule 160 welding pipe caps with the same inner and outer diameter as the pipe as

shown also in Appendix C. The welds are full penetration with a standard 37.5 degree bevel on each part. The cylinder material is Type 316L stainless steel.
The minimum thickness of the wall of the vessel nozzle is 0.035 in. as shown in Appendix C. The ID of the nozzle is 0.180 so that the nominal stress at MAWP3 is pr/t= 2200*0.090/.035= 5700 psi.

Thick wall pressure vessel calculations for the main body in accordance with Timoshenko (2) show a von Mises stress (Timoshenko (3)) of 5.7 ksi which gives a factor of safety of 32 on the 316L steel at ~70K and 17 (Aerospace Materials ...(4)) at room temperature. All welding at Acme was done by ASME Code certified welders. Acme tested all four cylinders at 3300 psig.

InSync Systems fabricated all of the panel plumbing in their shop under SEMI (Semiconductor Equipment and Materials International) rules. All pressure boundaries are Type 316 stainless. All welding is automatic Orbital. Fabrication conditions are clean to meet the SEMI standards. Table 4 and Appendix D show the properties of the components in the InSync assemblies. The pressure ratings for the components are seen to be a minimum of 200 psig for the low pressure system, 1000 psig for the 980 psig system and 2200 psig for the 2200 psig system. SEMI standards do not require a pressure check of plumbing in order to maintain the cleanliness of the internal surfaces. InSync did a vacuum leak test of the plumbing in each panel with the satisfactory results shown in Appendix E. InSync did the panel connecting plumbing at Livermore. The table shows the tubing and fittings to be well above the 157 psig MAWP1.

This note provides for (1) pressure proof testing at 1.27 X MAWP1 of all of the branches which are rated at an MAWP1 of 157 psig, (2) leak testing at 0.5 X MAWP2 of the TPC circuit and (3) pressure proof testing of the high pressure portion of the Reclamation Panel and Cylinder circuits at 0.85 X MAWP3. The 157 psig branches test pressure level is limited by the 200 psig limit of the Supply Panel regulator output pressure gages. The TPC circuit test pressure is limited for operational convenience noting that the chambers have been tested to 1.5 X MAWP2 separately and that the valves and hoses are rated well above MAWP2. The Reclamation Panel and Cylinder test pressure level is limited by the need to preserve the high pressure rupture discs. Here it is noted that the chambers have been pressure tested separately to 1.5 X MAWP3 plus the valves and Swagelok flex tubing are rated well above MAWP3.

Table 4. Component Pressure Ratings

Component	Pressure Rating	Remarks
Valves, Supply and Reclaim Panel	3500 psig	Nupro SS-HBVCR4-P-C
Valves, Chamber Panel	1000 psig	Nupro SS-8BG-VCR-3C
Valves, Chamber discharge	1000 psig	Nupro SS-8BG-VCR-3C
Reclamation Cylinders	2200 psig	Acme Cryogenics
Pressure regulators, S.& R.Panels	3500 psig	Tescom 64-2663KRA10
Pressure regulators, Chmbr Disch	3500 psig	Tescom 64-2663KRH19
Rupture disc, low pressure	157 psig,+/-5%	Zook 306546
Rupture disc, high pressure	2230 psig,+/-5%	Zook 306953
Pressure transducer, low pressure	5000 psig	Bendix C2143000C-834655
Pressure transducer, high pressure	10000 psig	Bendix C214250C-834655
Pressure gage, low pressure	200 psig	Tescom 4802-0200M
Pressure gage, high pressure	3000 psig	Tescom 4802-3000M
Oxygen getter	150 psig	Oxisorb S511-HV
SAES Getter	150 psig	Monotorr Phase 1
Mass flow controller	1500 psig	Brooks 5964C4MAP35KA
VCR plugs, 1/4 in.	5100 psig	Cajon SS-4-VCR-P
VCR caps, 1/4 in.	5100 psig	Cajon SS-4-VCR-CP
VCR caps, 1/2 in.	5100 psig	Cajon SS-8-VCR-CP
VCR gaskets, 1/4 in., unplated, nickel	NA	Cajon NI-4-VCR-2-GR-VS
Welding fittings	5100 psig	Swagelok Microfit
Tubing, 1/4 in.	4140 MSWP	316L, ASTM A269
Tubing, 3/8 in.	2770 MSWP	316L, ASTM A269
Tubing, 1/2 in.	2910 MSWP	316L, ASTM A269

Pressure Testing Preparation

The purpose of the pressure testing is to demonstrate that the overall system is leak tight as assembled and that all panel and interconnect plumbing is pressure safe. The low pressure rupture disc bodies are massive and difficult to open without jeopardizing the integrity of the panel plumbing and the discs themselves so that a buffer array as shown in Fig. 7 will be used to remove any pressure difference on the discs during pressure testing.

Prior to testing it is necessary it is necessary to carry out the following procedures. Please refer to Figs. 2 and 7 for component identification.

First introduction of gas into the system:

The gas should be introduced into the system in stages. The gas handling system is under a slight pressure, a few psi, from when the system was assembled at InSync.

1. The Dirty Gas Bottle should be installed and attached to the supply gas panel with a regulator and CGA flex tube connector
2. Perform a cycle purge on the section of tubing where the bottle was connected. Use the Ar cylinder as a purge gas.
   b) Hook up Ar cylinder with a regulator and CGA hose
   c) Open Valve 11
   d) Crack Ar Cyl and regulator
   e) Cycle Valve 11 a few times ending with Valve 11 open
   f) Close then Crack Ar cyl a few times
   g) Allow Ar to flow for a few minutes
   h) With Ar bleeding off, close Valve 11
   i) Open Ar Cylinder completely
   j) Make sure Regulator is closed
   k) Open Valve 10

The other dirty supply lines should be purged in a similar manner. This will require opening the valves corresponding to V11 which are V21 and V31, closing them as above and opening the V10 equivalents, V20 and V30. When the Ar purge is complete, purge for a few seconds with the gas that is going to be used in the system on that line to clean out any Ar.

3. Proceed to introduce the gas into the rest of the system opening only one valve at a time until you reach the Mass Flow Controller.
4. Make sure the Mass Flow Controller is in the closed position before gas is introduced on the inlet side of the controller. Once gas pressure is built on the inlet side of the Mass Flow Controller, crack the controller open and allow a little gas to flow through, then open the controller slowly until it is full open.
5. Flow gas through the remainder of the system making sure to go thru both the chamber section of tubing and the reclaim sections.
6. Gas should be collected in the reclaim cylinders starting with Reclaim 4 and working back to Reclaim 1. Cryo (LN2) will have to be used to collect the gas in the reclaim cylinders.
7. If necessary, gas can be vented through Valve 95.

Adding a new cylinder of Dirty Gas (at least Research Grade):

1. Ensure all valves (V10-V11-V12, V20-V21-V22, V30-V31-V32) are closed near the cylinder, including the main valve on the cylinder.
2. Remove the old cylinder.
3. Place the new cylinder in the rack and attach the CGA fitting leading to the Gas Handling system.

4. Cycle purge the lines with the following prescription that shows Xe as an example. There should be a bottle of Ar on the system. If you are replacing the Ar cylinder, use the new cylinder of Ar for the cycle purge.
   d) Hook up Xe cylinder with a check valve in the discharge line to prevent inflow
   e) Open Valve 22 (Ar for Cycle Purge)
   f) Ar Cyl should be open. If not, follow cycle purge above to ensure that opening the Ar cyl does not introduce dirt into the system.
   g) Open Valve 22 to introduce gas into the purge line
   h) Open Valve 11
   i) Open Valve 12
   j) Allow Ar to flow and blow the line out
   k) Close Valve 11
   l) Close Valve 12
   m) Close Ar Cyl Valve
   n) Cycle Valve 21
   o) Close Valve 22
   p) Open Valve 11
   q) Crack Xe Cyl open
   r) Close Valve 11
   s) Work Xe Cyl valve open and closed to get dirt out ending in Closed position
   t) Cycle Valve 11 ending in closed position
   u) Open Xe Cyl Valve
   v) Make sure Regulator is Closed
   w) Open valve 10
   x) Now use the regulator to introduce gas into the system

Pressure Testing

The following testing is to be carried out by a Pressure Inspector, a Pressure Installer, a mechanical engineer and the chief experimenter .

Clear the area and put up the signs and barricades.

1. Overall system low pressure test.

Having swept the plumbing in accordance with the previous procedure connect a research grade gas bottle to the Ar supply connection with a regulator and CGA flex hose.

Check that a rupture disc buffer array has been installed which connects the supply panel vent line to the four 157 psig rupture disc discharge connections as shown in Fig. 7.
Check that the source bottle supply and regulator valves are closed.
Check that all valve positions on the control boards show closed.

Check that the four reclamation cylinders are connected to their respective pigtails as shown on the Insync schematic (Fig. 2).
Check that TPC1 is connected between V91 and V96 and that jumpers are connected between V93 and V97 and between V88 and V98.
Check that 3 supply, 2 TPC and 4 reclaim regulators are closed (adjusting handle fully CCW).
Open the source bottle stop valve and set the regulator to 200 psig.
Verify that PT1 and PT2 read zero psig.
Reduce the source pressure to ~20 psig.
Open all valves one at a time except V83, V86 and V95.
This involves a total of 43 numbered valves as follows,

V10, V11, V12, V13, V20, V21, V22, V23, V30, V31, V32, V33, V40, V41, V42, V43, V50, V51, V52, V53, V60, V61, V62, V63, V70, V71, V72, V80, V81, V82, V84, V85, V87, V88, V89, V90, V91, V92, V93, V94, V96, V97, V98,

plus 3 Supply Panel, 4 Reclaim Panel and 2 TPC pressure regulators for an overall total of 52 items.
Raise the source pressure to 50 psig, verify that PT1 and PT2 read 50 psig.
Shut off the source pressure and show that PT1 and PT2 hold 50 psig for 5 minutes.
If there is a leak, leak hunt with an audio leak detector, repair the leak and retest.
Repeat this pressurize, shut off , hold procedure at 100, and 150 psig.
Raise the source pressure to 200 psig, verify that PT1 and PT2 read 200 psig.
Shut off the source pressure and show that PT1 and PT2 hold >195 psig for a period of one hour.
If the pressure falls below 195 psig, shut off the source pressure and vent the system by simultaneously cracking V-Test 1 and V-Test 2 and adjusting them for a pressure drop rate of ~15 psi/ min with the pressure at V-Test 1 kept ~5 to10 psig below that at V-Test 2, repair the leak and return directly to the 200 psig test level for verification.
When the 200 psig test results are satisfactory vent the system in the same way.
Close the 43 numbered valves and the 9 pressure regulators.
Remove the buffer array.

2. Supply Panel Input High Pressure Test

Since the Supply Panel input manifold will be pressurized directly to a bottle pressure MOP of up to 2000 psig in normal operation and since it is not pressure relieved it is necessary to test it to 3300 psig to provide for a MAWP0 of 2200 psig following the 200 psig testing.

Connect a regulated high pressure clean gas source to a Source Panel input station.
Verify that the other two input stations are closed.
Open valves V10, V12, V20, V22, V30 and V32.
Raise the source pressure to 1100 psig and note that the Supply Panel regulator input pressure gages all read 1100 psig.

Shut off the source pressure and show that the input pressure gages hold 1100 psig for 5 minutes.
If there is a leak, leak hunt with an audio leak detector, repair the leak and retest.
Raise the source pressure to 2200 psig
Shut off the source pressure and show that the input pressure gages hold 2200 psig for 5 minutes.
If there is a leak, leak hunt with an audio leak detector, repair the leak and retest.
Raise the source pressure to 3300 psig.
Shut off the source pressure and show that the pressure gages hold >3300 psig for 30 minutes.
Repeat the leak hunt, repair, retest procedure as necessary.
When the 3900 psig test results are satisfactory vent the system by opening V31.
Close V10, V12, V20, V22, V30, V31 and V32.

3. Reclamation Panel High Pressure Test

There is need to check the integrity of the high pressure portion of the Reclamation Panel. The cylinders have been tested to 3300 psig as required for an MAWP3 of 2200 psig. The flex hoses which connect the four cylinders to the panel are rated at 3100 psig. The tubing, pressure transducers and pressure regulators are rated higher than the 3300 psig as is seen in Table 4. The burst discs will fail at MAWP3 within their tolerance band.

Verify that all valves and pressure regulators on the Reclamation Panel are closed.
Fill Reclaim 1 thru the MFC with enough Ar to give 1800 psig plus 0, minus 200 psig when liquefied and equilibrated to room temperature.
The fill sequence is to supply the gas from the Ar Supply connection on the Source Panel, thru the getters and MFC, thru V94, V89, V63, V53, V43, V41, V40 to Reclaim 1.
Close V41 and show that the initial pressure is held within 30 psig over a 30 minute period.
If there is a leak, vent the cylinder at <140 psig thru the V42, V43, V53, V63, V89, V97, V93, V95 path, repair it and retest.
Transfer the gas thru the Reclaim 1 regulator at <140 psig and V42, V43, V51, V50 to Reclaim 2 and repeat the 1800 psig nominal pressure test as above, make up for any residue in Reclaim 1 using the initial fill sequence shown above except replace V43, V41, V40 with V51, V50.
Close V51 and show that the initial pressure is held within 30 psig over a 30 minute period.
If there is a leak, vent as above from Reclaim 2 and retest.
Transfer the gas thru the Reclaim 2 regulator at <140 psig and V52, V53, V61, V60 to Reclaim 3 and repeat the 1800 psig nominal pressure test as above, make up for any residue in Reclaim 2 using the initial fill sequence shown above.
Close V61 and show that the initial pressure is held within 30 psig over a 30 minute period.

If there is a leak, vent as above from Reclaim 3 and retest.
Transfer the gas thru the Reclaim 3 regulator at <140 psig and V62, V63, V71, V70 to Reclaim 4 and repeat the 1800 psig nominal pressure test as above, make up for any residue in Reclaim 3 using the initial fill sequence shown above except replace V63, V53, V43, V41, V40 with V71, V70.
Close V71 and show that the initial pressure is held within 30 psig over a 30 minute period.
If there is a leak, vent as above from Reclaim4 and retest.
If not, vent as above from Reclaim 4.
This concludes the testing._
Close all valves.
Leave the Ar bottle in place.
Remove the signs and barricades.

Labeling

Attach a standard LLNL pressure test label to the Gas Supply Valve Control Panel as follows,

ASSY Gamma Ray Imager

SAFETY NOTE MESN99-038-0A

MAWP Varies, see labels

FLUID Ar, Xe, CO2

TEMP varies, see labels

REMARKS Restricted use

TEST NO. (Supplied by tester)

BY DATE

Attach standard LLNL pressure test labels to each of the four reclamation cylinders and to each of the four valve panels as follows,

ASSY Reclamation Cylinder No. 1, 2, 3, 4

SAFETY NOTE MESN99-038-0A

MAWP3 2200 psig

FLUID Ar, Xe, CO2

TEMP 77 K to 50 C

REMARKS Restricted use

TEST NO. (Supplied by tester)

BY DATE

ASSY Gas Supply Panel Input, PN 10E0804-01

SAFETY NOTE MESN99-038-0A

MAWP0 2200 psig

FLUID Ar, Xe, CO2

TEMP 10 C to 50C

REMARKS Restricted use

TEST NO. (Supplied by tester)

BY DATE

ASSY Gas Supply Panel Output, PN 10E0804-01

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP 10 C to 50C

REMARKS Restricted use

TEST NO. (Supplied by tester)

BY DATE

ASSY Gas Reclamation Panel Input, PN 10E0804-02

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP 10 C to 50C

REMARKS Restricted use

TEST NO. (Supplied by tester)

BY DATE

ASSY Gas Processing Panel, PN 10E0804-03

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP 10C to 50 C

REMARKS Restricted use

TEST NO. (Supplied by tester)

BY DATE

ASSY Detector Chambers Fill Panel, PN 10E0804-04

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP -20C to 50 C

REMARKS Restricted use

TEST NO. (Supplied by tester)

BY DATE

Associated Procedures

1. OSP 132S.31

References

1. Chapter 32 - Pressure, Supplements 32.03 - Pressure Vessel and System Design and 32.05 - Pressure Testing, LLNL Health & Safety Manual

2. S. Timoshenko, Strength of Materials, Part 2, D. Van Nostrand, 1941, 239

3. S. Timoshenko, Strength of Materials, Part 2, Krieger, 1976, 454

4. Aerospace Structural Metals Handbook, Volume 2, DOD/Battelle, 1995

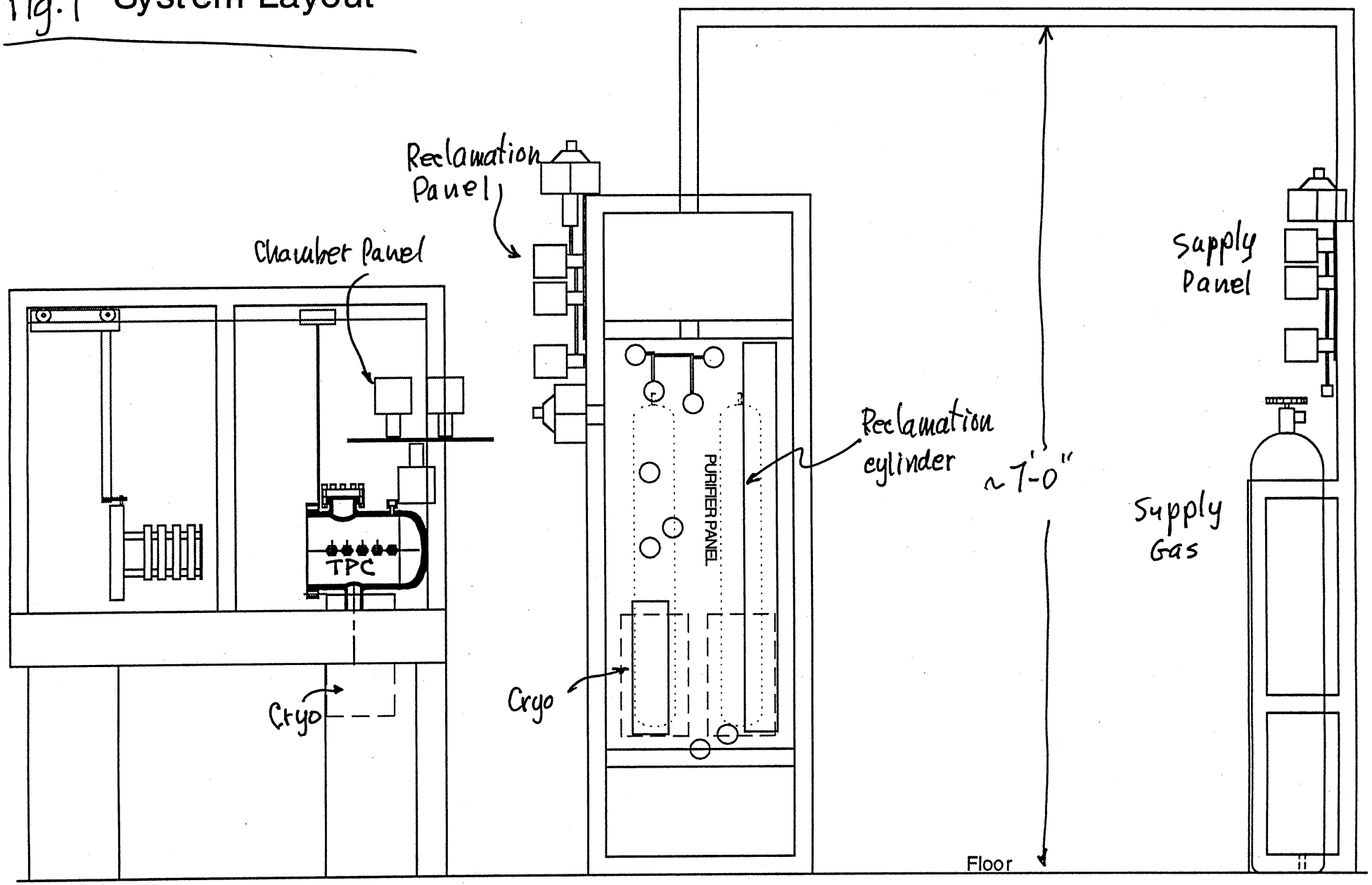
5. B-132S Facility Safety Procedure (FSP-132S)

6. LLNL Environmental Compliance Manual

7. LLNL Training Program Manual

8. Design Safety Standards Manual, ME Department, LLNL

Fig. 1 System Layout



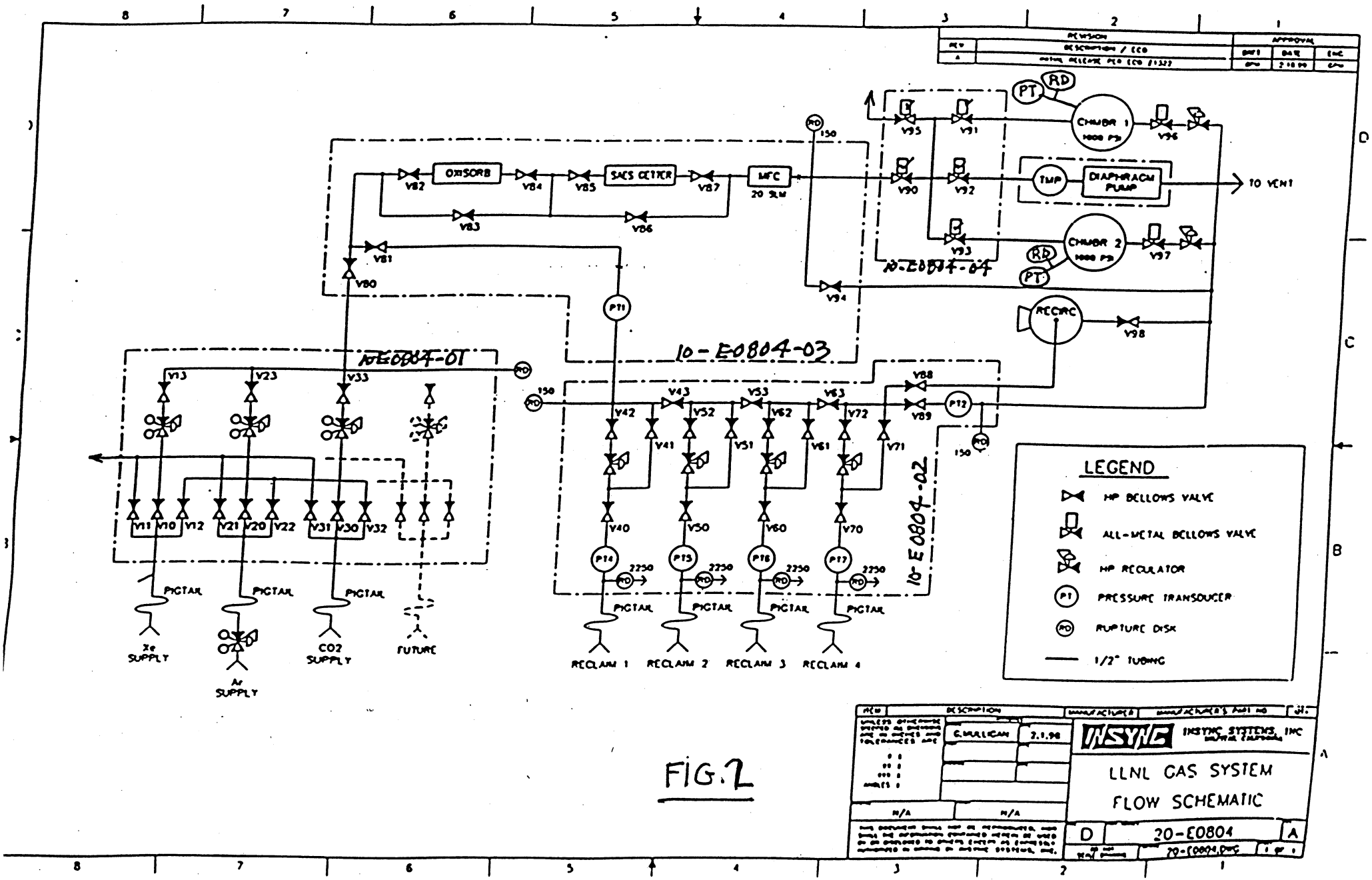
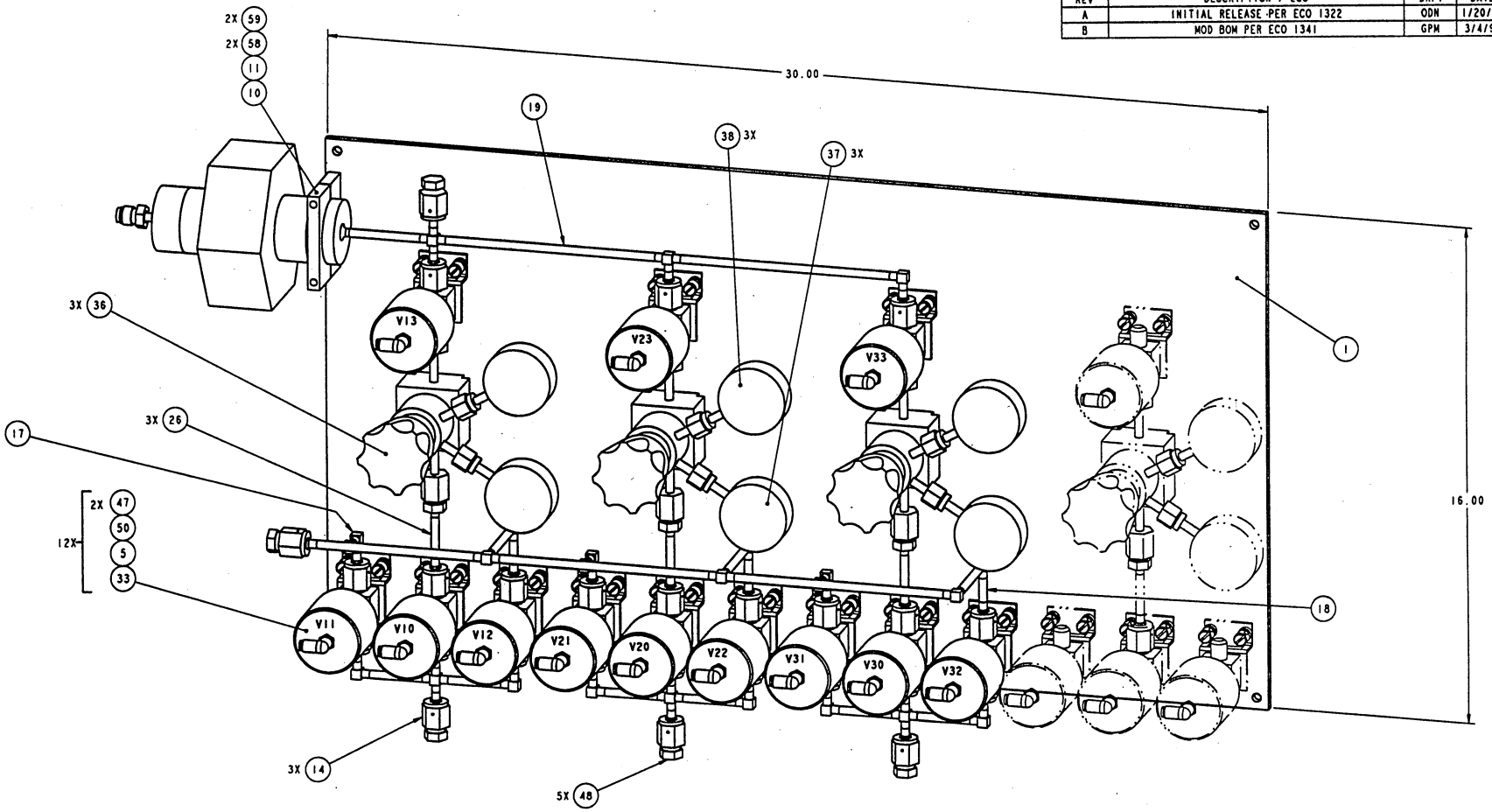

REVISION
REV
DESCRIPTION / ECO
APPROVAL
DWN
DATE
CHK
PT
RD
CHAMBR 1
1000 Pa
CHAMBR 2
1000 Pa
TMP
DIAPHRAGM PUMP
TO VENT
RECIRC
OXISORB
SAES GETTER
MFC
20 SLM
V80
V81
V82
V83
V84
V85
V86
V87
V90
V91
V92
V93
V94
V95
V96
V97
V98
PT1
PT2
PT12
PO
150
10-E0804-01
10-E0804-03
10-E0804-04
10-E0804-02
V13
V23
V33
V43
V53
V63
V73
V88
V89
V42
V52
V62
V72
V41
V51
V61
V71
V40
V50
V60
V70
V11
V10
V12
V21
V20
V22
V31
V30
V32
P14
P15
P16
P17
2250
PIGTAIL
Xe SUPPLY
Ar SUPPLY
CO2 SUPPLY
FUTURE
RECLAIM 1
RECLAIM 2
RECLAIM 3
RECLAIM 4
LEGEND
HP BELLOWS VALVE
ALL-METAL BELLOWS VALVE
HP REGULATOR
PRESSURE TRANSDUCER
RUPTURE DISK
1/2" TUBING
DESCRIPTION
MANUFACTURER
MANUFACTURER'S PART NO
INITIAL RELEASE PER ECO #1327
C.MULLIGAN
2.1.96
N/A
INSYNC SYSTEMS, INC
LLNL GAS SYSTEM
FLOW SCHEMATIC
D
20-E0804
A
20-E0804.DWG
1 OF 1

FIG. 2

REVISION		APPROVAL		
REV	DESCRIPTION / ECO	DRFT	DATE	ENG
A	INITIAL RELEASE PER ECO 1322	ODN	1/20/99	GPM
B	MOD BOM PER ECO 1341	GPM	3/4/99	GPM



10-E0804-01

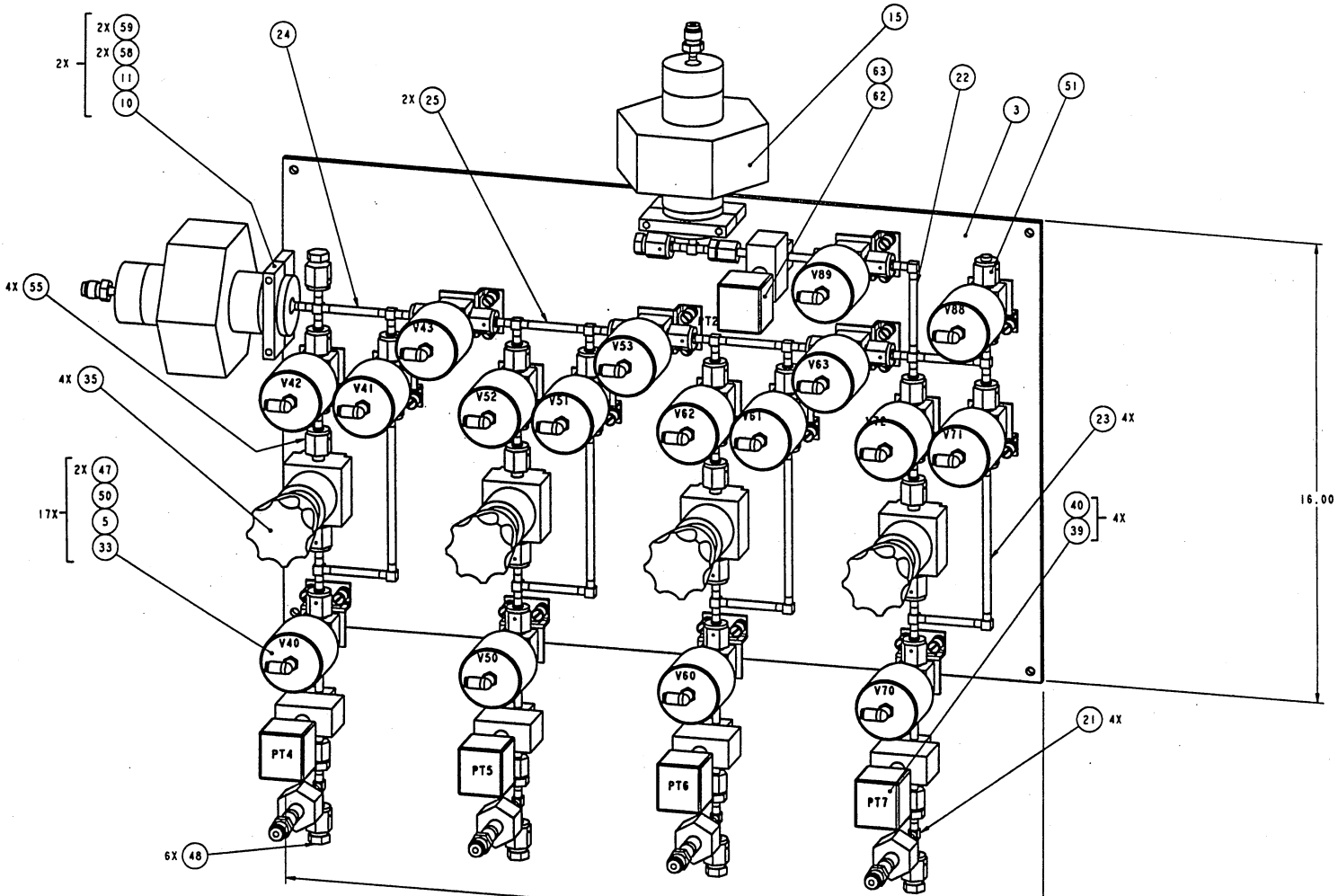
FIG. 3

UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:	APPROVALS		
	DRAWN	D. NOYES	DATE 1/19/98
.X ± 0.1	ENGR	G.MULLIGAN	DATE 1/20/98
.XX ± 0.01	CHECKED	J. ANDERSON	DATE 1/20/98
.XXX ± 0.001			
ANGLES ± 0.5			
MATERIAL SEE BOM	FINISH SEE NOTES		

INSYNC SYSTEMS, INC.
MILPITAS, CALIFORNIA

ASSY,
XENON DELIVERY SYSTEM,
LAWRENCE LIVERMORE NATL LAB

SIZE	PART NUMBER	REV
D	10-E0804	B
DO NOT SCALE DRAWING	FILENAME 10-E0804	SHEET 1 OF 4



10-E0804-02

FIG. 4

INSYNC SYSTEMS, INC.
MILPITAS, CALIFORNIA

SIZE	PART NUMBER	REV
D	10-E0804	B
DO NOT SCALE DRAWING	FILENAME 10-E0804	SHEET 2 OF 4

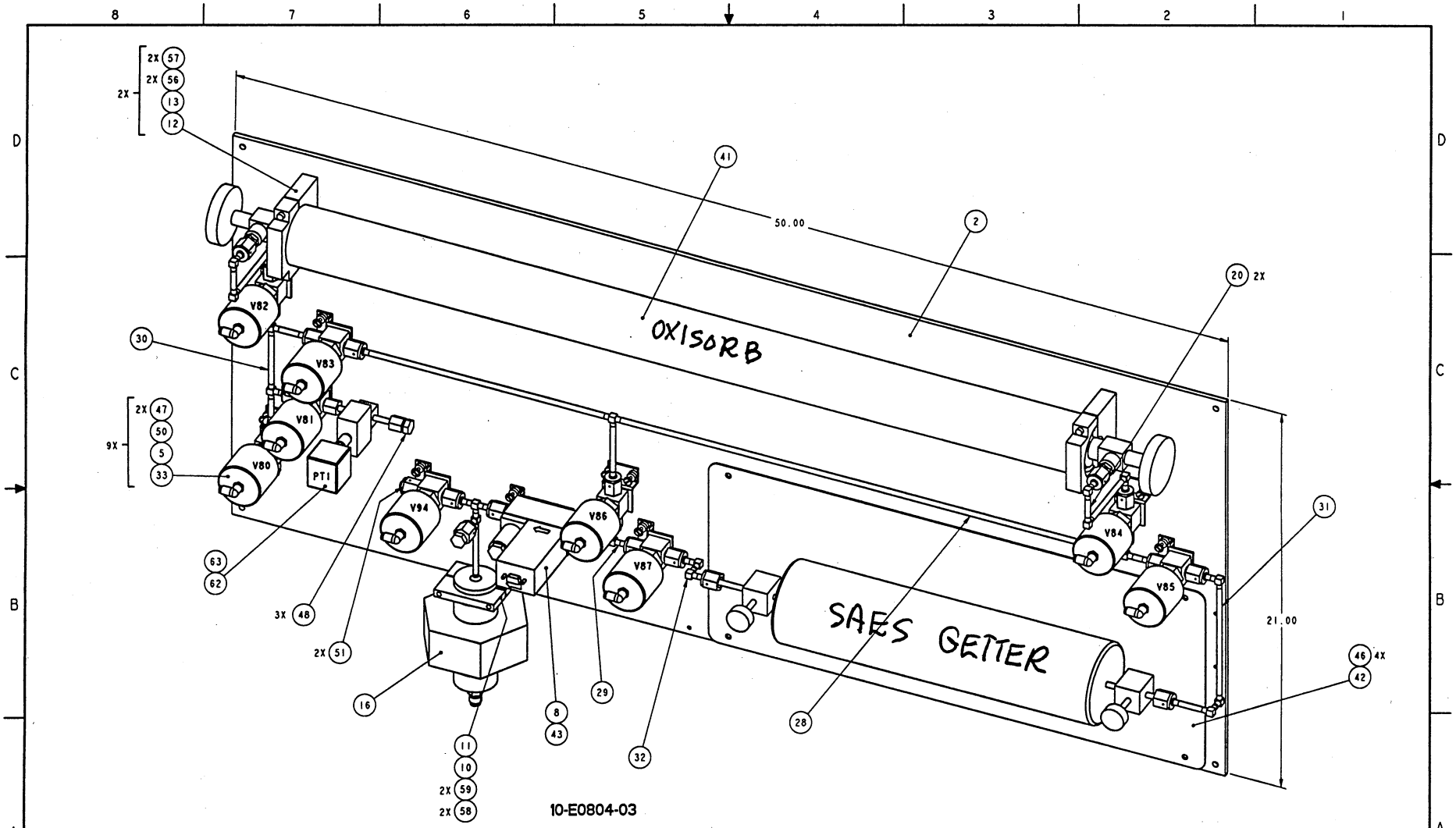
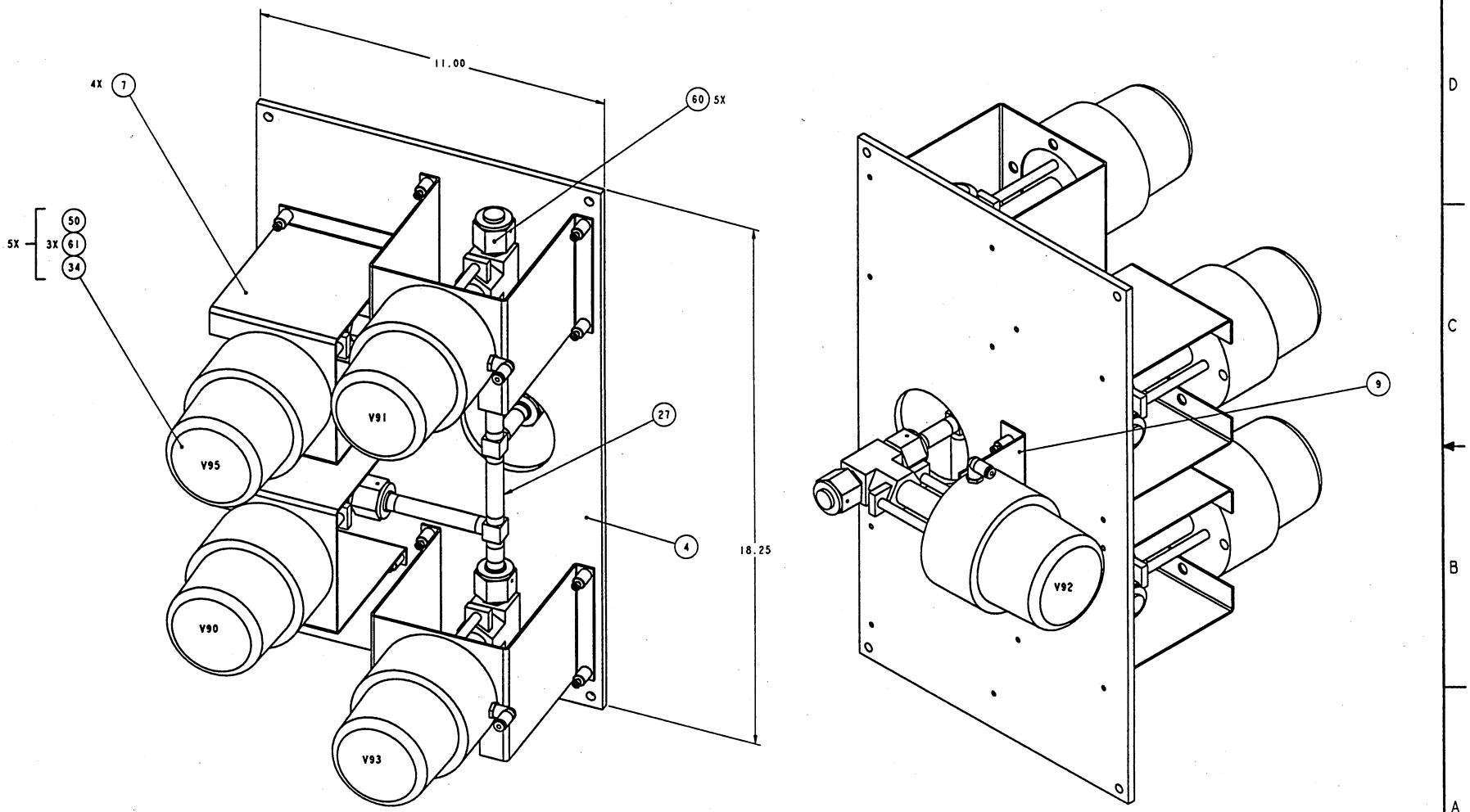


FIG. 5

INSYNC SYSTEMS, INC.
MILPITAS, CALIFORNIA

SIZE	PART NUMBER	REV
D	10-E0804	B
DO NOT SCALE DRAWING	FILENAME 10-E0804	SHEET 3 OF 4



10-E0804-04

FIG. 6

INSYNC SYSTEMS, INC.
MILPITAS, CALIFORNIA

SIZE	PART NUMBER	REV
D	10-E0804	B
DO NOT SCALE DRAWING	FILENAME 10-E0804	SHEET 4 OF 4

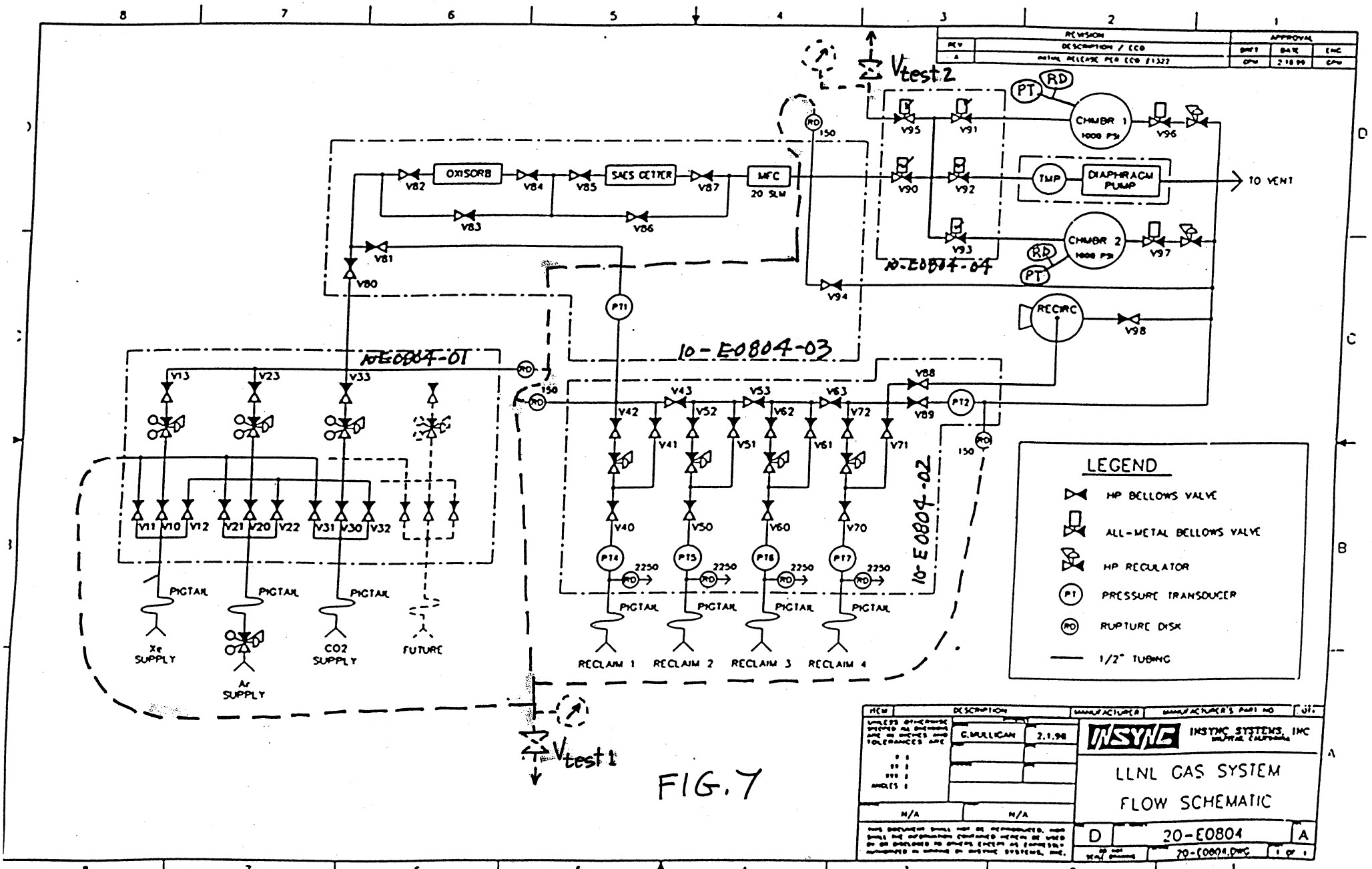

Vtest2
Vtest1
CHAMBR 1
1000 PSI
CHAMBR 2
1000 PSI
TMP
DIAPHRAGM PUMP
TO VENT
RECIRC
OXISORB
SAES GETTER
MFC
20 SLM
10-E0804-04
10-E0804-03
10-E0804-02
10-E0804-01
LEGEND
HP BELLOWS VALVE
ALL-METAL BELLOWS VALVE
HP REGULATOR
PRESSURE TRANSDUCER
RUPTURE DISK
1/2" TUBING
Xe SUPPLY
Ar SUPPLY
CO2 SUPPLY
FUTURE
RECLAIM 1
RECLAIM 2
RECLAIM 3
RECLAIM 4
PIGTAIL
LLNL GAS SYSTEM
FLOW SCHEMATIC
INSYNC SYSTEMS, INC
20-E0804

FIG. 7

ACME CRYOGENICS

APPENDIX A

FINAL INSPECTION AND TEST REPORT

ITEM NO. 225-819633 DESCRIPTION LIVERMORE LABS PRESSURE VESSEL

SHOP ORDER NO. M058560 SERIAL NO. 15473, 15474, 15475, 15476

PRESSURE TEST

TYPE TEST: PNEUMATIC ✓ HYDROSTATIC — CIRCUIT: —

PROOF TESTED AT FULL TEST PRESSURE OF 3300 PSIG WITH N2

AND HELD FOR 10 MINUTES/— HOURS; PRESSURE THEN REDUCED TO ____ PSIG FOR EXAMINATION FOR LEAKS.

SAFETY RELIEF VALVE SET AT N/A PSIG; PRESSURE SWITCH SET AT N/A

TEST PROCEDURE NO, — TESTED BY ____ TEST DATE 3/8/99

FINAL INSPECTION	INSP. STAMP
ALL PROCESS & INSTRUMENT LINES STRAIGHT, LEVEL & PLUMB	
ALL REQUIRED COMPONENTS INSTALLED, IN PROPER LOCATION, AND FLOW DIRECTIONS IS CORRECT	
ALL WELDS MEET QUALITY STDS. OF Q-113	
ALL BRAZED JOINTS-EVIDENCE OF COMPLETE BOND AROUND ENTIRE JOINT (360°)	N/A
PAINTED SURFACES SMOOTH & UNIFORM, FULL COVERAGE, NO RUNS OR SAGS, TOUCHED-UP WHERE REQUIRED	N/A
ALL REQUIRED TAGS & NAMEPLATES IN PLACE & CORRECT PER DRAWING	
FUNCTIONAL TEST PERFORMED	

PREPARATION FOR SHIPMENT	INSP. STAMP
ALL OPEN PORTS CLOSED/SEALED TO PREVENT CONTAMINATION	
ALL TEMPORARY & FLO-PEN MARKINGS HAVE BEEN REMOVED	
ALL GROSS STAINS & DISCOLORATION REMOVED FROM PIPING & FRAMES	
EQUIPMENT CLEANED FOR SHIPMENT (WIPED DOWN)	
SYSTEM PRESSURIZED TO ____ PSIG FOR SHIPMENT (SHOW EXACT PRESSURE, TEMP., DATE & TECHNICIAN'S INITIALS ON TAG ATTACHED TO EQUIPMENT).	N/A

THIS EQUIPMENT MEETS ALL ABOVE REQUIREMENTS AND IS APPROVED FOR SHIPMENT

Scott L. — QUALITY CONTROL TECHNICIAN

3/9/99 — DATE

TABLE 1A
SECTION I; SECTION III, CLASS 2 AND 3;* AND SECTION VIII, DIVISION 1
MAXIMUM ALLOWABLE STRESS VALUES S FOR FERROUS MATERIALS
(*See Maximum Temperature Limits for Restrictions on Class)

Line 27, Page 70-71		Line 17, Page 72		Line 17, Page 73	
Addenda	...	Maximum Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding			
Nominal Composition	16Cr - 12Ni - 2Mo				
Product Form	Smls. pipe	-20 to 100	16.7	950	...
Spec. No.	SA-312	150	...	1000	...
Type/ Grade	TP316L	200	14.1	1050	...
Alloy Desig./ UNS No.	S31603	250	...	1100	...
Class/ Cond./ Temper	...	300	12.7	1150	...
Size/ Thickness, in.	...	400	11.7	1200	...
P-No.	8	500	10.9	1250	...
Group No.	1	600	10.4	1300	...
Min. Tensile Strength, ksi	70	650	10.2	1350	...
Min. Yield Strength, ksi	25	700	10.0	1400	...
Applic. and Max. Temp. Limits (NP = Not Permitted) (SPT = Supports Only)		750	9.8	1450	...
		800	9.6	1500	...
I	NP	850	9.4	1550	...
III	NP	900	...	1600	...
VIII-1	850			1650	...
External Pressure Chart No.	HA-4				
Notes	...				

General Notes

(a) The following are the abbreviations used for Product Forms: (a) Wld. - Welded; (b) Smls. - Seamless.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) When used for Section III Class MC design, the stress values listed herein shall be multiplied by a factor of 1.1 (NE-3112.4); these values shall be considered as design stress intensities or allowable stress values as required by NE-3200 or NE-3300, respectively.

(d) For Section VIII applications, stress values in restricted shear such as dowel bolts or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of area shall be 0.80 times the values in the above Table.

(e) For Section VIII applications, stress values in bearing shall be 1.60 times the values in the above Table.

(f) Stress values for -20 to 100°F are applicable for colder temperatures when toughness requirements of Section III or Section VIII are met.

Min Allowable Tensile Stress

Allowable Stress used in ASME BPV Code Section VIII Div. 1 Calculations

$\frac{70}{16.7} > 4$ Safety Factor

APPENDIX B

ACME Cryogenics, Inc.
Pressure Vessel Calculations for:

Lawrence Livermore Labs Pressure Vessel
S/O: M058560, qty (4) ea

Vessel Description:
4" dia. x 36 OAL vessel w/(1) nozzle

Design Code:
ASME Boiler & Pressure Vessel Code Sect. VIII, Div. 1
1998 Edition

Special Notes: Vessel designed w/ SF=4 as is standard with code.

Design Engineer: A. Halsey Date: 1/15/99
Engineer Review: M A Fail, PE Date: 1/26/99

NOTE: ASME Sect 8, Div 1 uses Mat'l Allowable
Stresses = Min. tensile stress / 4 ∴ 4:1 S.F. is MET.

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Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
TOP HEAD	3000.0	158.0	3869.3	4253.4	0.0	1.099		Not applicable	0.000
SHELL	3000.0	158.0	3095.6	3402.9	0.0	1.099		Not applicable	0.000
BOTTOM HEAD	3000.0	158.0	3869.3	4253.4	0.0	1.089		Not applicable	0.000
N1	3000.0	158.0	3000.0	3000.0	0.0	1.000		Not applicable	0.000

Vessel MAWP hot & corroded is 3000 psi @ 158 degrees F.

Vessel MAP new & cold is 3000 psi @ 70 degrees F.

Vessel is not designed for external pressure.

Hydrotest pressure calculation based on MAWP

= 1.5*MAWP*1 = 4500 psi or PNEUMATIC = 1.25 x MAWP x 1 = 3750 psi

Vessel hydrotest pressure, horizontal position is 4500 psi.

Design notes:

Minimum thickness is 1/16 inch per UG-16(b).
Corrosion weight loss is 100% of theoretical loss.
UG-23 stress increase is 1.2.
Test liquid specific gravity is 1.
Minimum nozzle outside projection 1 inches.
Maximum stress allowed during field hydrotest is 90% of yield.
Butt weld thickness transitions made by removing material.
P-No 1 material >1.25 to 1.5 in. thick is preheated (UCS-56).
Interpretation VIII-1-83-66 has been applied.

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Thickness Summary

Component Identifier	Dia (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (in)
Top head	4.50 od		0.5310*	0.4323	0.85	internal			
Shell	4.50 od	30.00	0.5625	0.4783	0.85	internal			
Bottom head	4.50 od		0.5310*	0.4323	0.85	internal			

Nom t - vessel wall thickness
Req t - required vessel thickness due to governing loading + corrosion
E - longitudinal seam joint efficiency
* - head minimum thickness

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs