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An Automated Four-Zone Air Infiltration Measuring System

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Introduction

The Institute for Research in Construction of the National Research Council of Canada has long been involved in studies of air infiltration in houses and the associated heat losses. Methods have been developed by Tamura, Shaw and others[1-4] to estimate air infiltration rates. Along with this approach has been the development of air infiltration measuring techniques and apparatus using various gases as tracers or indicators for the detectors. Sulphur hexafluoride (SF_6) has been extensively used as a tracer gas because of its non-toxic properties and extremely low background concentration in outdoor air. A paper by Kumar, Ireson and Orr[5] describes an automated air infiltration measuring system using SF_6 in constant concentration and decay modes of operation. A similar infiltration measurement apparatus, the Mark II, was then assembled under a contract from IRC. The Mark II apparatus was originally a single zone automated system programmed to run in constant concentration mode.

There are several problems that may arise from the use of a single zone constant concentration system. The measurement of infiltration rates depends on the sensitive control of the tracer gas to maintain the constant concentration. This must not only be constant with time but uniform throughout the space being tested. Attempts can be made by manifold systems to distribute the single SF_6 source to various areas and to use a similar manifold arrangement to simultaneously sample air from all areas in the spaces. This may still allow for a buildup in tracer gas in one area while another area may become depleted due to the different back pressures along the various paths of the discharge and sample manifold arrangements. This problem may be alleviated if equal back pressures can be maintained along each discharge and sample leg respectively. Another reason for a multiple sample and discharge system arises if there are physically separated zones within the space, or zones separated from one another with restrictions in the mixing between zones. Concentrations of the tracer gas can then become quite different, especially if the leakage characteristics to the outdoors are different for the zones. This requires a separate control of the tracer level in each zone.

The use of a multi-zone control for the tracer gas level also allows a different type of study. This involves injecting into one zone only while sampling in all other zones to get a qualitative appreciation of air flows from the injected zone to other areas of the building. Finally, the leakage rates in different zones can be measured separately using separate sampling and discharge systems.

Multi-injection, multi-sample tracer gas techniques are being used in other countries. Grot et al[6] describe a system operating in the decay mode sampling through as many as ten ports and injecting through five ports on an hourly basis. Similarly, reports on multi-point constant concentration systems have been published in Sweden[7], Denmark[8], Switzerland[9] and the United Kingdom[10].

To alleviate the concerns of single zone operation, and allow multi-zone studies, the original Mark II apparatus was converted to a four-zone sample and injection system. A description of the remodelled equipment, its operation and programming are given in Appendix A. Two programs were written to control the machine in two modes of operation. The first program maintains a constant tracer gas level in four different zones, but calculates a single value for the infiltration rate based on the combined volume of all four zones. This bypasses problems of manifold systems and the need for equal backpressures. The second program maintains a constant tracer gas level in four different zones and calculates a separate air change rate for each zone.

Theory of Operation and Control

The use of tracer gas at a constant concentration in the house air to measure the air change rate is based on the following equation for steady state conditions:

$$\dot{I} = \frac{\dot{q}}{c}$$

where

$\dot{I}$ = infiltration rate, m^3 air/hr

$\dot{q}$ = tracer injection rate, m^3 tracer/hr

c = concentration of tracer in the house air, m^3 tracer/m^3 air.

As the air infiltration proceeds, tracer gas is lost to the outdoors along with the heated house air. The amount of tracer remaining in the house is measured by the detector section of the air infiltration measurement device, and the amount of additional tracer required to maintain the constant concentration is calculated and injected into the space. As is seen from the above equation, the amount of tracer gas injected into the space is directly proportional to the amount of air infiltration when the concentration of tracer gas in the air is maintained at a constant level.

The control of the amount of SF_6 added to the space is based on a normal rate of injection adjusted by a proportional control and a differential control. The proportional control takes the difference between the amount of SF_6 in the air and the set point and adjusts the amount of SF_6 injected in proportion to this difference. The differential control algorithm adjusts the amount of SF_6 injected based on the rate of change of the SF_6 concentration with time. The equation below presents this in mathematical form:

$$N = N_{norm} - \frac{K_P(C_0 - S)}{V_I} - \frac{K_D(C_0 - C_1)}{V_I}$$

where:

V_I = volume of SF_6 per injection; all amounts of SF_6 injected are integral multiples of this volume, m^3

N = integer number of SF_6 volume injections, each of volume V_I

N_{norm} = normal number of SF_6 volume injections, adjusted after every calculation of N

K_P = proportional gain factor, constant

K_D = differential gain factor, constant

C_0 = SF_6 concentration of present reading

C_1 = SF_6 concentration of previous reading

S = set point or control point for SF_6 concentration

The Mark II injects SF_6 by firing the injector valve set. The volume of SF_6

injected is thus a multiple of the volume of the injector valve set. The normal number of injections is adjusted after each calculation of N based on the difference between N and N_{norm} and a small gain factor applied to this difference. The infiltration level is calculated from the sum of the number of injections giving the volume of SF_6 injected over the time period.

Calibration and Tests

Calibration of the Mark II was done using a sealed test room of about 25 m^3 volume at the Prairie Regional Station of IRC. Two types of tests were performed. The first calibrated the SF_6 detector against a known concentration of SF_6 varying from 2.3 parts per billion (ppb) to 13.2 ppb plus or minus 0.1 ppb. Measured amounts of SF_6 were injected into the test room and allowed to mix thoroughly. The equilibrium detector voltage was measured at each concentration for each of the four zone sample valve sets and a least squares linear regression was applied to the data. This calibration routine must be carried out at regular intervals and should be done at least once a year. Any very low leakage chamber can be used, with the only stipulation being that it is of sufficient size so that the small injected amounts of SF_6 can produce accurate concentrations in the order of parts per billion. The equation for the initial calibration for each valve set is presented below followed by the index of determination, r^2.

Zone 1: SF_6 (ppb) = -2.0363 + 0.2025 · (mV), r^2 = 0.9969

Zone 2: SF_6 (ppb) = -2.2038 + 0.1915 · (mV), r^2 = 0.9980

Zone 3: SF_6 (ppb) = -2.4088 + 0.2010 · (mV), r^2 = 0.9974

Zone 4: SF_6 (ppb) = -2.1215 + 0.1722 · (mV), r^2 = 0.9963

The differences in the calibration curves are due to carrier gas pressure differences flowing through each of the four sampling valves and switching valve to the column and detector. The pressure differences are inherent in the different valve mechanisms themselves and in the different tubing paths required to route the carrier gas.

Field tests were conducted in a low leakage house in Saskatoon to examine the stability of the SF_6 level as controlled by the Mark II. Figure 1 is a plan of the main floor of the house with the sample and injection points for zones 1, 2 and 3 shown. Zone 4 was in the unfinished basement. Figure 2 is a graphical presentation of the concentration of SF_6 tracer in four separately controlled zones within the house. During this test the furnace fan was run continuously and all interior doors were left open. Air sampling was done at a central location in each zone and the tracer was injected at a forced air register within the zone. The tracer shows an acceptably constant concentration over time in all zones and all zones show approximately the same concentration.

An example of a qualitative air flow test is shown in Figure 3. For this test, all forced air circulation was shut off and the house was heated with small electric resistance heaters. The SF_6 discharge system was suppressed from within the software by setting the maximum number of SF_6 discharges to zero for all value sets. This left the Mark II only capable of sampling the air in each zone. At the start of the test, 4.5 ml of pure SF_6 was injected into the house using a syringe. This was done near the sampling point for Zone 1, in one injection. In Figure 3, the concentration of tracer in all four zones is plotted over time, starting immediately after the time of injection. Zone 1 shows a high concentration of tracer at the start which then decays. Zones 2, 3 and 4 show a negligible concentration at the start which then rises to an equilibrium value within one hour. Using this type of test a qualitative appreciation of air flows within the house by convective forces can be obtained. Similarly by operating the mechanical systems, air flows by various means and mixing times between zones can be investigated.

A second unoccupied low leakage house was used to test the overall air leakage measurement accuracy of the system. To do this a fan was installed in an exterior doorway and air was exhausted from the house, creating a negative internal pressure relative to outdoors throughout the house. This ensured that all openings were infiltrating outside air. The Mark II also measured the air infiltration summing the results in all zones. Three separate measurements were accomplished in the available test period. The results are plotted in Figure 4. The results for the Mark II show an infiltration rate from 6.2 percent to 17.9 percent lower than that measured through the exhaust fan.

The third test site was at a large three-story institutional building with a total volume of 42,000 m^3. This building is mechanically ventilated and controlled by four separate HVAC systems controlling four zones. The Mark II was installed to sample air and inject SF_6 at each HVAC system. Zone one is made up of the basement and the main floor. Zone two is the second floor and zone three is the third floor, which housed the mechanical room and equipment. Zone four is comprised of all the stairwells and stair shafts in the building. The air change rates varied upwards from 0.3 air changes per hour. The facility is located in Lethbridge, Alberta and was completed in 1981. Figure 5 is a graphical presentation similar to Figure 2, showing the concentration for SF_6 over time in each of the four zones. Discharge volumes for each injection were increased for this test. Again, the tracer shows relatively constant values.

Tests were also performed on the Mark II using the sealed test room, to determine the machine's sensitivity to the proportional and differential gain factors K_P and K_D. These factors determine how quickly the machine is able to respond to widely varying air change rates. The machine's sensitivity to the update rate applied to the normal number of discharges N_{norm} was investigated at the same time. These three parameters were changed for each test. The room was ventilated with a known air change rate and the Mark II monitoring was initiated with no SF_6 tracer gas in the room, so that it immediately began injecting a maximum amount of SF_6 after each air sample was taken. After the level of SF_6 was stabilized at the control level, the ventilation was increased in one step. When the tracer concentration was stabilized again, the ventilation rate was decreased in a single step to the original level. The concentration of tracer gas and the number of injections per cycle were continuously recorded throughout the test period.

Figure 6 gives results using values of 0.5 for the proportional gain factor K_P, 0.25 for the differential gain factor K_D, and 0.1 for the update rate on N_{norm} as defined on page 4. The top portion of the graph shows the ventilation rate in the sealed test room, varying by step inputs as shown. The centre portion shows the number of injections per cycle, one point for each cycle. These are all integer numbers. The bottom portion of the graph shows the SF_6 concentration in the room. The control level was at 10 ppb.

The concentration remains fairly stable once it has reached equilibrium. There is a slight decrease in the concentration immediately following the step increase in the ventilation rate and similarly a slight increase in SF_6 level following the step decrease in ventilation. Both perturbations lasted for only a short period of time and the concentration of tracer soon returned to the control level.

Summary and Conclusion

The Mark II SF_6 unit works well in maintaining a constant concentration of SF_6 tracer gas in four separate zones. From monitoring control and injection of tracer gas the machine can calculate a bulk infiltration rate or individual infiltration rates for each of the four zones in the building. The calibration of the machine's detector should be performed on a regular basis, at least yearly and more frequently with continuous use. Control of the machine can be altered by changing operation inputs during startup, so that the injection of tracer gas can be suppressed in any of the four zones. By setting the injection rate to zero and monitoring the dispersal of a slug injection of tracer gas, an appreciation of air flows in a building can be obtained.

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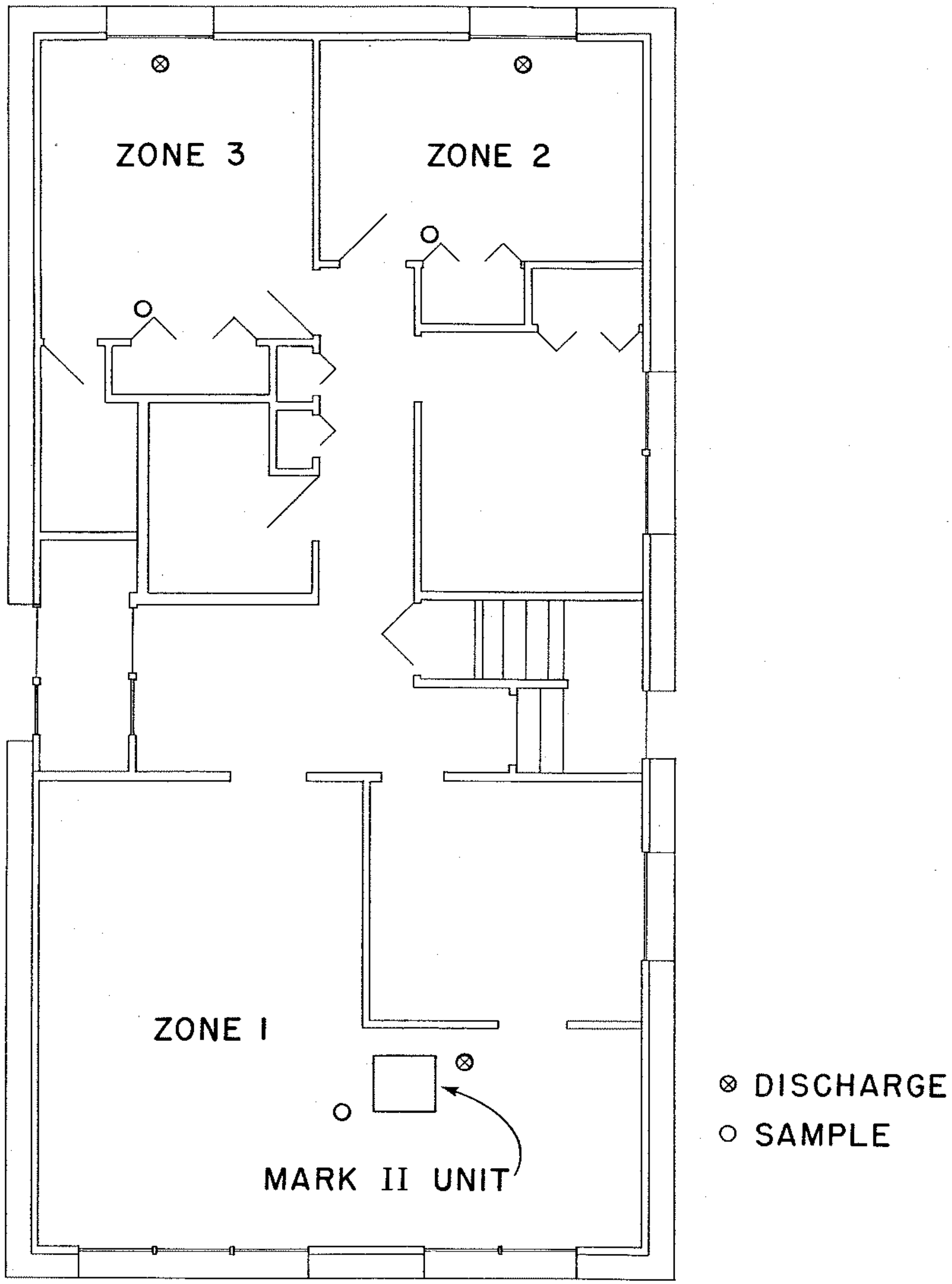


Figure 1. Plan of low leakage house used for tests, showing sample and discharge points in three main floor zones. Zone 4 is in the basement with separate sample and discharge points.

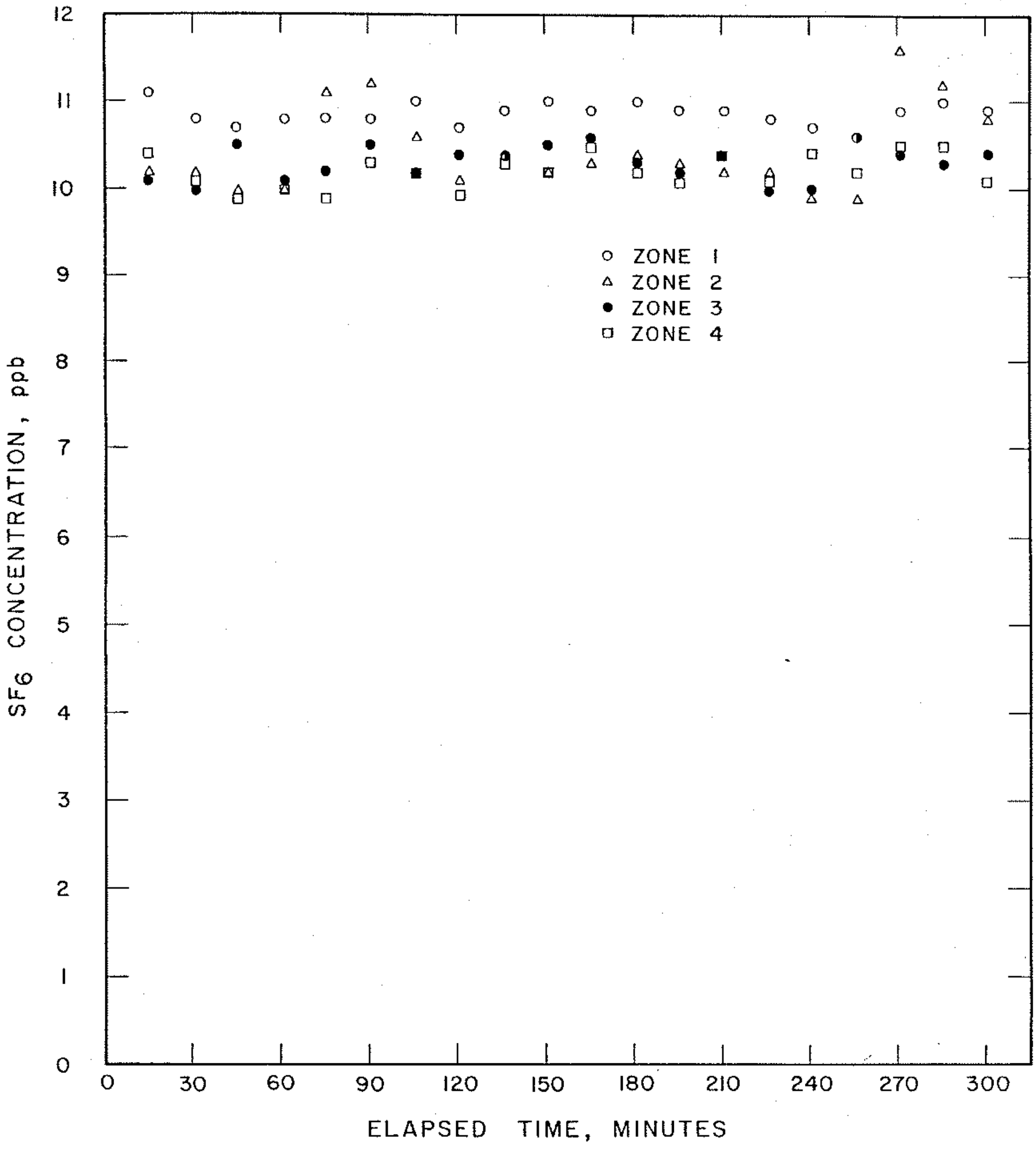


Figure 2. Tracer gas concentration in low leakage house.

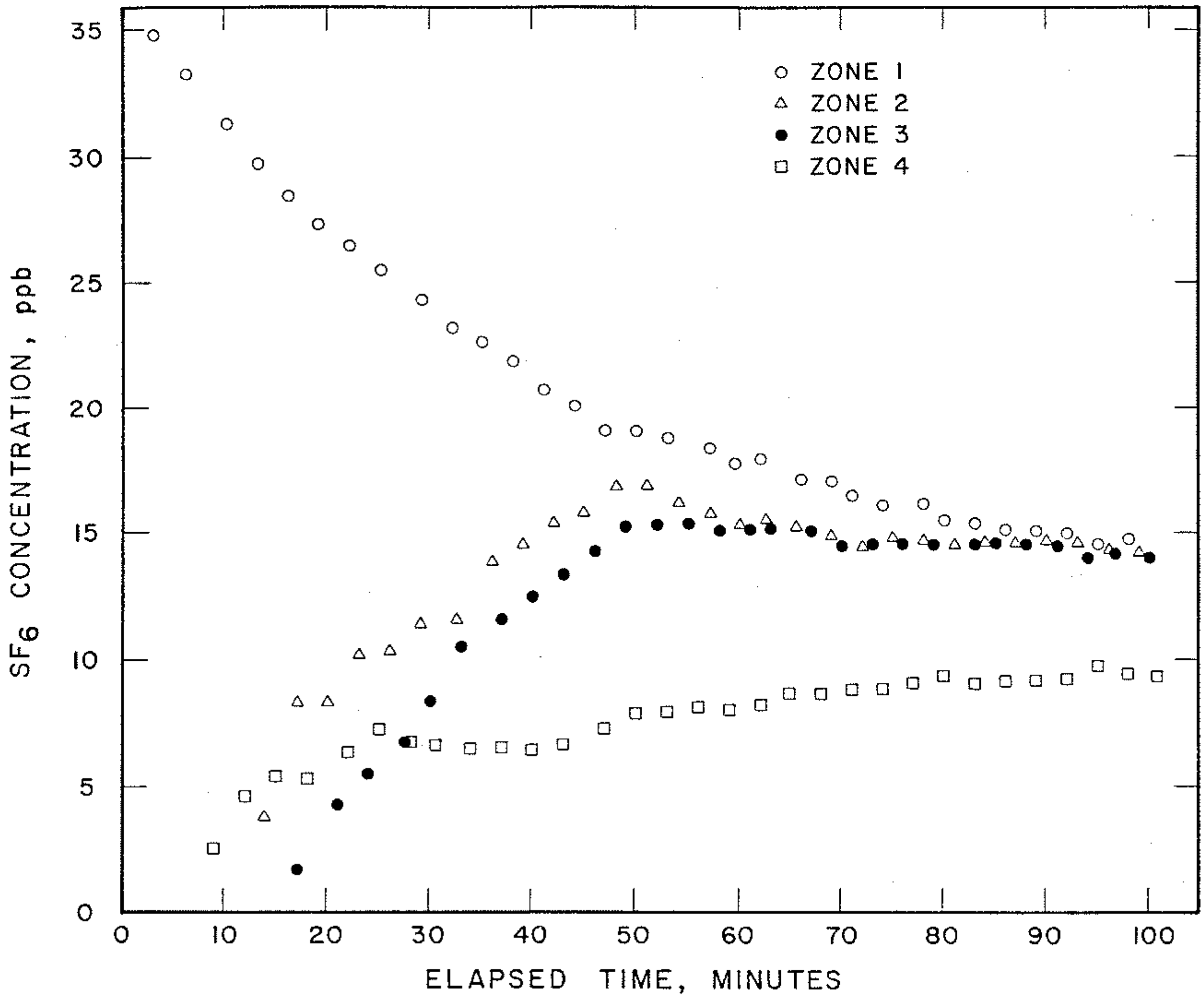


Figure 3. Tracer gas dispersion test with slug injection in zone 1.

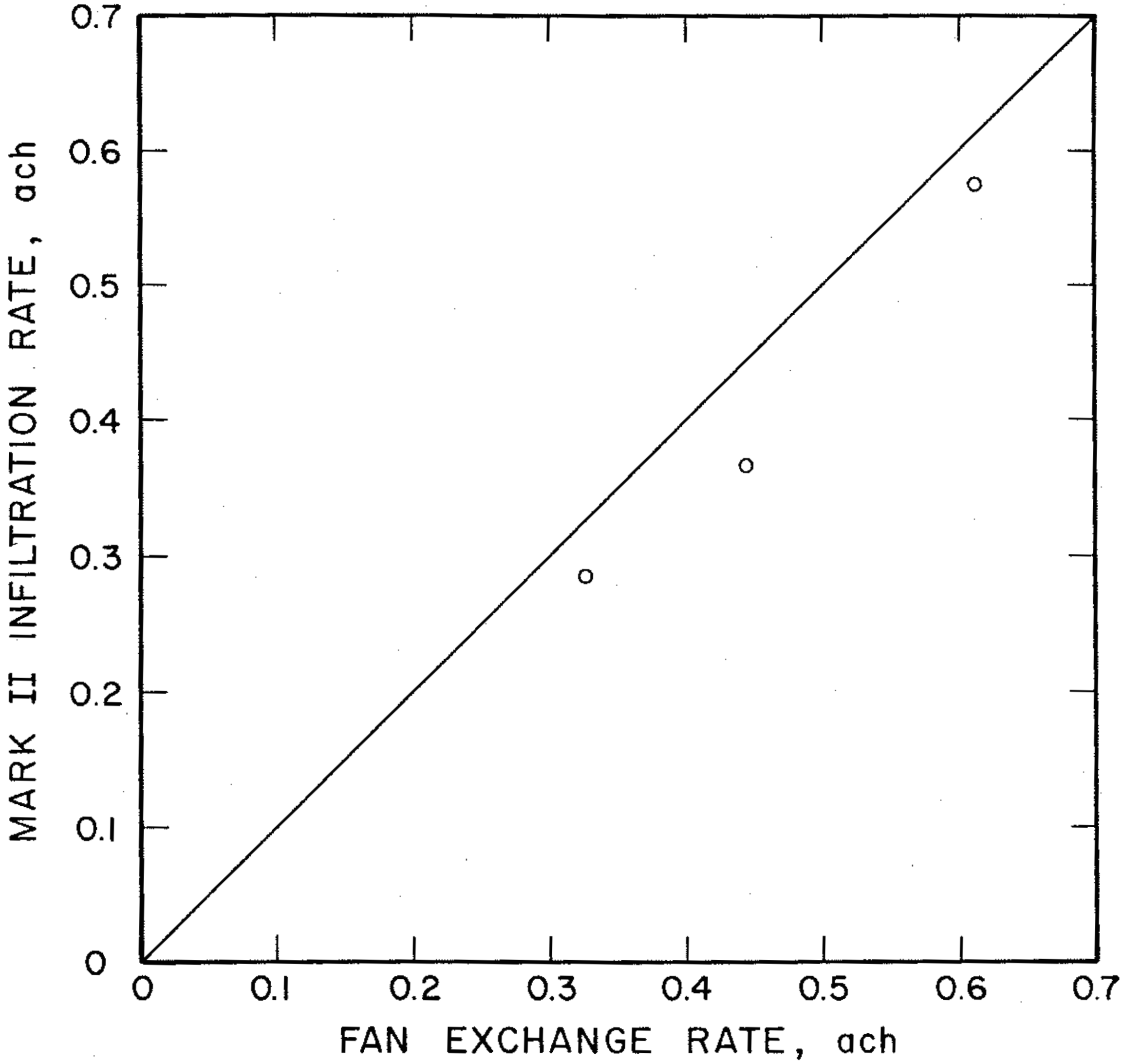


Figure 4. Comparison of fan induced air change rate with Mark II results.

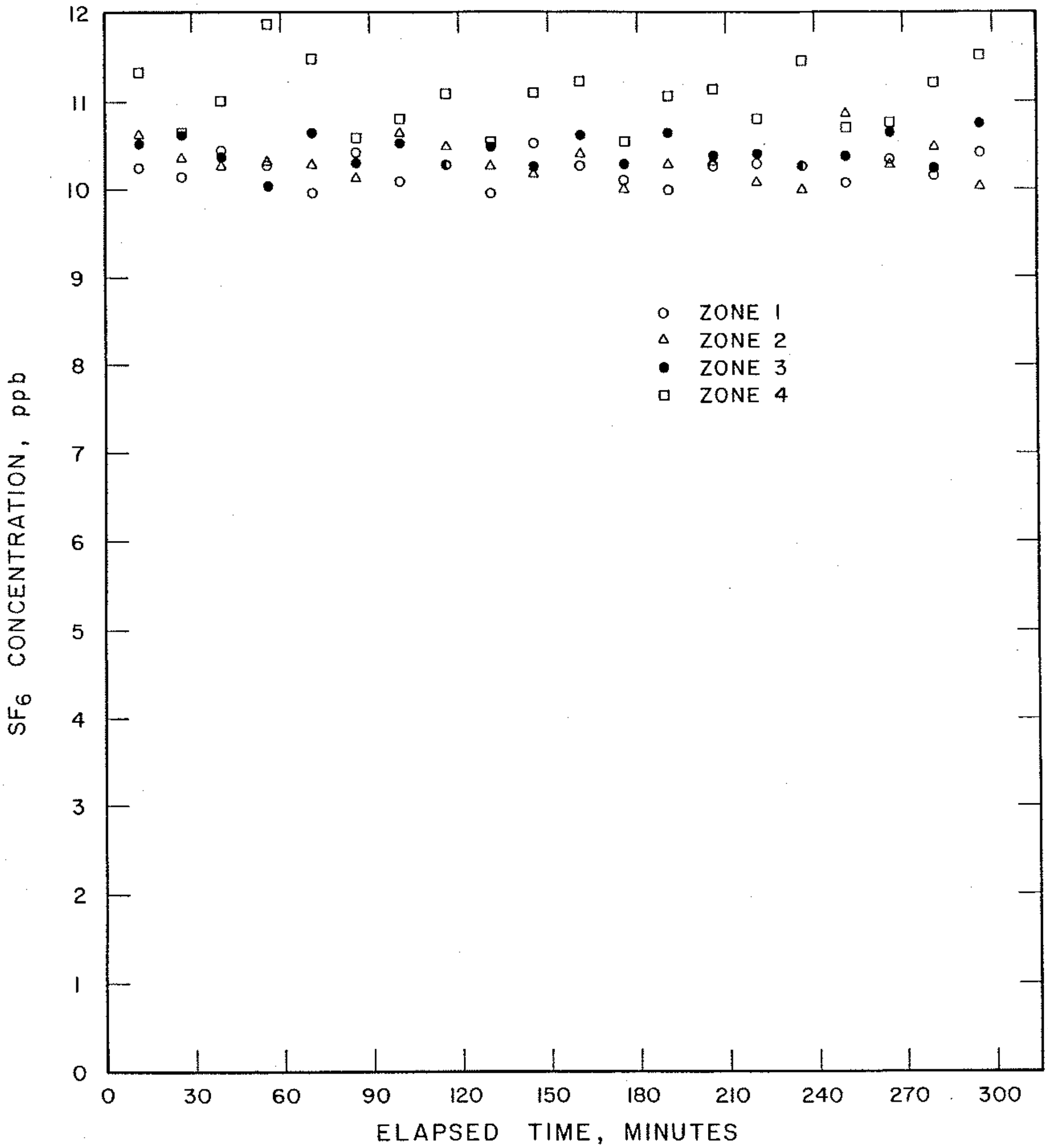


Figure 5. Tracer gas concentration in large four-zone institutional building.

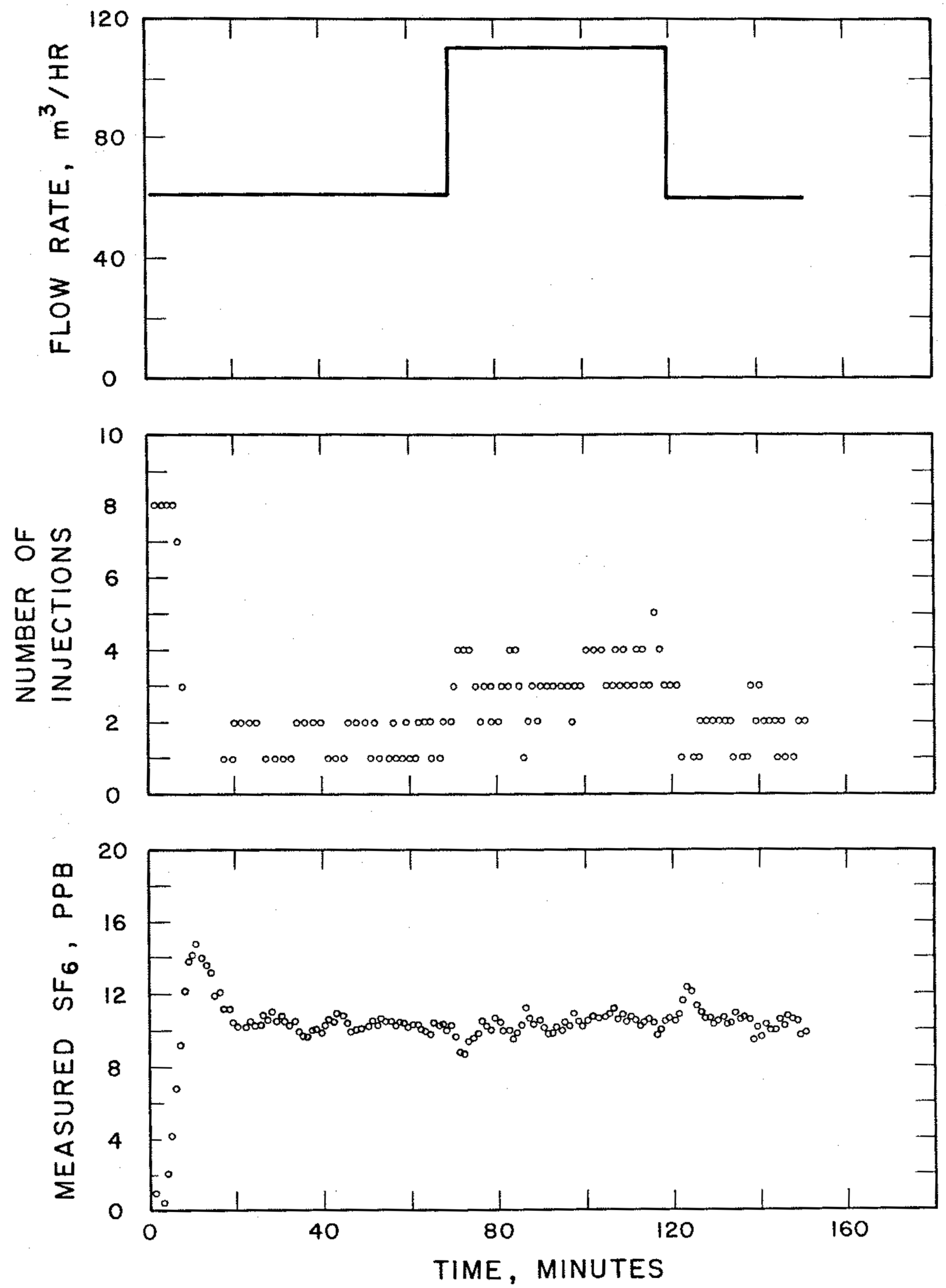


Figure 6. Response of Mark II to ventilation rate change.

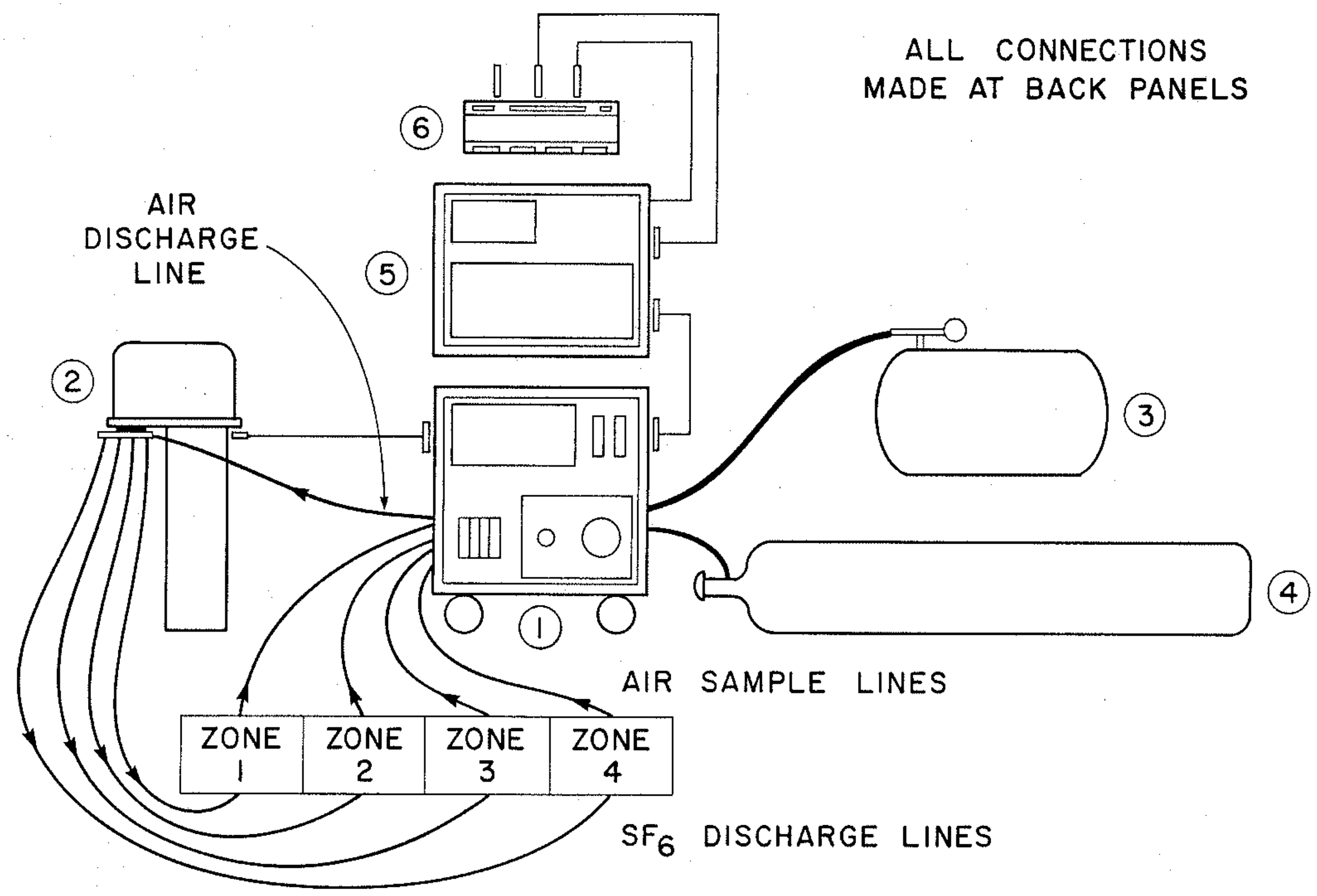
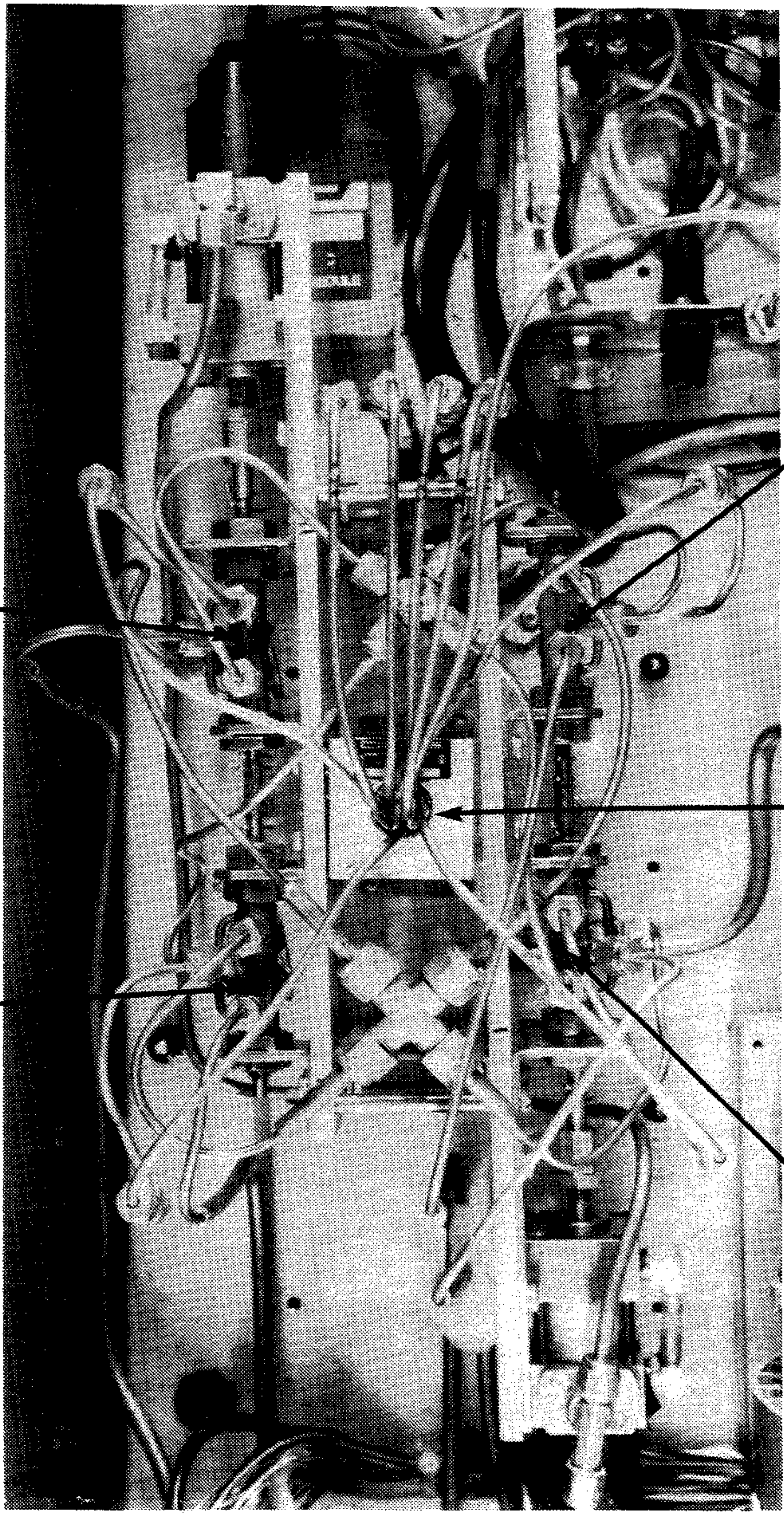


Figure 7. Schematic of Mark II, (1) lower chassis, (2) SF_6 discharge unit, (3) air tank, (4) argon tank, (5) upper chassis, (6) HP 9825 calculator.


SAMPLE VALVE 4
SAMPLE VALVE 2
SAMPLE VALVE 1
ROTARY SWITCHING VALVE
SAMPLE VALVE 3

Appendix A

Description of Equipment

There are six main components which comprise the Mark II. These are shown on Figure 7 and are labelled to match the numbers below.

(1) The first of these is the lower chassis module, installed on a wheeled trolley. The lower chassis houses an SF_6 detector chromatograph. The detector cell is fitted with a low energy source of β radiation. This is an isotope of Nickel, Ni63 with a strength of 10 milliCuries mounted coaxially around a collector pin within the detector cell. The detector cell must be continually flushed with a dry, oxygen free supply of argon carrier gas. A sample of house air with SF_6 tracer gas can be injected into the stream of argon by a valving arrangement. This sample is pushed along by the argon carrier through a length of tubing called a column. This is packed with 100-120 mesh aluminum oxide Al_2O_3, which separates the components of the air sample by retarding each component by a different amount. As well the lower chasis contains sample and switching valves, air pumps, electrical relays and an argon carrier gas regulator with space for a small argon bottle for use in transit.

(2) The SF_6 discharge unit is the SF_6 supply bottle with a four set, eight valve discharge unit mounted to it in a sealed removable enclosure. This unit includes an SF_6 pressure regulator which can be adjusted to vary the volume of a single SF_6 discharge on each of the valve sets.

(3) The third component is the pressurized air tank used to actuate the sliding sample valves.

(4) The fourth component is the large argon carrier gas bottle.

(5) The fifth component is the upper chassis containing a system voltmeter and the interface panel and interface circuit boards for the sample and switching valves and the discharge valve sets.

(6) The last major component is a Hewlett Packard 9825S calculator which acts as the central processor unit and data storage device, using the data storage tape. There are three ports at the back of the HP9825S for the insertion of three Hewlett Packard interfaces. These consist of the system clock, a 16-bit input/output interface and an HP-IB (interface bus) interface.

The heart of the SF_6 air infiltration apparatus is an ITI Model 505 SF_6 detector chromatograph distributed by Ion Track Instruments Inc. of Burlington, Massachussetts. This unit has been altered by removing the rotary sampling valve and replacing it with a four-valve arrangement for sampling in four zones. Each of these four sampling valves is a Con-Dyne Model LOV-8-6 with sliding action. Two valves are mounted to an air driven sliding actuator so that as the actuator is fired, the front valve takes a sample. As the actuator is released and returns to starting position, the the rear valve takes a sample. Two of these systems are mounted back to back with all four valves and two actuators (Figure 8). In between the systems is a stream selection valve. This is a Carle Model 2029 rotary valve for four zone selection with uninterrupted flow for the non-sampling streams.

The detector and valves are all housed in the lower chassis unit. Setup of the Mark II is accomplished as follows. The main power supply comes to the lower chasis and is distributed to other components from the rear panel. From Figure 7 it can be seen that the four air sample lines from the zones are connected to the lower chasis rear panel. A single air discharge line is connected to the SF_6 discharge unit and electrical connection betseen the SF_6discharge unit and the tower chasis is made by a special 10-wire electrical cable. The air discharge line is split in four at the SF_6 discharge unit and fed to each discharge valve set. A hose from each discharge valve set then goes to the discharge point in each zone.

The pressurized air tank for operating the sample valves is connected by an air hose and couplers to the lower chassis rear panel. The argon bottle is connected to the argon regulator at the rear of the lower chassis by a special high pressure flexible hose. The upper chassis sits on the lower chasis and is connected to the lower chassis by a large electrical interface cable.

The HP9825S calculator sits on top of the upper chassis. The three ports at the back of the HP9825S are for the insertion of the three Hewlett Packard interfaces, that is the system clock, a 16-bit input/output interface and an HP-IB (interface bus) interface. The 16-bit interface is permanently wired to the upper chassis. The HP-IB interface has a cable for attachment to the rear panel of the upper chassis. An additional cable may be piggy-backed on this rear panel connection for the addition of an optional Hewlett Packard HP9871A printer.

Operation and Programming

Once all the components have been properly installed, the pre-start sequence must be completed as follows.

(1) First, the suggested regulator pressure on the SF_6 discharge bottle is 2.2 psig. Adjustment can be made to meet this pressure, although any pressure may be used if the corresponding discharge volumes for each valve set are measured and input when the program asks for them.

(2) The argon tank valve should be opened and the regulator pressure at the front of the lower chassis should be set to 100 kPa (12 psig).

(3) The carrier gas valve beside the argon regulator should be opened at the front of the lower chasis and the Rotameter above it should be set to 0.12 scfh. The back pressure on the SF_6detector should also read 100 kPa (12 psig) on the small pressure gauge on the ITI panel. If it does not, adjustment should be made to the argon regulator pressure and Rotameter setting.

(4) The four Rotameters to the left of the argon pressure regulator should be set to a minimum flow on each gauge. One Rotameter will have its flow directed through the argon carrier gas Rotameter to allow a stream of argon gas to flush the column and detector; this Rotameter will have to be adjusted when the argon is directed through it.

(5) The Range on the front of the ITI detector chromatograph should be turned to Standing Current and the Zero adjust knob should be turned completely counter-clockwise. The standing current should be above 60 mA for good operation of the machine and will increase as the column and detector are flushed of any impurities.

(6) The air pumps can be switched on by the two toggle switches on the ITI panel. Only one pump is needed as the other is a backup. The pump

connected at time of publication is controlled by the right toggle switch.

(7) The program tape should now be inserted into the appropriate slot on the HP9825S and all power switches turned on. The control program will automatically load and run and will direct the user to perform the final setup. This consists of setting the Range to 20 and zeroing the SF_6 detector on the ITI panel.

The program gives an opportunity to adjust any of the input parameters by pressing the Special Function key "f0" at the upper right of the keyboard. The user can edit the inputs by keying in the new data and pressing "CONTINUE". If the current data is still valid then pressing "CONTINUE" will maintain the data. The inputs that are required are the location, the concentration of SF_6 in the discharge SF_6 bottle, a description and the volume of each building zone, the volume of SF_6 mixture metered by each of the four injector valve sets, an initial value for the normal number of SF_6 discharges for each of the four test zones and a maximum number of discharges to each zone. As well the update rate for the normal number of discharges is input as is the gain factor for the differential control and the gain factor for the proportional control. These three values are not normally adjusted but remain the same. The initial value for the normal number of SF_6 discharges does not need to be determined with a great deal of accuracy, as it will be adjusted by the actual number of discharges and the update rate; it will find its own normal value based on the actual requirement for the tracer. An expected range of infiltration rates is normally known based on the construction and age of the house, eg. 0.3 to 0.6 ach for a standard

Saskatoon home built within the last 25 years. Using an expected value for the infiltration rate, an initial normal rate of injection can be calculated based on the following equation.

$$N_{norm_o} = \frac{V_{zone}\ I}{15\ Conc_{SF_6}\ V_I}$$

where:

N_{norm_o} = initial normal number of injections

V_{zone} = volume of the zone to be tested, m^3

I = expected infiltration rate, ach

15 = average number of machine cycles per hour

$Conc_{SF_6}$ = concentration of SF_6 in the discharge bottle, %

V_I = volume of a single SF_6 injection, ml

The maximum number of injections should usually not be greater than three times the normal rate of injection.

There are eleven other special function keys labelled "f1" to "f11". Function f1 prints a summary of all the hourly air change rates and corresponding times on the paper tape to a maximum of 200 hours. Function f2 allows the machine to print only the hourly air change rate and the time on the calculator paper tape. Function f3 allows the machine to print this as well as the baseline reading, the SF_6 peak concentration, the number of SF_6 discharges and summations of the SF_6 peaks and number of discharges for each sample taken in all zones. Function f4 lists the program on the optional HP9871A printer. Function f5 terminates the program after the completion of the current four zone control loop. Function f6 rotates the stream selection or switching valve one quarter turn for manual operation. Function f7 actuates one of the sample valve sets, toggling between the two sets allowing manual triggering of the sampling sequence. Functions f8 to f11 actuate one SF_6 discharge valve set releasing one volume of SF_6 mixture to the corresponding zone for manual injection from operator control.

When initiating a new test in a house or test space, the concentration of SF_6 in the space is probably near zero. The Mark II programmed control level for SF_6 concentration is 10 parts per billion (ppb). A starting concentration close to the control level can be reached by using the manual SF_6 discharge keys for each zone and allowing some amount of time for the SF_6 to become uniformly distributed throughout the space. The approximate total number of manual injections to each zone can be estimated using the equation below:

$$N_i = \frac{V_{zone}}{Conc_{SF_6} \times V_I}$$

where:

N_i = initial total number of discharges to the zone

V_{zone} = volume of zone, m^3

V_I = volume of a single SF_6 injection, ml

$Conc_{SF_6}$ = concentration of SF_6 in the discharge bottle, %.

Appendix B is a listing of the constant concentration, four-zone program for the Mark II HP9825S. This listing calculates a single infiltration rate rather than zone infiltration rates. Lines 0 to 37 are for initialization and set-up of the program and machine. Lines 38 to 56 are for the start-up of the machine, for synchronizing the sampling valves, the switching valve and the control loop. This is done by firing sample valve one and looking for oxygen indication through one of the switching valve ports. Lines 57 to 87 are the four-zone loop for direction to the SF_6 measurement, control and inject modules. Lines 88 to 117 check time parameters, calculate air change rates at appropriate times, file information on the small data tape and check boundary conditions to see that the machine is operating satisfactorily. All these checks are done after each four-zone control sequence, and if the operator wishes to end the test, the termination occurs in this segment. Lines 118 to 129 make up the "BASERD" subroutine to measure the baseline voltage of the SF_6 detector before a sample is passed through. Lines 130 to 203 make up the major "PEAKRD" subroutine to first of all look for the oxygen voltage peak and then look for and measure the SF_6 voltage peak as it passes through the detector. The voltage is converted to a tracer concentration and the amount of SF_6 to be injected is calculated in order to maintain the constant concentration. Within the PEAKRD subroutine is the "START" subroutine. This commences at the point where the SF_6 peak is recognized and measured and is set to run while the first oxygen peak is sampled when synchronizing the program and valves. Lines 208 and 213 make up the "INJECT" subroutine to inject SF_6 on command from the program. Data entry is done in the subroutine "DE" in lines 214 to 233. This subroutine can be entered at any time by pressing the function key f0. Data can be re-entered by pressing the "CONTINUE" key or new data can first be keyed in. Lines 234 to 241 make up the "REPRINT" subroutine entered by pressing the function by f1. Lines 242 to 254 make up the error catching subroutine which prints an error message and continues or restarts the program.

Appendix B

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0: "CONSTANT CONCENTRATION METHOD":
1: dim L$[20],G[18],T[24],I[24],A[1],A$[1,8],C$[16],B[2]
2: dim H[200],K[200],D[4],M[4],N[4],O[4],P[4],R[4]
3: 0→r0→r1→O;1→r13
4: on err "FSET"
5: wrt 9,"B"
6: wrt 9,"R";red 9,C$
7: "  "→L$
8: trk 0;ldk 1
9: ldf 5,L$,G[*]
10: fxd 1;cfg 1;cfg 2;cfg 3;cfg 4;cfg 5;cfg 6;sfg 14
11: for I=6 to 185
12: fdf I
13: idf F,B
14: if B=0;gto 16
15: next I
16: fmt 1,c5,f10.0
17: fmt 2,c,f5.1,c,f5.1,c,f3.0
18: fmt 3,c5,f10.3
19: fmt 4,c5,f10.0
20: fmt 5,c2,f8.1,c2,f4.0
21: fmt 6,f3.0,f6.0,f7.3
22: fmt 7,c9,f1.0,f6.0
23: fmt 8,c6,f1.0,f9.0
24: wtb 2,129,130,131,132,273,274,275,276,2,0
25: for I=1 to 50
26: dsp "AUTO :PRESS f0 TO CHANGE DATA"
27: wait 200;if flg2;gto 30
28: next I
29: gto 32
30: gsb "DE"
31: cfg 2;wrt 9,"R";red 9,C$;gto 25
32: dsp "SET RANGE #20"
33: for I=1 to 5;beep;wait 1000;next I
34: dsp "ZERO SF6 DETECTOR"
35: for I=1 to 10;beep;wait 500;next I
36: dsp "SET SF6 REGULATOR TO 2.2 PSI"
37: for I=1 to 3;beep;wait 2000;next I
38: clr 7;rem 7;llo 7
39: wrt 724,"D.000001S,N1S,E4S,R1,T3,F1"
40: wtb 2,66;wait 1000;wtb 2,130,65;wait 1000;wtb 2,129
41: for A=1 to 2;wait 30000;next A;1→K;0→B;1000→A;gsb "BASERD"
42: wtb 2,68;wait 2000;wtb 2,132
43: R+.1→M
44: gsb "START"
45: if D>M*1000;beep;beep;beep;gto 55
46: clr 7;rem 7;llo 7
47: wrt 724,"D.000001S,N1S,E4S,R1,T3,F1"
48: 0→B→D;1000→A
49: gsb "BASERD"
50: wtb 2,67;wait 2000;wtb 2,131
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51: R+.1→M
52: gsb "START"
53: if D<M*1000;gto 38
54: wtb 2,66;wait 1000;wtb 2,130,65;wait 1000;wtb 2,129
55: for A=1 to 2;wait 30000;next A;0→O→D[1]→P[1]→R[1]→N[1]→M[1]
56: clr 724;lcl 724
57: for K=1 to 4
58: if flg6;gsb "REPRINT"
59: 0→G→B→A;if flg2;gsb "DE"
60: clr 7;rem 7;llo 7
61: wrt 724,"D.000001S,N1S,E4S,R1,T3,F1"
62: gsb "BASERD"
63: if K=1;wtb 2,68
64: if K=2;wtb 2,67
65: if K=3;wtb 2,132
66: if K=4;wtb 2,131
67: gsb "PEAKRD"
68: if K=1;wtb 2,66;wait 1000;wtb 2,130,65;wait 1000;wtb 2,129
69: if K=2;wtb 2,66;wait 1000;wtb 2,130,65;wait 1000;wtb 2,129
70: if K=2;wtb 2,66;wait 1000;wtb 2,130
71: if K=3;wtb 2,65;wait 1000;wtb 2,129,66;wait 1000;wtb 2,130
72: if K=4;wtb 2,65;wait 1000;wtb 2,129
73: if N>0;gsb "INJECT"
74: if D=5;gto 77
75: if flg3;cfg 3;cfg 4;prt "***FALSE PEAK***"
76: if abs(R)>30;prt "***BASE LINE***";cfg 4
77: if D=5;wrt 16.7,"NO PEAK #",K,P
78: if flg5;gto 117
79: if flg4;gto 83
80: wrt 16.8,"zone #",K,P
81: wrt 16.2,"S",D,"B",R[K]*1000,"N",N[K]
82: wrt 16.5,"$S",P[K],"$N",M[K]
83: if K=1;wait 3000
84: if K=2;wait 2000
85: if K=3;wait 3000
86: if K=4;wait 4000
87: wait 10000;next K
88: if flg4;gto 91
89: wrt 16.1,"TIME:",T
90: prt ""
91: if abs(R)>60;wrt 16,"BASE LINE DRIFT";gto 117
92: if r8>r7;r8-24→r8
93: "if r12<=15;if r6>15;gto 98":
94: "if r12<=30;if r6>30;gto 98":
95: "if r12<=45;if r6>45;gto 98":
96: if r12>r6;gto 98
97: gto "Noprint"
98: (r1-r5)/(r7-r8)*1000/((r0-r4)/(r9-r10))→r11
99: r11/G[5]→r11
100: r11→H[r13]→I[W+1]
```

```
101: P→K[r13]→T[W+1]
102: r13+1→r13;if r13<201;gto 104
103: 200→r13;for I=2 to 200;H[I]→H[I-1];K[I]→K[I-1];next I
104: wrt 16.3,"AC/hr",r11
105: wrt 16.4,"TIME",P
106: rcf F,L$,G[*],T[*],I[*],A[1]
107: rcf 5,L$,G[*]
108: if W=0;F+1→F;for I=1 to 24;0→I[I]→T[I];next I
109: if F>185;prt "TAPE FULL";gto 118
110: r1→r5
111: r7→r8
112: r0→r4
113: r9→r10
114: "Noprint":
115: r6→r12
116: gto 57
117: rcf F,L$,G[*],T[*],I[*],A[1]
118: wrt 16.4,"END @",T
119: dsp "  PROGRAM TERMINATED PROPERLY!"
120: stp
121: "BASERD":
122: trg 724;red 724,A$[1]
123: for I=1 to 100
124: trg 724;red 724,A$[1]
125: val(A$[1])→C
126: C+B→B
127: wait 5
128: next I
129: B/100→R→R[K]
130: R+.5→L
131: R+.005→M
132: dsp "base line = ",R*1000,"mv."
133: ret
134: "PEAKRD":
135: 0→E;for H=1 to 25
136: trg 724;red 724,A$[1]
137: val(A$[1])+E→E
138: A+1→A
139: if A>5000;5→D;wrt 9,"R";gto 190
140: next H;E/25→E;if E<L;gto 135
141: 0→E;for H=1 to 25
142: trg 724;red 724,A$[1]
143: A+1→A
144: if A>5000;5→D;wrt 9,"R";gto 190
145: val(A$[1])+E→E
146: next H;E/25→E;if E>R+.05;gto 141
147: R+.05→C→G
148: 0→E
149: for H=1 to 50;wait 5
150: trg 724;red 724,A$[1]
```

```
151: val(A$[1])+E→E
152: A+1→A
153: if A>5000;5→D;wrt 9,"R";gto 190
154: next H
155: E/50→E
156: if E<C;E→C;gto 148
157: "START":
158: 0→E
159: for I=1 to 10
160: wait 1
161: trg 724;red 724,A$[1]
162: val(A$[1])+E→E
163: next I
164: A+10→A;if A>5000;5→D;wrt 9,"R";gto 190
165: E/10→E
166: if E<M;gto 158
167: beep;wrt 9,"R"
168: M→G
169: for H=1 to 50
170: 0→E
171: for I=1 to 5
172: trg 724;red 724,A$[1]
173: val(A$[1])→D
174: D+E→E
175: wait 5
176: next I
177: E/5→E
178: if E>G;E→G
179: next H
180: if G>C;G→C;gto 168
181: clr 724;lcl 724
182: (C-R)*1e3→D
183: if K=1;D*.2025-2.0363→D
184: if K=2;D*.1955-2.2038→D
185: if K=3;D*.201-2.4088→D
186: if K=4;D*.1722-2.1215→D
187: if O-D>5;if D<16;sfg 3
188: if O-D<5;if D>16;if D<24;O[K]-D→Z
189: D→D[K]→O→O[K];R*1e3→R
190: red 9,U,V,W,X,Y
191: int(U*1e8+V*1e6+W*1e4+X*100+Y)→A[1]→T
192: W+X/60+Y/3600→B[2];if B[1]-B[2]>23;B[2]+24→B[2]
193: X→r6
194: B[2]→r7
195: int(W*100+X)→P
196: if D=5;int(G[K+6])→N;gto 198
197: G[K+6]-G[2]*(D-10)*G[5]/G[3]/G[K+10]/10-G[1]*Z→N
198: int(N+1)→N
199: if N<1;0→N
200: if N>G[14+K];G[14+K]→N
```

```
201: N*G[K+10]*G[3]/100→S
202: G[4](N-G[K+6])+G[K+6]→G[K+6]
203: if B[2]>24;B[2]-24→B[2]
204: B[2]→B[1];r9+1→r9
205: D+r0→r0;D+P[K]→P[K]
206: S+r1→r1;N+M[K]→M[K];N→N[K]
207: ret
208: "INJECT":
209: for I=1 to N
210: wtb 2,80+K;wait 250;wtb 2,272+K;wait 350
211: wtb 2,144+K;wait 250;wtb 2,272+K,2,0;wait 1000
212: next I
213: ret
214: "DE":
215: ent "LOCATION:",L$
216: ent "SF6 CONCENTRATION (%):",G[3]
217: ent "METERING TUBE VOLUME CC #1:",G[11]
218: ent "METERING TUBE VOLUME CC #2:",G[12]
219: ent "METERING TUBE VOLUME CC #3:",G[13]
220: ent "METERING TUBE VOLUME CC #4:",G[14]
221: ent "AVERAGE # DISCHARGES #1:",G[7]
222: ent "AVERAGE # DISCHARGES #2:",G[8]
223: ent "AVERAGE # DISCHARGES #3:",G[9]
224: ent "AVERAGE # DISCHARGES #4:",G[10]
225: ent "MAXIMUM # DISCHARGES #1:",G[15]
226: ent "MAXIMUM # DISCHARGES #2:",G[16]
227: ent "MAXIMUM # DISCHARGES #3:",G[17]
228: ent "MAXIMUM # DISCHARGES #4:",G[18]
229: ent "UPDATE RATE FOR ´N´:",G[4]
230: ent "DIFFERENTIAL CONTROL RATE:",G[1]
231: ent "PROPORTIONAL CONTROL RATE:",G[2]
232: ent "HOUSE VOLUME:",G[5]
233: rcf 5,L$,G[*];cfg 2;ret
234: "REPRINT":
235: wrt 16," "
236: wrt 16,"   TIME AC/hr:"
237: for I=1 to r13-1
238: wrt 16.6,I,K[I],H[I];next I
239: wrt 16.1,"TIME",T
240: wrt 16," "
241: cfg 6;ret
242: "FSET":
243: if rom=0;if ern=44;prt "File",F,"not verified ";F+1→F
244: if erl=107;gto 107
245: if erl=118;gto 117
246: if erl=124;gto 124
247: if erl=136;gto 136
248: if erl=142;gto 142
249: if erl=150;gto 150
250: if erl=161;gto 161
251: if erl=172;gto 172
252: prt "rom",rom;prt "ern",ern;prt "erl",erl
253: gto 3
254: end
```