LBL-19326
UC-38

Lawrence Berkeley Laboratory

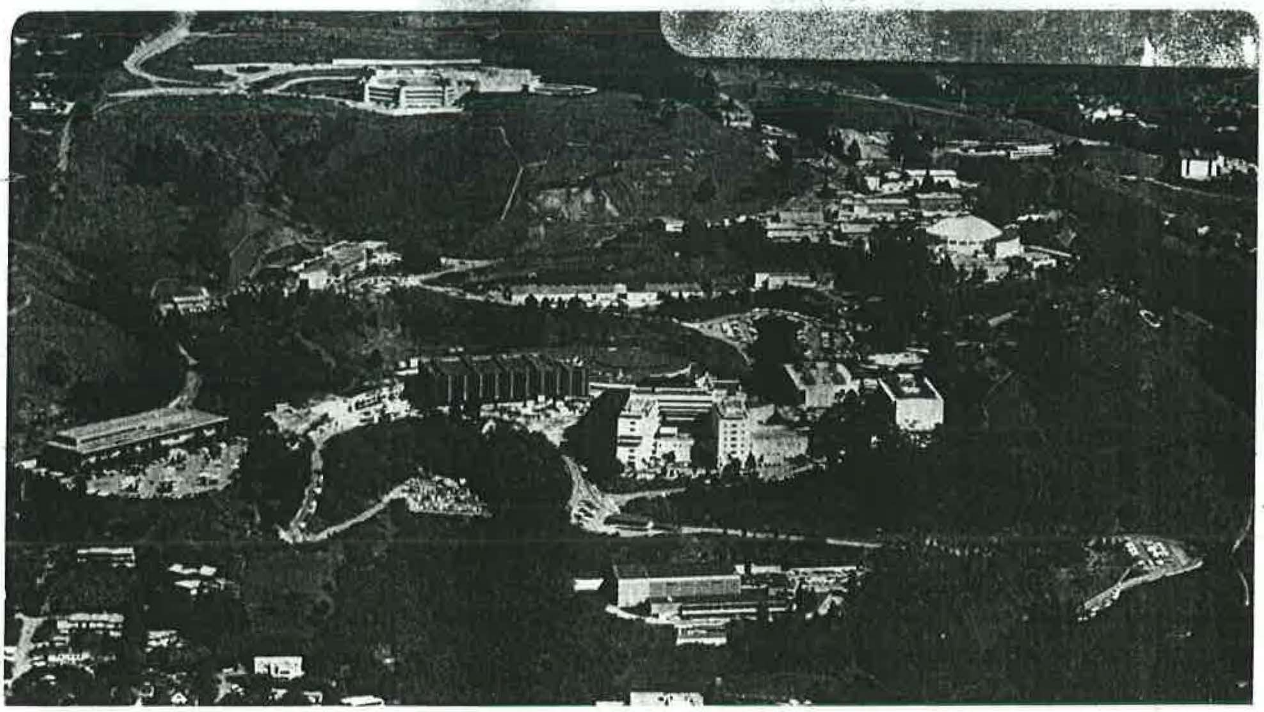
UNIVERSITY OF CALIFORNIA

Engineering Division

AN AUTOMATED SYSTEM FOR MEASURING
VACUUM OUTGASSING RATES

R. Dormido, W.G. Ghiorso, L. Schalz,
and S.S. Rosenblum

June 1985



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-19326

AN AUTOMATED SYSTEM FOR MEASURING VACUUM OUTGASSING RATES*

Ruth Dormido, William G. Ghiorso, Loren Schalz, and Stephen S. Rosenblum

University of California
Lawrence Berkeley Laboratory
One Cyclotron Road
Berkeley, CA 94720

June 1985

*This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

AN AUTOMATED SYSTEM FOR MEASURING VACUUM OUTGASSING RATES*

Ruth Dormido, William B. Ghiorso, Loren Schalz, and Stephen S. Rosenblum†

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Introduction

Particle accelerators and particle physics detectors require large electrical insulators with metal embedments having vacuum on one side and an insulating fluid or gas on the other. For high vacuum requirements they may be fabricated out of sintered alumina using vacuum brazing to attach the metal pieces. Although this produces quite acceptable devices, it is very time-consuming and expensive, involving the pressing, firing and grinding-to-size of the alumina parts, the manufacture of a brazing fixture and the fabrication of the individual braze foils. After firing in a vacuum oven, if there are any vacuum leaks in the braze joints, the part usually must be rejected. For moderate vacuum service one can use cast or machined plastics which are glued together. Although this is a much less expensive fabrication method, the vacuum outgassing rates of these assemblies can be three orders of magnitude higher than the brazed alumina ones, which may be unacceptable for many applications.

In particular, for a heavy ion accelerator driver for inertial confinement fusion energy production, one requires many miles of high quality insulators. It was with these ideas in mind that we undertook a program at Lawrence Berkeley Laboratory to develop castable insulators using plastics filled with inorganic materials.

Work has been done on all these aspects and is detailed in the HIFAR group semi-annual reports. The systems were selected mostly on the basis of manufacturer's data on the electrical and mechanical performance of the materials in electrical utility service. Very little data was available on vacuum outgassing. In the course of making the necessary vacuum outgassing measurements, it became clear that if the data-taking were automated it could be easily done with a few hours labor per week per sample rather than

*This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

†Present address: Varian Associates, Palo Alto, CA 94303.

about the 8 hours/sample required with manual data acquisition and analysis. The system that was developed is based on an Hewlett Packard HP-85 computer which controls the experiment and then evaluates the data and plots it.

Description of Experimental Method

The measuring system uses the conductance of a fixed orifice and the readings of two Bayard-Alpert gauges to determine outgassing rates. A schematic diagram of the vacuum system is shown in Figure 1. It consists of a 14 inch diameter stainless steel vessel separated from a trapped diffusion pump by a movable orifice. The entire system is constructed of welded stainless steel and sealed with copper gaskets except for the diffusion pump and trap and the two gate valves which are sealed with Viton gaskets. The movable orifice is constructed from a 6 inch gate valve with a special insert, a tapered hole 0.182 inches in diameter. This hole has a calculated conductance of 1.75 liters/sec for air when the gate valve is in its "closed" position. For most of the time during a measurement, this "orifice valve" is open which approximates the normal situation in an accelerator where the pumping speeds for desorbed gasses are high. This prevents spuriously high outgassing rates which would occur if the low conductance orifice were always in place thereby allowing desorbed gasses to be reabsorbed rather than pumped away.

When an outgassing rate is to be measured, the orifice valve is closed under computer control and the pressure on the two Bayard-Alpert ionization gauges (Figs. 1 and 2) is monitored and logged on paper and magnetic tape until it reaches equilibrium(typically 3-15 minutes). The difference between the two gauge readings(always more than an order of magnitude in pressure) multiplied by the known orifice conductance is taken to be the measured outgassing rate. In addition, a UTI Residual Gas Analyzer attached to the sample space was used to take scans of the entire mass range from mass 1-300. In all cases, no significant peaks were seen except for those expected in clean vacuum systems (masses 2,18,28,44).

The measurements were done according to the following procedure:

1) Close gate valve to diffusion pump, open the orifice valve, and vent the system with 99.998% pure argon gas.

2) Remove the blank flange on the end of the sample chamber for exactly 2 minutes. During this time remove the previous sample and insert the new sample.

3) Install the blank flange with a new copper gasket and rough pump the system with a mechanical pump via a pre-baked zeolite trap.

4) After the pressure reaches 10^{-2} torr close rough pump valve and open gate valve to diffusion pump. At this point the measurement of time for the experiment begins. Typically, it takes about 10 minutes from the start of roughing to get the system onto the diffusion pump.

5) The orifice valve is normally kept open and the system pressure is logged on paper and on magnetic tape as a function of time. After 1 hour, the orifice valve is closed and the pressure rise in the sample space is monitored until it reaches its exponential saturation value. The outgassing rate is recorded, and the orifice valve is opened. This procedure is repeated several times throughout the measurement period which occupies typically 40-100 hours (this set of data is called "initial pumpdown").

6) Next, the chamber is heated to 140° C and the outgassing rate is measured several times in the same manner as described in 5), except that this part would only continue for 24 hours.

7) Following vacuum bakeout, the system was allowed to cool, during which time outgassing data is collected as in 5 above(this set of data is called "after vacuum bakeout").

During the early measurements, the data was taken manually, i.e. the experimenter had to manually close the orifice valve and log the results by hand. As a result of automation the computer reads the gauges and opens and closes the orifice. The main improvements in the data taking resulting from this automation aside from reduction of labor is that the data points were taken much more frequently and at equally spaced intervals on a logarithmic time scale.

The quality of the performance of the system can be judged by the high level of reproducibility of the blank runs in figures 2a and 2b. An electronic functional block diagram is shown in figure 3. The interface to the HP-85 is through the HP-BCD interface which was chosen to be compatible with the digital output of the Varian Model 845 ion gauge supply.

The data acquisition program source code is given in Appendix A. In addition to this, there are several programs which generate log-log plots of the data vs. time, which are similar to figure 1, which is done on the attached HP-7470 plotter.

Acknowledgements

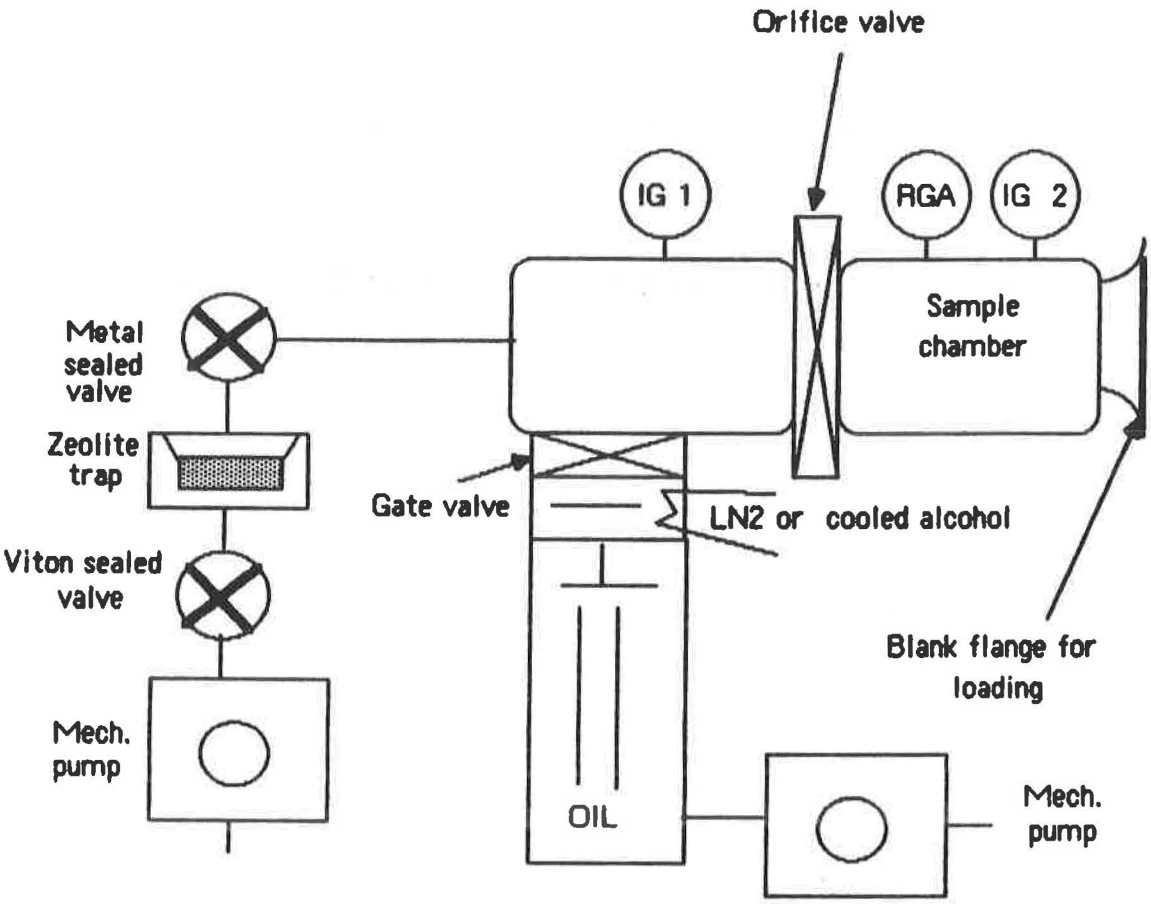
The authors would like to acknowledge E. C. Hartwig and A. Faltens for providing support and encouragement to carry out this work.

FIGURE CAPTIONS

1. Schematic Diagram of the Vacuum System IG = ionization gauge, RGa = residual gas analyzer.

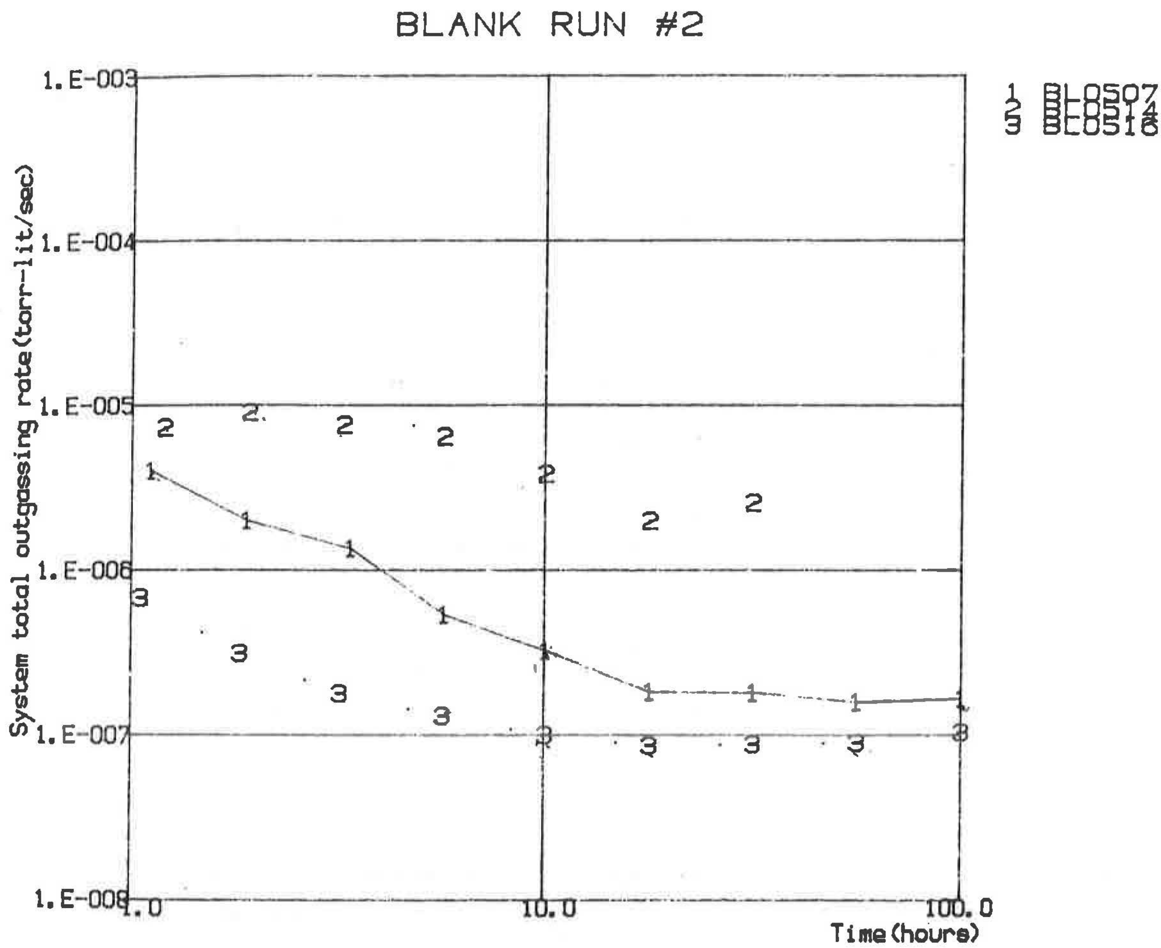
2(a) and 2(b): Two Blank Runs Showing Empty Chamber Outgassing Rate as a Function of time

3. Electronic block diagram of data acquisition and control system.



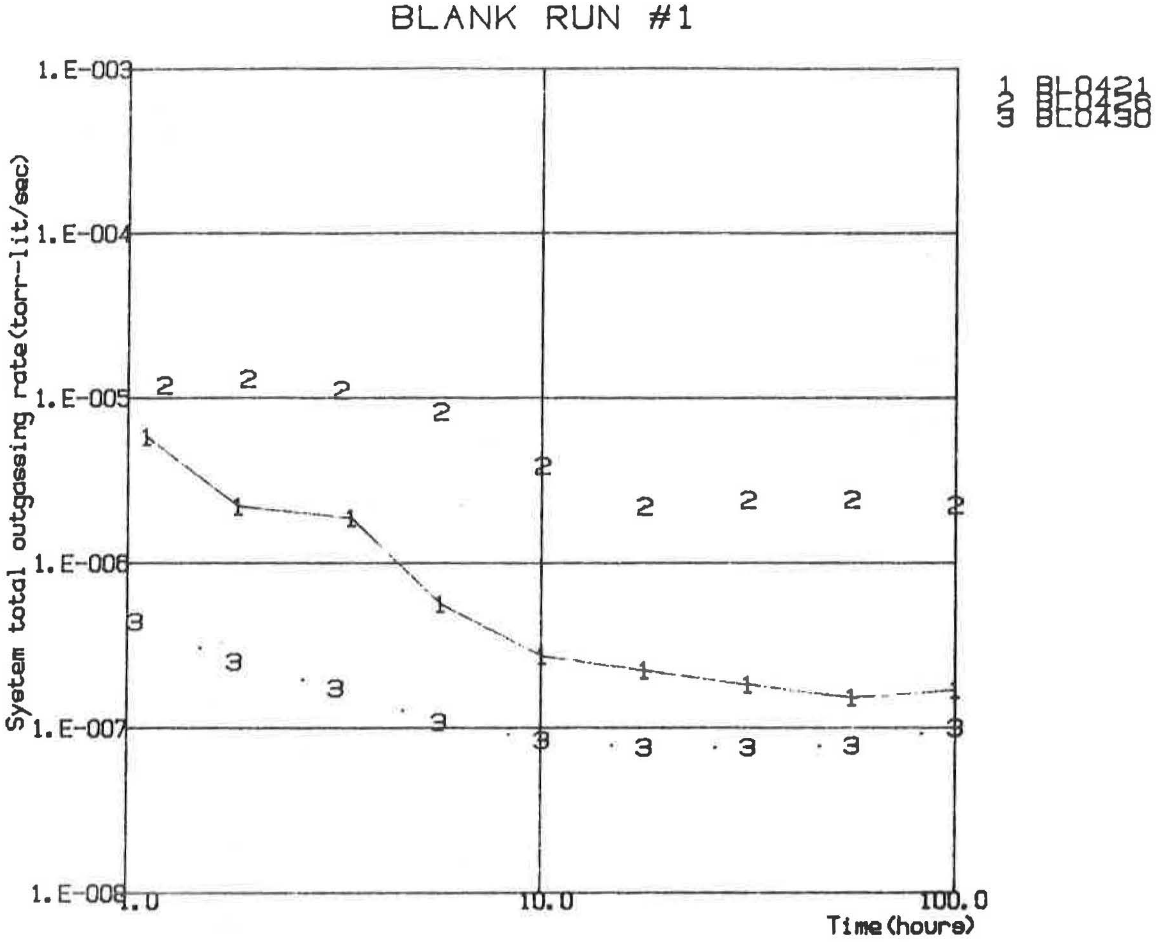
XBL 853-1692

Figure 1



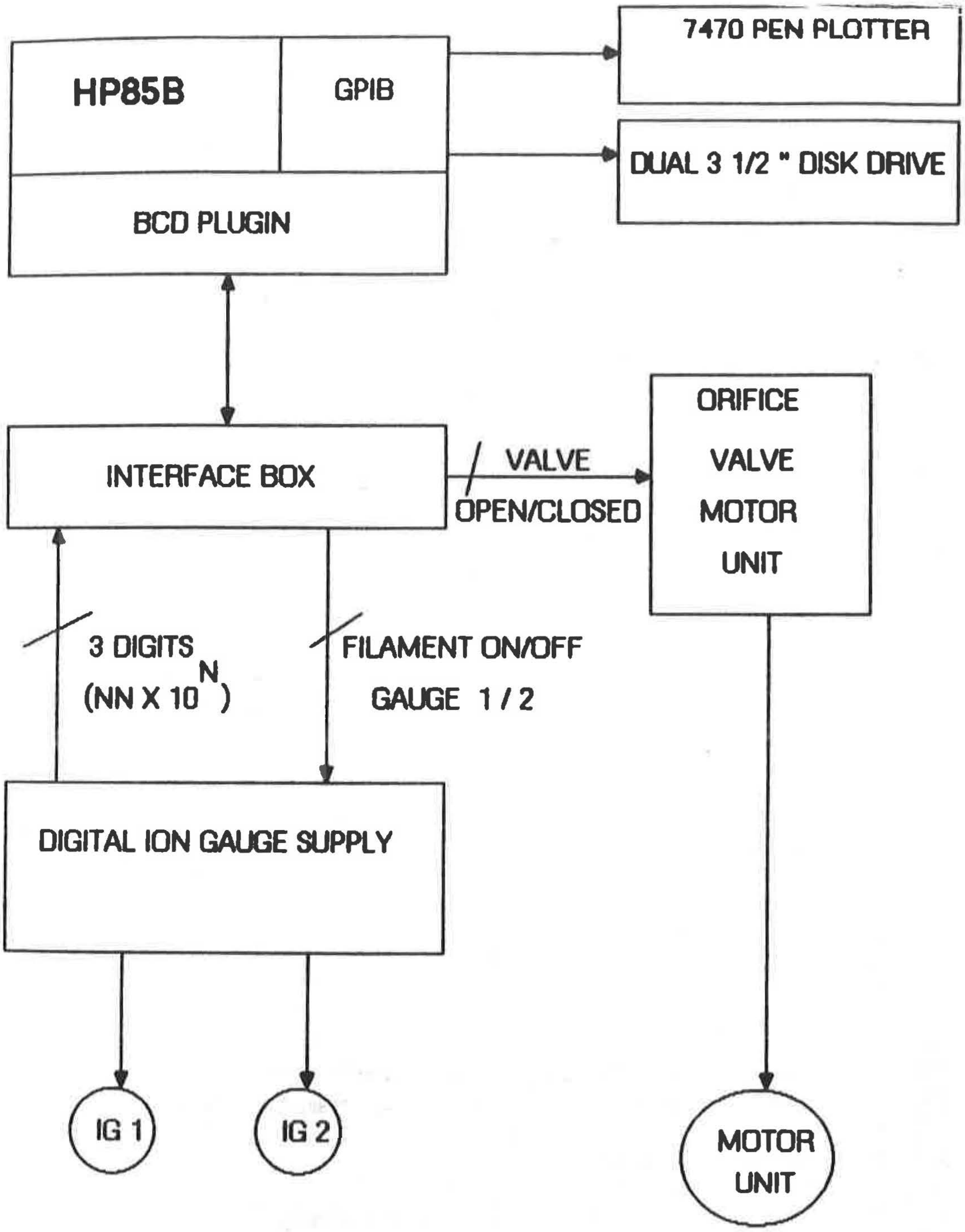
XBL 853-1691

Figure 2(a)



XBL 853-1690

Figure 2(b)



XBL 853-1693

Figure 3

```
    !
 _J ! OUTGASSING EXPERIMENT
 30 !
 40 ! RUTH DORMIDO 8/18/83
 50 ! LOREN SHALZ  2/07/84
 60 !        version APR 2#1(SSR)
 70 !
 80 ! variable/arrays
 90 ! A$      valve open/closed
100 ! A1$      Last valve open/closed
110 ! B$      Used in obtaining pressure reading
120 ! B       Returns pressure reading from subroutine
130 ! C$      filament on/off
140 ! C1$     Last filament on/off
150 ! C       Save current cursor column location
160 ! D$      gauge G1/G2
170 ! D1$     Last gauge G1/G2
175 ! D9$     date string returned by calls to DATE$(yy/mm/dd)
180 ! D       DATE function argument
181 ! D0      Julian date number of startup date
190 ! D2      D( ,D2) is next to last in D(,)
200 ! D3      D( ,D3) is last in D(,)
210 ! D(,)    Phase 3 readings
?20 !         D(1,n) is ith pressure reading.
 30 !         D(2,n) is time of ith pressure reading in elapsed seconds.
!40 !         After 5th reading, D( ,4) & D( ,5) are next latest & latest readings.
  0 ! E       See pressure read subroutine
260 ! F1      Timer #1 timed out flag
270 ! F2      Timer #2 timed out flag
?80 ! F3      Timer #3 timed out flag
290 ! H$      hhh:mm:ss formed in FNH$
300 ! H       Used by FNH$
310 ! H4      Used by FNH$
320 ! H()     Used by FNH$
330 ! I5      Interval counter.
340 ! J5      Sample within interval counter.
350 ! K5      Processing phase
360 !         Phase 1 - valve open, reading gauge 2
370 !         Phase 2 - filament 1 warmup period(valve open)
380 !         Phase 3 - valve closed, watch gauge 1 pressure rise, take a sample.
390 ! N$      Data file name
400 ! N3     Counts phase 3 readings
410 ! N4     Where to store a phase 3 reading in D()
420 ! N5      Number of intervals. 1st starts at 1 hr. from startup,
430 !         2nd at 10 hr. from startup, 3rd at 100 hr from startup, etc.
440 ! P1$    Phase 1 title
450 ! P3     .05 * dP/dT @ T0
460 ! P()    Last gauge 2 pressure and time reading. Used to calculate
470 !        outgassing rate.
480 ! Q$     Operator responses to queries
490 ! R      Save current cursor row location
 '2 ! R7     Key 7 flag
 94 ! R8     Key 8 flag
500 ! S      FNH$'s argument
505 ! S0     Seconds from midnight of startup time
510 ! S1     Seconds/minute
520 ! S2     Seconds/hour
530 ! S3     Msec/sec
```

```
535 ! S9    Stores time in FNR0.
540 ! T     Returns reading time from subroutine
550 ! T4    Time between reads in sec.
560 ! T5    Next valve closure time in seconds from startup.
570 ! T6    Next filament 1 startup time in seconds from startup
580 ! T7    Marks valve closure time in sec from startup
590 ! T8    Current time from startup
600 ! T9    Used with T8 to decied when to update time info on crt
610 ! T1()  Time between phase 1 readings in MINUTES for each interval.
620 ! T2()  Filament 1 warmup time in MINUTES for each interval.
630 ! T3()  Time between phase 3 readings in SECONDS for each interval.
640 ! T4()  Maximum phase 3 reading time in MINUTES for each interval.
650 ! V     Time in SECONDS for valve to close.
660 ! X     Used by subroutine to acquire pressure.
670 ! Z     Number of values put into Z()
680 ! Z1    Index when printing values in Z() to tape.
690 ! Z()   Values to print to tape.
700 !
710 ! Tape file format
720 !
730 !      where P1=G1 pressure reading
740 !            P2=G2 pressure reading
750 !            T1=time of P1 in seconds from startup time
760 !            T2=time of P2 in seconds from startup time
770 !
780 !
790 ! Comment     string containing operator comment
800 ! Julian date numeric containing yyddd of startup date
810 ! time        numeric containing startup time in seconds from midnight
815 !             of startup date
820 ! -1.E99      indicates start of phase 1 G2 readings
830 ! P2,T2       G2 readings
840 !   .
850 !   .
860 !   .
870 ! -2.E99      Indicates phase 1 interruption for RGA via key 7
880 !   T         Time of interruption in seconds from startup
890 ! -3.E99      Indicates end of phase 1 interruption for RGA via key 8
900 !   T         Time interruption ended in seconds from startup
910 ! -6.E99      Indicates start of G1 readings prior to valve closure
920 ! P1,T1
930 !   .
940 !   .
950 !   .
960 ! -4.E99      Indicates start of G1 readings after valve closure
970 ! P1,T1
980 !   .
990 !   .
1000 !   .
1010 ! -5.E99      Indicates sample results
1020 !   R          outgassing rate
1030 ! P2,T2       base pressure
1040 ! P1,T1       sample pressure
1050 !
1060 DIM A$[6],A1$[6],B$[7],C$[3],C1$[3],D$[2],D1$[2],H$[9],N$[6],P1$[23],Q$[95]
1070 DIM D(2,3),H(3),N(3),P(2),T1(3),T2(3),T3(3),T4(3),Z(6)
1080 INTEGER X
1090 !
1100 D3=3 @ D2=D3-1
1110 !
```

```
1120 N5=3 ! number of intervals
1130 FOR I=1 TO N5
  40 READ N(I),T1(I),T2(I),T3(I),T4(I)
1150 NEXT I
1160 DATA 4,20,15,30,30
1170 DATA 4,20,15,30,30
1180 DATA 1,20,15,30,30
1190 !
1200 S1=60 ! sec/min
1210 S2=3600 ! sec/hr
1220 S3=1000 ! msec/sec
1230 V=60 ! time for full valve movement in sec.
1240 !
1250 READ P1$
1260 DATA "Phase 1 - valve opening"
1270 !
1280 PRINTER IS 2
1290 !
1300 ! Set date and time if necessary
1310 !
1320 CLEAR
1330 D=DATE DIV 1000
1340 IF D>=84 THEN 1570
1350 OFF ERROR
1360 LINPUT "Enter date as mm/dd/yyyy",Q$
1370 ON ERROR GOTO 1350
1380 D=MDY(Q$)-MDY("12/31/"&VAL$(VAL(Q$[7,10])-1))
1390 D=D+VAL(Q$[9,10])*1000
  00 SETTIME D,0
1410 OFF ERROR
1420 LINPUT "Enter time as hh:mm:ss",Q$
1430 ON ERROR GOTO 1410
1440 SETTIME HMS(Q$),D
1450 OFF ERROR
1460 CLEAR
1470 D=DATE
1480 T=TIME
1490 DISP "Date = ";DATE$
1500 DISP "Time = ";TIME$
1510 DISP
1520 LINPUT "Are date and time ok?",Q$
1530 IF Q$="N" THEN 1350
1540 !
1550 ! Initialize bcd interface registers. Set valve open, filaments off, G2.
1560 !
1570 A$="OPEN" @ C$="OFF" @ D$="G2"
1580 GOSUB 4340
1590 !
1600 ! Obtain data file name. Create and open file.
1610 !
1620 CLEAR
1630 DISP "Outgassing measurements"
1640 DISP @ DISP DATE$;" ";TIME$ @ DISP
  50 LINPUT "Enter data file name",Q$
1660 I=LEN(Q$)
1670 IF I=0 OR I>6 THEN 1650
1680 N$=Q$
1690 CLEAR
1700 DISP "Creating ";Q$
1710 CREATE N$,INT(12100+255)/256
```

```
1720 ASSIGN# 1 TO N$
1730 !
1740 CLEAR
1750 DISP "Enter comment <= 95 characters"
1760 DISP "for file ";N$
1770 LINPUT "",Q$
1780 PRINT# 1 ; Q$
1790 !
1800 ! Establish startup time. Elapsed time returned by FNRO will be
1810 ! referenced to this point in time. Print startup time on tape.
1820 D=DATE @ D9$=DATE$ ! make sure date does not change between DATE & TIME
1830 T=TIME
1840 IF DATE#D OR DATE$#D9$ THEN 1820
1845 D0=MDY(D9$[4,8]&"/19"&D9$[1,2]) ! startup julian date
1846 S0=T ! startup time
1850 Z=2 @ Z(1)=D @ Z(2)=T
1860 GOSUB 5280
1870 CLEAR
1880 PRINT @ PRINT
1890 PRINT "Outgassing measurements" @ PRINT
1895 PRINT Q$ @ PRINT
1900 PRINT "File ";N$;"  ";HGL$(DATE$);"  ";HGL$(HMS$(T)) @ PRINT
1910 PRINT "Interval  #samples  Start time"
1920 FOR I5=1 TO N5
1930 T5=10^(I5-1)*S2 ! sec from startup
1940 PRINT USING 1950 ; I5,N(I5),FNH$(T5)
1950 IMAGE 5D,5X,5D,6X,9A
1960 NEXT I5
1970 PRINT
1975 ENABLE KBD 64+32+1+2 ! selectallowed keys
1980 !
1990 ! Loop over the intervals
2000 !
2010 FOR I5=1 TO N5
2020 !
2030 ! Loop over the samples in the interval
2040 !
2050 FOR J5=1 TO N(I5)
2060 !
2070 ! ############################## Phase 1 ###############################
2080 !
2090 K5=1
2100 !
2110 ! Determine valve closing time(T5) and filament #1 turn on time
2120 ! in seconds from startup. Skip to next sample if we're to late.
2130 !
2140 T5=10^(I5-1+(J5-1)/N(I5))*S2 ! sec from startup
2150 T6=T5-T2(I5)*S1 ! sec from startup
2160 IF FNRO>=T6 THEN 3940
2170 T9=0
2180 !
2190 ! Clear screen. Open valve. Turn on filament 2. Print -1e99 to tape to
2200 ! indicate phase 1 data.
2210 !
2220 A$="OPEN" @ C$="ON" @ D$="G2"
2230 GOSUB 4340 ! Start to open valve,filament on
2240 T7=FNRO ! mark start of opening valve
2250 GOSUB 5440 ! clear screen
2260 OFF CURSOR
2270 ALPHA 1,1
```

```
2280 DISP TAB(5);P1$
2290 PRINT
2300 PRINT "Interval";I5;" Sample";J5;FNH$(T5)
2310 PRINT "Valve opened ";HGL$(DATE$);" ";HGL$(TIME$)
2320 Z=1 @ Z(1)=-1.E99
2330 GOSUB 5280
2340 GOSUB 6100 ! Wait for valve to open
2350 !
2360 ! Read gauge 2 pressure every T5(I5) minutes until time to
2370 ! warm up filament 1. Printreadings on paper and tape.
2380 ! Display time information on crt.
2390 !
2400 T4=T1(I5)*S1
2410 GOSUB 5560
2420 F1,R7,R8=0
2430 ON TIMER# 1,T4*S3 GOSUB 6760
2440 ON KEY# 7,"CLOSE" GOSUB 7000
2450 ON KEY# 8,"OPEN" GOSUB 7001
2460 OFF CURSOR
2470 ALPHA 1,1
2480 DISP P1$[1,20]
2490 !
2500 IF F1 THEN F1=0 @ GOSUB 5560
2502 IF R7 THEN R7=0 @ GOSUB 6270
2503 IF R8 THEN R8=0 @ GOSUB 6520
2510 T8=FNR0
2520 IF T8>=T6 THEN 2700
2530 IF T8<T9+2 THEN 2500 ! 2 sec between crt updates
2540 T9=T8
2550 OFF CURSOR
2560 ALPHA 3,1
2570 DISP "DATE ";DATE$
2580 DISP "TIME ";TIME$;"  current"
2590 DISP TAB(5);FNH$(T8);"  elapsed"
2600 DISP TAB(5);FNH$(T6-T8);"  to filament 1 on"
2610 DISP TAB(5);FNH$(T5-T8);"  to valve closure"
2620 DISP TAB(5);FNH$(T4-READTIM(1));"  to next reading"
2630 GOTO 2500
2640 !
2650 ! ############################## Phase 2 ##############################
2660 !
2670 ! Read gauge 2 pressure for base pressure. Turn on filament 1.
2680 ! Wait for filament 1 to warm up.
2690 !
2700 OFF TIMER# 1
2710 OFF KEY# 7
2720 OFF KEY# 8
2730 K5=2
2740 IF A$="OPEN" AND C$="ON" AND D$="G2" THEN 2770
2750 PRINT "END PHASE 1 ";HGL$(DATE$);" ";HGL$(TIME$)
2760 !
2770 GOSUB 5560 ! read base pressure
2780 P(1)=B @ P(2)=T ! save for outgassing rate calculation
2790 !
2800 C$="OFF" ! turn off filament 2
2810 GOSUB 4340
2820 D$="G1" ! switch to gauge 1
2830 GOSUB 4340
2840 C$="ON" ! turn on filament 1
2850 GOSUB 4340
```

```
2860 !
2870 F1,F3=0
2880 ON TIMER# 1,(T5-FNRO)*S3 GOSUB 6760 ! flag valve closure
2890 ON TIMER# 3,5*S1*S3 GOSUB 6800 ! read G1 every 5 min till valve closure
2900 Z=1 @ Z(1)=-6.E99 ! Tape id for G1 readings before valve closure
2910 GOSUB 5280
2920 !
2930 OFF CURSOR ! meanwhile update time display on crt
2940 FOR I=1 TO 8 ! clear upper lines, leaving any error messages
2950 OFF CURSOR
2960 ALPHA I,1
2970 DISP
2980 NEXT I
2990 OFF CURSOR
3000 ALPHA 1,1
3010 DISP TAB(5);"Phase 2 - Filament 1 warmup"
3020 PRINT "Filament 1 ";HGL$(DATE$);" ";HGL$(TIME$)
3030 T9=0
3040 !
3050 IF F1 THEN F1=0 @ GOTO 3230
3060 IF F3 THEN F3=0 @ GOSUB 5560 ! read G1
3070 T8=FNRO
3080 IF T8<T9+2 THEN 3050 ! update crt every 2 sec
3090 T9=T8
3100 OFF CURSOR
3110 ALPHA 3,1
3120 DISP "DATE ";DATE$
3130 DISP "TIME ";TIME$;"  current"
3140 DISP TAB(5);FNH$(T8);"  elapsed"
3150 DISP TAB(5);FNH$(T5-T8);"  to valve closure"
3160 GOTO 3050
3170 !
3180 ! ############################## Phase 3 ##############################
3190 !
3200 ! Close valve. Watch gauge 1 pressure rise.
3210 ! Take sample. Compute outgassing rate.
3220 !
3230 OFF TIMER# 1
3240 OFF TIMER# 3
3250 GOSUB 5560 ! final G1 reading before valve closure
3260 K5=3
3270 T9=0
3280 A$="CLOSED" ! start valve closure
3290 GOSUB 4340
3300 T7=FNRO ! mark valve closure start
3310 N3=0 ! reset number of phase 3 readings
3320 P3=-9.9E100 ! reset slope at t0
3330 !
3340 Z=1 @ Z(1)=-4.E99 ! phase 3 id to tape
3350 GOSUB 5280
3360 !
3370 OFF CURSOR
3380 ALPHA 1,1
3390 DISP TAB(5);"Phase 3 - valve closing"
3400 FOR I=3 TO 8
3410 OFF CURSOR
3420 ALPHA I,1
3430 DISP
3440 NEXT I
3450 PRINT "Valve closed ";HGL$(DATE$);" ";HGL$(TIME$)
```

```
3460 !
3470 GOSUB 6100 ! wait for valve to close
3480 !
3490 ! Valve is closed. Start timing readings. Take first reading.
3500 !
3510 T9=0
3520 T7=FNRO ! mark start of gauge 1 reads
3530 F1=0
3540 ON TIMER# 1,T3(I5)*S3 GOSUB 6760
3550 GOSUB 5820 ! take pressure reading
3560 OFF CURSOR
3570 ALPHA 1,1
3580 DISP TAB(5);"Phase 3 - Valve closed"
3590 !
3600 IF F1 THEN F1=0 @ GOTO 3700
3610 T8=FNRO ! update timing info on crt
3620 IF T8>T7+T4(I5)*S1 THEN 3750 ! check for timeout
3630 IF T8<T9+2 THEN 3600 ! update every 2 sec.
3640 T9=T8
3650 OFF CURSOR ! update
3660 ALPHA 3,1
3670 DISP FNH$(INT(T8-T7));" since valve closed."
3680 GOTO 3600
3690 !
3700 GOSUB 5820 ! read gauge 1 pressure
3710 !
3720 IF P3=-9.9E100 THEN 3600 ! test for dp/dt < .05 dp/dt @ t0
3730 IF (D(1,D3)-D(1,D2))/(D(2,D3)-D(2,D2))>P3 THEN 3600
3740 !
3750 OFF TIMER# 1 ! take sample
3760 GOSUB 5820
3770 !
3780 Z(2)=2*(B-P(1)) ! compute outgassing rate
3790 Z=6
3800 Z(1)=-5.E99 ! sample data tape id
3810 Z(3)=P(1) ! base pressure
3820 Z(4)=P(2) ! base pressure time
3830 Z(5)=B ! sample pressure
3840 Z(6)=T ! sample pressure time
3850 GOSUB 5280 ! print to tape
3860 !
3870 ON ERROR GOSUB 5670 ! print to paper
3880 PRINT
3890 PRINT USING "16A,D.DE" ; "Base pressure = ",P(1)
3900 PRINT USING "18A,D.DE" ; "Sample pressure = ",Z(5)
3910 PRINT USING "18A,D.DDE" ; "Outgassing rate = ",Z(2)
3920 PRINT "Elapsed time = ";FNH$(T)
3930 !
3940 NEXT J5 ! next sample
3950 !
3960 NEXT I5 ! next interval
3970 !
3980 ! ############################## All done ##############################
3990 !
4000 ASSIGN# 1 TO * ! close file
4010 C$="OFF"
4020 GOSUB 4340 ! turn off filament
4030 A$="OPEN" ! open valve
4040 GOSUB 4340
4050 !
```

```
4060 CLEAR
4070 DISP "Outgassing experiment complete"
4080 DISP
4090 T8=FNR0
4100 DISP "Total elapsed time = ";FNH$(T8)
4110 STOP
4120 !
4130 ! ########################### Subroutines ##############################
4140 !
4150 ! Subroutine to set valve, gauge and filament states  and
4160 ! take pressure readings via BCD interface.
4170 !
4180 ! uses Flag 3 for starting
4190 !
4200 !  On entry
4210 !
4220 ! A$ is desired valve setting OPEN/CLOSED
4230 !  C$ is desired filament setting ON/OFF
4240 !  D$ is desired gauge G1/G2640 !
4250 !
4260 !  B returns pressure
4270 !  T returns time pressure was read in seconds from startup.
4280 ! Port 10 bit assignments:
4290 ! 1: fil.on. Filament goes on on low to high transition
4300 ! 2: fil.off. Filament goes on on low to high transition
4310 ! 4: G2/G1 (high/low)
4320 ! 8: open/close (high/low)
4330 !
4340 IF FLAG(3) THEN GOTO 4700
4350 !
4360 !
4370 ! ##set control registers##
4380 !
4390 RESET 3
4400 ! set interrupt mask
4410 CONTROL 3,1 ; 0
4420 ! set mantissa digits (2)
4430 CONTROL 3,3 ; 2
4440 ! set exponent digits (1)
4450 CONTROL 3,4 ; 1
4460 ! set function digits (0)
4470 CONTROL 3,5 ; 0
4480 ! set digits to right of dp
4490 CONTROL 3,6 ; 1
4500 !
4510 ! ####set logic sense####
4520 !
4530 ! set control and handshake
4540 CONTROL 3,7 ; 32
4550 ! set input data
4560 CONTROL 3,8 ; 0
4570 ! set function data
4580 CONTROL 3,9 ; 0
4590 ! set sign and port 10
4600 ! sign of exp inverted to
4610 ! fix floating input
4620 CONTROL 3,10 ; 16
4630 ! Guarantee valve open, filament off, G2 and set "first time flag"
4640 CONTROL 3,2 ; 8+4@ WAIT 1000 @ CONTROL 3,2 ; 8+4+2 ! Open, G2, filament off
4650 A1$="OPEN" @ C1$="OFF" @ D1$="G2"
```

```
4660 SFLAG 3 ! initialize just once
4670 !
  80 ! ***write to Port 10***
 690 !
4700 X=0
4710 IF D$#D1$ THEN 4810 ! New gauge requested?
4720 !
4730 IF A$="OPEN" THEN X=X+8 ! Same gauge. Set valve & gauge.
4740 IF D$="G2" THEN X=X+4
4750 CONTROL 3,2 ; X ! Set valve and gauge. Drop filament on & off lines.
4760 WAIT 1000
4770 IF C$=C1$ THEN GOTO 4900 ! New filament state requested?
4780 IF C$="ON" THEN CONTROL 3,2 ; X+1@ WAIT 2000 @ GOTO 4900 ! Turn on filament.
4790 IF C$="OFF" THEN CONTROL 3,2 ; X+2@ GOTO 4900 ! Turn off filament
4800 !
4810 IF A1$="OPEN" THEN X=X+8 ! New gauge. Turn off filament.
4820 IF D1$="G2" THEN X=X+4
4830 CONTROL 3,2 ; X@ WAIT 1000 @ CONTROL 3,2 ; X+2 ! Drop & raise fil off.
4840 X=0 ! Switch to new gauge with filaments off
4850 IF A$="OPEN" THEN X=X+8
4860 IF D$="G2" THEN X=X+4
4870 CONTROL 3,2 ; X@ WAIT 1000
4880 IF C$="ON" THEN CONTROL 3,2 ; X+1@ WAIT 2000 ! Fil on
4890 !
4900 A1$=A$ @ C1$=C$ @ D1$=D$
4910 !
4920 ! ******read gauge******
4930 IF C$="OFF" THEN RETURN ! Read only if filament on
  40 SET TIMEOUT 3;4000
4950 ON TIMEOUT 3 GOTO 5010
4960 ENTER 3 USING "K" ; B$
4970 T=FNRO
4980 IF B$[1,1]="+" THEN E=1 ELSE E=0
4990 B=VAL(B$[2,7])
5000 RETURN
5010 OFF TIMEOUT 3 @ C$="OFF" @ B=0 @ HALT 3
5020 T=FNRO
5030 RETURN
5040 END
5050 !
5060 ! Function to convert seconds to hhh:mm:ss
5070 !
5080 DEF FNH$(S)
5090 H=MAX(0,S)
5100 H(1)=H DIV S2 ! hours in S
5110 H4=H-H(1)*S2 ! minutes & seconds left
5120 H(2)=H4 DIV S1 ! minutes
5130 H(3)=INT(H4 MOD S1) ! seconds
5140 H$=VAL$(H(1)) ! 3 digits for hours
5150 H4=LEN(H$)
5160 IF H4<3 THEN H$=RPT$(" ",3-H4)&H$
5170 FOR H4=2 TO 3 ! 2 digits or minutes and seconds
5180 H$=H$&":"
  90 IF H(H4)<10 THEN H$=H$&"0"
 200 H$=H$&VAL$(H(H4))
5210 NEXT H4
5220 FNH$=H$
5230 FN END
5240 !
5250 ! Subroutine to print values to tape. If error, display message
```

```
5260 ! on crt lne 10 and keep going.
5270 !
5280 ON ERROR GOTO 5340
5290 FOR Z1=1 TO Z
5300 PRINT# 1 ; Z(Z1)
5310 NEXT Z1
5320 OFF ERROR
5330 RETURN
5340 OFF ERROR
5350 OFF CURSOR
5360 ALPHA 10,1
5370 DISP "Tape ERR ";ERRN;". ";HGL$(TIME$)
5380 OFF CURSOR
5390 ALPHA 13,1
5400 RETURN
5410 !
5420 ! subroutine to clear all 4 screens
5430 !
5440 FOR I=1 TO 4
5450 OFF CURSOR
5460 ALPHA 1+(I-1)*16,1
5470 CLEAR
5480 NEXT I
5490 OFF CURSOR
5500 ALPHA 1,1
5510 RETURN
5520 !
5530 ! subroutine to read gauge pressure and print pressure
5540 ! and time of reading to both tape and paper.
5550 !
5560 GOSUB 4340 ! take reading
5570 Z=2 @ Z(1)=B @ Z(2)=T ! print reading to tape
5580 GOSUB 5280
5590 ON ERROR GOSUB 5670
5600 PRINT USING 5610 ; D$,B,FNH$(T)
5610 IMAGE 2A," = ",D.DE," after ",9A
5620 OFF ERROR
5630 RETURN
5640 !
5650 ! Subroutine to trap print to paper errors
5660 !
5670 OFF CURSOR
5680 ALPHA 12,1
5690 DISP "Print ERR ";ERRN;". ";HGL$(TIME$)
5700 OFF CURSOR
5710 ALPHA 13,1
5720 RETURN
5730 !
5740 ! Subroutine to take gauge 1 measurements during phase 3.
5750 ! P3 = dP/dT @ valve closure is estimated using readings D2 & D2-1.
5760 ! The points are stored in
5770 ! D(,). After the D3rd point D(1,D2),D(2,D2) contain the next to last reading
5780 ! and D(1,D3),D(2,D3) containthe last reading.
5790 ! D(1,n) is pressure.
5800 ! D(2,n) is time of pressure reading in elapsed seconds.
5810 !
5820 GOSUB 4340 ! take pressure reading and count it
5830 N3=N3+1
5840 IF N3<=D2 THEN 5890
5850 IF N3>D3 THEN 5910
```

```
5860 !
5870 P3=(D(1,D2)-D(1,D2-1))/(D(2,D2)-D(2,D2-1))*.05
5880 !
5890 N4=N3 ! store current here
5900 GOTO 5950
5910 N4=D3 ! make room for latest
5920 D(1,D2)=D(1,D3)
5930 D(2,D2)=D(2,D3)
5940 !
5950 D(1,N4)=B ! store latest
5960 D(2,N4)=T
5970 !
5980 Z=2 @ Z(1)=B @ Z(2)=T ! print on tape
5990 GOSUB 5280
6000 !
6010 ON ERROR GOSUB 5670
6020 PRINT USING 6030 ; B,FNH$(T)
6030 IMAGE "G1 = ",D.DE," after ",9A
6040 OFF ERROR
6050 RETURN
6060 !
6070 ! Subroutine to wait for valve motion. T7 marks start of motion.
6080 ! V is time in sec to complete motion.
6090 !
6100 T8=FNR0
6110 F2=0
6120 ON TIMER# 2,(V-(T8-T7))*S3 GOSUB 6780
6130 T9=0
6140 IF F2 THEN F2=0 @ GOTO 6220
6150 T8=FNR0
6160 IF T8<T9+2 THEN 6140
6170 T9=T8
6180 OFF CURSOR
6190 ALPHA 3,1
6200 DISP "Valve "&A$&" in ";INT(V-(T8-T7));" sec"
6210 GOTO 6140
6220 OFF TIMER# 2
6230 RETURN
6240 !
6250 ! Subroutine to close valve and turn on filament 1 for RGA.!
6260 ! Subroutine is called by hitting key #7 in Phase 1.
6270 IF A$="CLOSED" AND C$="ON" AND D$="G1" THEN RETURN
6280 C$="OFF" @ A$="CLOSED" ! Turn off filament, close valve
6290 GOSUB 4340
6300 D$="G1" ! Switch to gauge 1
6310 GOSUB 4340
6320 C$="ON" ! turn on filament
6330 GOSUB 4340
6340 T8=FNR0 ! acknowledgeon printer and on tape
6350 PRINT "Valve closed for RGA";
6360 PRINT TAB(8);HGL$(DATE$);" ";HGL$(TIME$)
6370 C=CURSCOL @ R=CURSROW
6380 OFF CURSOR
6390 ALPHA 14,1
6400 DISP "Valve closed for RGA"
6410 Z=2
6420 Z(1)=-2.E-99
6430 Z(2)=T8
6440 GOSUB 5280
6450 OFF CURSOR
```

```
6460 ALPHA R,C
6470 RETURN
6480 !
6490 ! Subroutine to open valve and turn on filament 2 after RGA.
6500 ! Subroutine is called by hitting key #8 in Phase 1.
6510 !
6520 IF A$="OPEN" AND C$="ON" AND D$="G2" THEN RETURN
6530 C$="OFF" @ A$="OPEN" ! Filament off, valve open
6540 GOSUB 4340
6550 D$="G2" ! switch to gauge 2
6560 GOSUB 4340
6570 C$="ON" ! Turn on filament
6580 GOSUB 4340
6590 T8=FNRO ! acknowledge on printer and on tape
6600 PRINT "Valve opened after RGA";
6610 PRINT TAB(8);HGL$(DATE$);" ";HGL$(TIME$)
6620 C=CURSCOL @ R=CURSROW
6630 OFF CURSOR
6640 ALPHA 14,1
6650 DISP " "
6660 Z=2
6670 Z(1)=-3.E-99
6680 Z(2)=T8
6690 GOSUB 5280
6700 OFF CURSOR
6710 ALPHA R,C
6720 RETURN
6730 !
6740 ! Subroutines to set flag when timer 1,2 OR 3 times out.
6750 !
6760 F1=1 @ RETURN
6770 !
6780 F2=1 @ RETURN
6790 !
6800 F3=1 @ RETURN
6810 !
6820 ! FNRO returns elapsed time in seconds from startup time
6830 !
6840 DEF FNRO
6850 D9$=DATE$
6860 S9=TIME
6870 IF DATE$#D9$ THEN 6850
6880 FNRO=(MDY(D9$[4,8]&"/19"&D9$[1,2])-D0)*86400+S9-S0
6890 FN END
6970 !
6980 ! Subroutines to set flags for key 7,8 hit
6990 !
7000 R7=1 @ RETURN
7001 R8=1 @ RETURN
```