U.S. DEPARTMENT OF ENERGY

PNNL-18229

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Multi-Channel Auto-Dilution System for Remote Continuous Monitoring of High Soil–CO_2 Fluxes

JE Amonette
JL Barr

April 2009

Pacific Northwest
NATIONAL LABORATORY

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

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Summary

Geological sequestration has the potential capacity and longevity to significantly decrease the amount of anthropogenic CO_2 introduced into the atmosphere by combustion of fossil fuels such as coal. Effective sequestration, however, requires the ability to verify the integrity of the reservoir and ensure that potential leakage rates are kept to a minimum. Moreover, understanding the pathways by which CO_2 migrates to the surface is critical to assessing the risks and developing remediation approaches. Field experiments, such as those conducted at the Zero Emissions Research and Technology (ZERT) project test site in Bozeman, Montana, require a flexible CO_2 monitoring system that can accurately and continuously measure soil-surface CO_2 fluxes for multiple sampling points at concentrations ranging from background levels to several tens of percent. To meet this need, researchers at Pacific Northwest National Laboratory (PNNL) are developing a multi-port battery-operated system capable of both spatial and temporal monitoring of CO_2 at concentrations from ambient to at least 150,000 ppmv.

The system consists of soil-gas sampling chambers and a sensing unit based on an infrared gas analyzer (IRGA). Headspace gas from the chambers is continuously pumped through a relay-driven manifold that directs gas from individual chambers into the IRGA. A unique feature of the system is its ability, based on feedback from the IRGA, to automatically dilute the sample gas stream with N_2 using a network of gas-flow controllers, thus allowing measurement of CO_2 levels beyond the normal IRGA limit of 3000 ppmv. The entire system is controlled by a programmable datalogger that also stores the output from the IRGA and gas-flow controllers. The system consists of 27 sampling chambers, thus allowing detailed spatial monitoring of a moderately sized test area (~100 m^2). Power can be provided either by an AC source or by an off-grid power-generation system consisting of six deep-cycle batteries charged by both wind and photovoltaic power sources. Dilution gas is provided by a liquid N_2 dewar containing the equivalent of 135,000 L of $N_2(g)$, enough for 4 weeks of continuous operation. The system is remotely controlled and monitored by connecting the datalogger communication port to a cellular-based modem and antenna.

On 27 August 2008, a shallow test injection of CO_2 was started at the ZERT site using a horizontal well located about 2 m below the surface and 1 m below the water table. The PNNL team set up a 27-chamber sampling grid directly above and extending northwest of the injection well. Concentrations were monitored continuously in twenty of these steady-state flux chambers during 13 days of injection (308 h) and for 33 days post injection. These concentration data can be converted directly to flux data using a flow-rate specific constant.

With the 20-chamber setup, data were collected on a 2.7-h cycle continuously for nearly 7 weeks. We centered the southeastern side of the sampling grid on a known leakage spot, and this was clearly borne out by the spatially resolved data. Unfortunately, some of the fluxes were still high enough (> 470 µmol m^{-2} s^{-1}) to saturate the analyzer. In general, the release showed near-immediate breakthrough at the hot spot, and a steady state was obtained after about 1 week of injection. The spatial extent of the emissions was generally less than 5 m laterally from the injection well. After injection ceased, fluxes at the hot spots dropped rapidly. However, at least 2 weeks were needed for the soil system to return to its initial state.

During the injection, we observed several major negative excursions in CO_2 flux data from those expected, based on trends in the data. These excursions were correlated with periods of high wind power

density (proportional to the cube of the wind velocity) and, to a lesser extent, wind direction. Data from our system was compared to that from a LI-8100 non–steady-state flux chamber system (LI-COR Biosciences, Lincoln, NE) located immediately adjacent to five of our chambers and equipped with a special air vent. In some instances, the excursions seem to be artifacts of our chamber design, whereas in others, the excursions seem to represent a real effect of sustained wind power on the CO_2 fluxes emanating from the soil. This comparison also showed that our chambers yielded flux values that were about five times greater than those obtained by the LI-8000 system. Further investigation showed the resistance to air flow inside the narrow vent tubes used to vent ambient air into our chambers, combined with the outflow rates we used, induced a vacuum inside the chambers large enough to cause a significant convective flux of CO_2 from the soil into our chambers, thus explaining the higher flux data we obtained.

Based on these results, we established several priorities for the coming fiscal year. Our primary task will be to modify to our chamber venting system to yield pressure drops of about 0.5 Pa and avoid wind-induced perturbations. Other priorities include developing 1) a two-stage dilution system to expand our range to cover the full range of possible CO_2 concentrations, and 2) an improved data reduction and visualization approach with Internet-based accessibility. During the 2009 field season, we also plan on exploring the impact of moisture content on CO_2 flux patterns.

Acknowledgments

Work was funded by the U.S. Department of Energy (DOE) Office of Fossil Energy as part of the Zero Emissions Research and Technology (ZERT) program, and by the DOE Office of Biological and Environmental Science within the Office of Science as part of the Carbon Sequestration in Terrestrial Ecosystems (CSiTE) program. We thank Dr. Jennifer L. Lewicki (Lawrence Berkeley National Laboratory) for sharing her ZERT-site precipitation data and Dr. Joseph A. Shaw (Montana State University) for all other ZERT-site weather data. Ms. Kadie Gullickson (Montana State University) collected the soil moisture data. Dr. Laura Dobeck (Montana State University) conducted the injection and provided overall site monitoring and expertise. Mr. Steven J. Walsh (Pacific Northwest National Laboratory) generated the two-dimensional plots of the discrete chamber data.

Acronyms and Abbreviations

A-h	ampere-hour(s)
CSiTE	Carbon Sequestration in Terrestrial Ecosystems (program)
DOE	U.S. Department of Energy
IRGA	infrared gas analyzer
MFC	mass flow controller
PNNL	Pacific Northwest National Laboratory
ppmv	parts per million – volumetric
μmol	micromol
WPD	wind power density
ZERT	Zero Emissions Research and Technology

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1.0 Introduction

Geological sequestration has the potential capacity and longevity to significantly decrease the amount of anthropogenic CO_2 introduced into the atmosphere by combustion of fossil fuels such as coal (White et al. 2003, 2005; McGrail et al. 2006). Effective sequestration, however, requires the ability to verify the integrity of the reservoir and ensure that potential leakage rates are kept to a minimum. Moreover, understanding the pathways by which CO_2 migrates to the surface is critical to assessing the risks and developing remediation approaches. Field experiments, such as those conducted at the Zero Emissions Research and Technology (ZERT) project test site in Bozeman, Montana, require a flexible CO_2 monitoring system that can accurately and continuously measure soil–surface CO_2 fluxes for multiple sampling points at concentrations ranging from background levels to several tens of percent. To meet this need, we are developing a multi-port battery-operated system capable of both spatial and temporal monitoring of CO_2 at concentrations from ambient to at least 150,000 ppmv.

The system consists of soil surface-flux chambers, a central measurement and control system, and an off-grid power supply system. The flux chambers are connected to the central system by 30-ft lengths of 0.25-in.-OD tubing to transfer gas samples from the chamber interior to the analyzer. The measurement and control system consists of a CO_2/H_2O gas analyzer; a datalogger for measurement recording and system control; a chamber selection and control system composed of latching microvalves, manifold, and AC/DC relays; and a sample dilution system consisting of two flow meters and one flow controller that precisely adjust and measure the incoming sample concentration by dilution with inert gas flow. The off-grid power system is energized by a three-panel photovoltaic array and two wind turbines. This energy is stored in six 12-V deep-cycle batteries and utilized by the system through an AC inverter.

This report summarizes the design of the various components of the system, including the sampling chambers, the measurement and control system, and the off-grid power supply, and then presents the results of a 7-week field test of the integrated system at the ZERT project test site.

2.0 Chamber Design

2.1 Design Considerations

Accurate real-time monitoring of subsurface CO_2 flux and concentration changes associated with CO_2 outflow from a subsurface point or line source requires an appropriately designed sampling chamber. The key considerations for the ZERT field work included

- multi-component chamber construction
- small footprint to improve spatial resolution of measurements and to minimize disturbance to subsurface conditions while sampling
- chamber headspace sized for fast response time necessary for monitoring rapidly changing fluxes and concentrations and compatible with small-sample flow rates necessary for the project
- appropriate headspace mixing for non–steady-state conditions
- low-cost construction utilizing easily obtainable materials to allow placement of multiple chambers throughout the horizontal well injection site.

A multi-component design with a fixed cylindrical base and removable end cap has several advantages. It 1) minimizes long-term disturbance of the subsurface conditions by allowing the enclosure to be open to the atmosphere between sampling campaigns, 2) improves the seal between the chamber base and soil surface, and 3) eliminates uncertainty due to placement of the chamber for successive measurements at a single site. Thus, the same end cap or top can be used sequentially on several fixed base portions inserted and left in the soil at different locations.

The ideal sampling system minimizes disruption of subsurface gas distribution. Disruption can occur by 1) pulling from the sample chamber at a high flow rate, thereby altering flow paths and acting as a sink; 2) subtending a large basal area, which allows pressure differentials to change concentration gradients within a significant volume of the subsurface; and 3) sampling for long periods, which magnifies the previous two disturbances. Reducing the basal area occupied by the sampler minimizes these issues and improves the spatial resolution of the field measurements

The impact of chamber geometric factors varies with the type of flux measurement. For steady-state flux measurements, the basal area of soil surface sampled is used in flux calculations and the chamber volume (in combination with the ambient air influx rate) determines the response rate (i.e., how quickly steady state is attained). For non–steady-state flux measurements, the headspace volume-to-basal-surface-area ratio is part of the flux calculation. In our system, for which both types of flux measurements are desired, all three factors (volume, basal area, and ambient air influx rate) need to be considered. The ratio of the chamber headspace volume to the basal area through which soil gas flux is sampled was sized to provide the fast response time necessary for rapidly changing fluxes/concentrations and small-sample flow rates. A ratio of 0.17 m for chamber headspace volume to basal area was employed and can easily be modified in the field by changing the length of the headspace cylinder if experimental conditions so dictate.

The sample chamber base has inlet and exit ports located above the soil surface that allow for mixing of the headspace gases when used in conjunction with an external diaphragm pump. Mixing homogenizes gas concentrations in the headspace, provides faster response to changes in gas fluxes and concentrations, and permits sampling of smaller volumes while retaining high accuracy and precision.

2.2 Final Design and Construction

The flux chambers consist of a base and an upper headspace-sampling component (Figure 2.1). The base is constructed of a 4-in.-diameter PVC tube (with a highly beveled end for soil insertion) attached to the male portion of a Spears Union (497-040). The upper component consists of the threaded female portion of the Spears Union, 4-in. PVC pipe, and a PVC cap with machined surfaces to accommodate pass-throughs for a 1/8-in.-OD vent tube and stainless-steel circular perforated sampling tube. Once the base is inserted into the soil, the upper component creates an airtight seal by threading onto the base and compressing the integrated O-ring onto the base sealing surface. Basal area subtended by the chamber is 8.11e-3 m^2, and headspace volume is 1.38e-3 m^3.

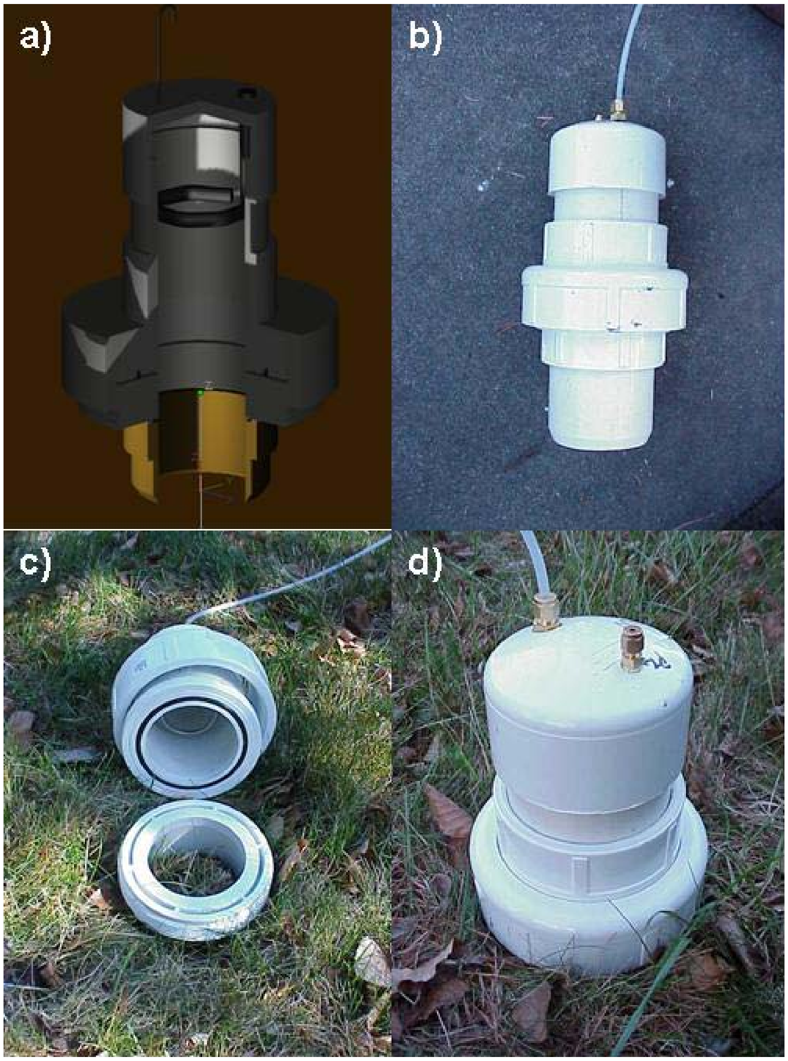

Figure 2.1. Soil Surface-Flux Sampling Chamber: a) cutaway view showing circular perforated sampling tube for headspace mixing, b) pre-installation – assembled, c) installed – top unattached, d) installed – top attached without 4-in.-long, 1/8-in.-OD vent tube

3.0 Measurement and Control System

3.1 Design Considerations

The infrared gas analyzer (IRGA) used to detect CO_2 and H_2O (LI-7000, LI-COR Biosciences, Lincoln, NE) has a maximum detection level of 3000 ppmv (0.3%) for CO_2 in the linear response range. Data collected in the 2006 and 2007 ZERT injection tests demonstrated the need to be able to detect significantly higher concentrations (up to 10–20%) with a steady-state flux-measurement approach. To accommodate this measurement range using the IRGA, we decided to develop an automatic dilution system using N_2 as the diluent. The dilution factor would need to be known precisely to allow accurate calculation of the actual CO_2 concentration and the flux associated with the soil chamber. Moreover, the dilution would need to be automated to allow routine unattended analysis under field conditions.

In our design, the N_2 dilution gas enters the system after the sample gas has been pushed from a sample pump (Aqua Lifter AW-20, Tom Aquarium Products, Gardena, CA) and before sample gas entry into the IRGA optical cell (Figure 3.1). The effect of the dilution on the IRGA response is rapid due to the proximity of the dilution inlet to the optical cell. A datalogger/control system (CR23X, Campbell Scientific, Logan, UT) sets the dilution-gas flow rate through a mass flow controller (MFC) using feedback from the current CO_2 concentration read at the analyzer (Figure 3.2). When the analyzer approaches saturation, the CR23X signals the MFC to start the dilution gas in a staged fashion. The dilution flow increases through several stages in a time-delayed series until the IRGA response is back within the linear operating range (i.e., < 3000 ppmv). From measured flow rates of the incoming sample, dilution gas, and optical cell outflow, the dilution factor is determined and stored, together with the corresponding IRGA response, by the CR23X. Analysis of each chamber is performed during a 6-min cycle time. Successive chambers are selected for analysis by the CR23X, which controls a valve manifold that directs flow to either the IRGA system (from the actively analyzed chamber only) or exhaust (from all other chambers) (Figure 3.1).

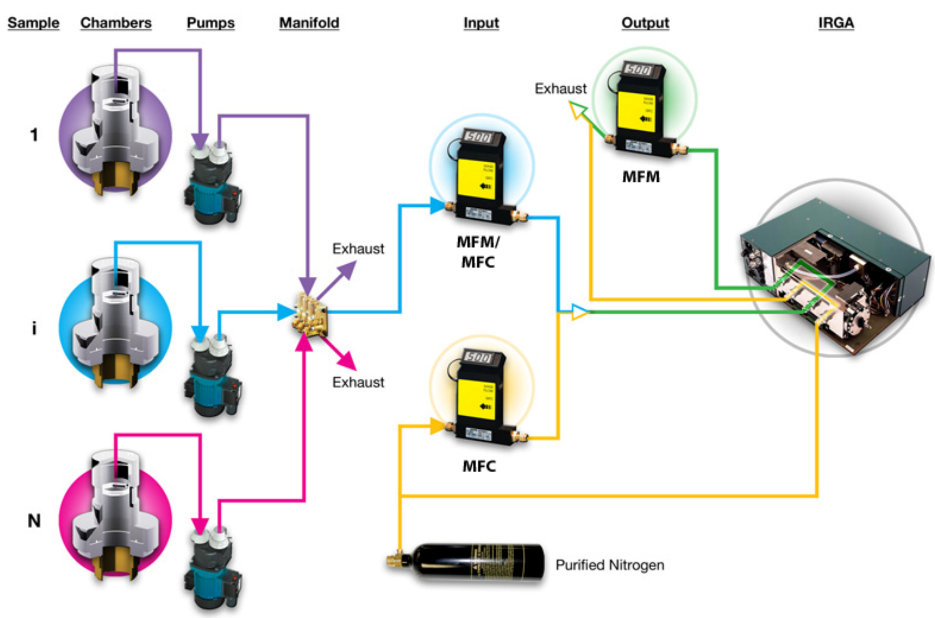

Figure 3.1. Plumbing Schematic for CO_2 Analysis by Automated Sampling and Dilution System

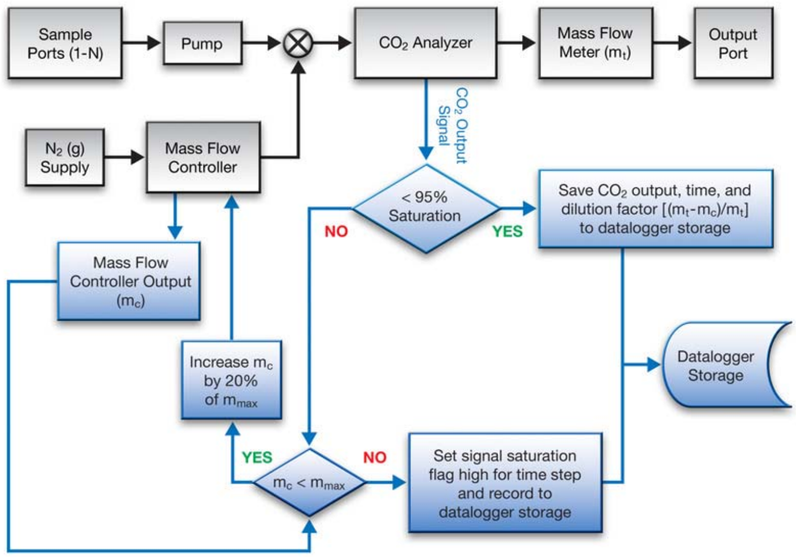

Figure 3.2. Logic and Sample Flow Paths for CO_2 Analysis by Automated Sampling and Dilution System

3.2 Testing and Verification of the System

For the system to work appropriately in the field, several criteria must be met: 1) instrument response should be stable at elevated concentrations, 2) cross-contamination from successive chamber measurements should be negligible, 3) all of the chambers should respond to the same input conditions in the same fashion, and 4) the system should be capable of being calibrated against a known standard.

The capability of the system to accurately dilute samples in real time is demonstrated in Figure 3.3. These data, collected during the 2008 field test at the ZERT site, show the staged activation of the dilution system when the IRGA detector is saturated. In this instance, two of a total of five possible dilution stages were activated. The dilution factors for these two stages were about 20x and 30x. With the higher dilution factor, the sample is diluted below the IRGA saturation limit of 3000 ppmv, and a stable dilution-corrected concentration value of 81,000 ppmv is attained. A slow decay in the dilution factor is balanced by a corresponding increase in the IRGA reading to yield a constant sample concentration as expected. Small oscillations in the sample pump rate impact the dilution factor and sample concentration but do not significantly affect the time-averaged result, which is taken during the last 2 min of the 6-min measurement cycle.

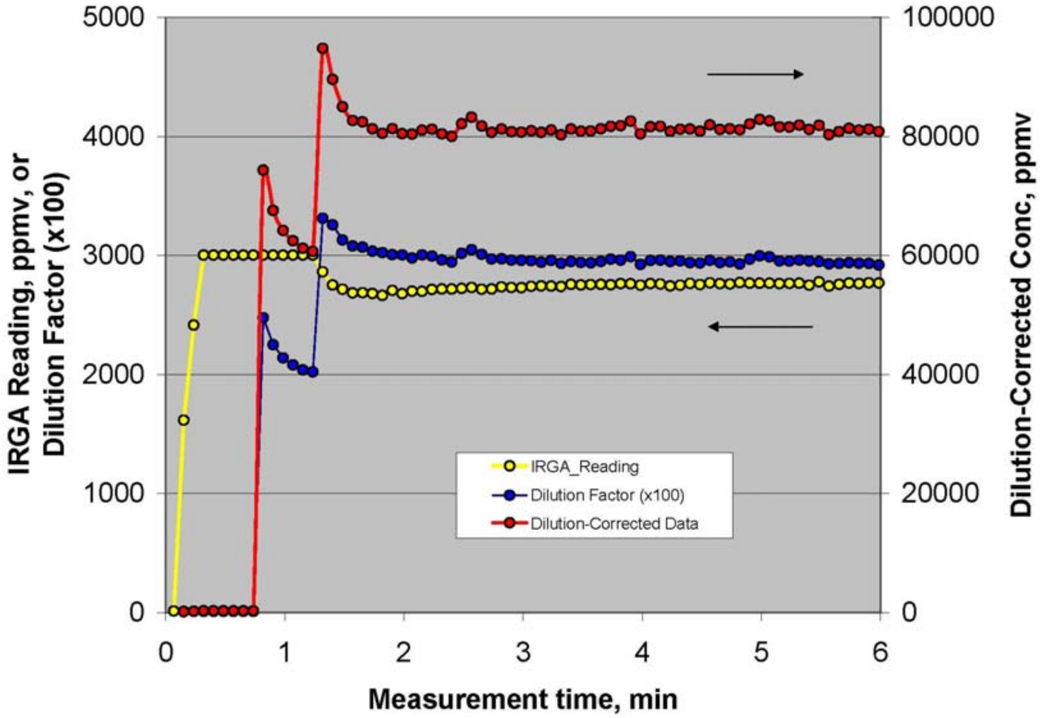

Figure 3.3. Typical Data for Dilution Process Showing Staged Dilution Based on Feedback from IRGA Reading (yellow, left axis). Upon saturation, two dilution stages (five stages are possible) are implemented until IRGA reading drops below saturation level. Dilution factors (about 20x and 30x) are shown (blue, left axis) together with dilution-corrected data (red, right axis).

To conceptually demonstrate the ability of the system to meet the remaining criteria, we conducted a series of laboratory tests on an earlier smaller-scale version of the full field system. The laboratory system differed from the system used in the 2008 ZERT test injections by having only seven channels, each of which was pumped by a separate Aqua-Lifter AW-20 pump located upstream of an eight-channel brass valve manifold.

For the multi-port and real-time dilution capability, we prepared two identical sample chambers filled to the normal depth with quartz sand and connected them to a sample gas inflow. Flow into one of the chambers was controlled by a valve that was closed at the start of the experiment and then opened about 2 h into the experiment. A N_2/CO_2 gas mixture containing about 1.5% CO_2 was used at a nominal flow rate of 41 mL/min. Our control software was programmed to alternate sampling between each sample chamber on a 6-min cycle. At the initialization segment of each sample cycle, the analysis cell in the IRGA was flushed with N_2 for 15 s, and then normal sample flow resumed with staged dilution of the CO_2 by N_2 as needed. The results of the experiment (Figure 3.4, blue and red symbols) show the evolution of the CO_2 concentrations in the headspace of the sample chambers over the course of several hours and demonstrate the breakthrough of the CO_2 plume into the sample chamber headspace. A third dataset in yellow (collected in a separate run) demonstrates the response to both low- and high-flux conditions in the same chamber. For this test the transition to the high-flux condition occurred 93 min after the start of the low-flux condition (Figure 3.4).

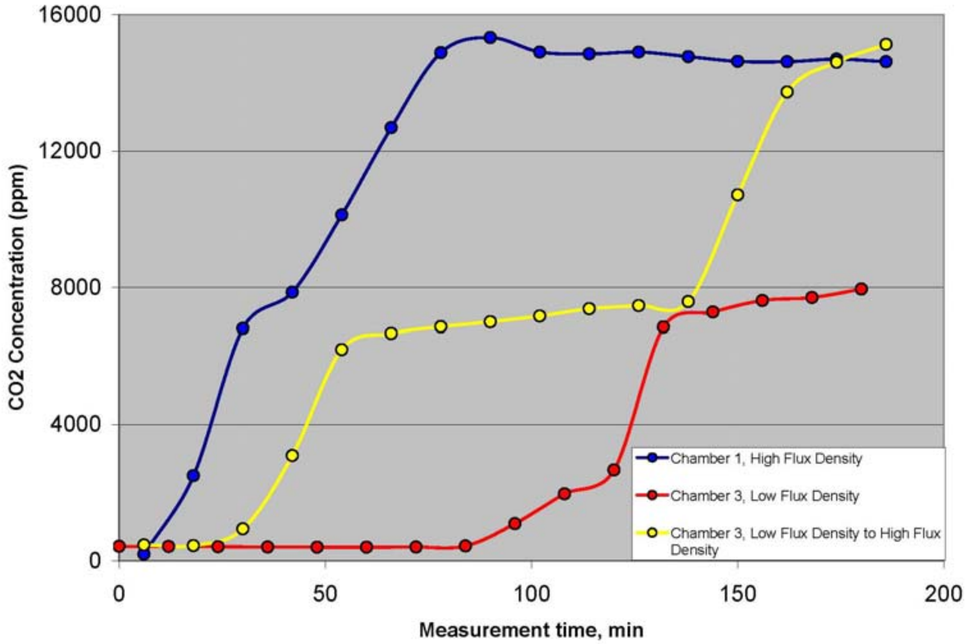

Figure 3.4. Demonstration of Multi-Port Capability and Lack of Cross-Contamination for Two Surface-Flux Chambers Operating at Different Flux Densities

It is important that the system response remain unchanged, regardless of which head unit–base combination is used. Figure 3.5 shows the response of six tests in which various lid and base combinations were examined with identical chamber inlet conditions, two of which were repeated with an active fan circulation, all yielding nearly identical results.

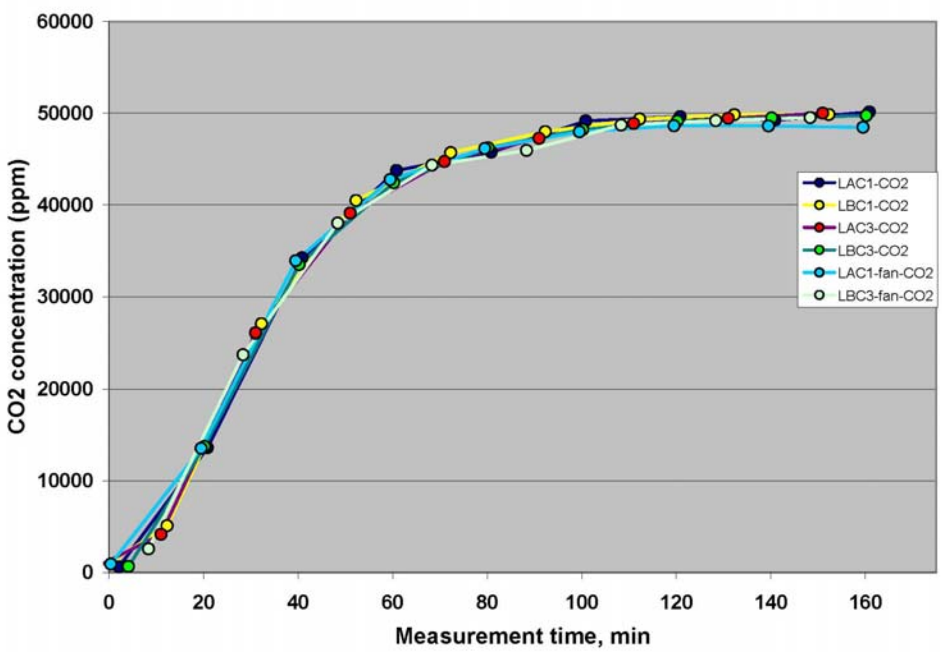

Figure 3.5. System Response to Same Flux-Density Scenario Using Interchangeable Chamber Tops/Bases

To test the accuracy of the staged CO_2-dilution process, we prepared a series of CO_2 standards (1100-86,000 ppm in N_2) and analyzed them using the 6-min procedure. The standards, which had been prepared in 6-L "Summa" canisters, were introduced to the analyzer at constant pressure (10 psi controlled by a regulator) by connection to a sampling port and pump. The results (Figure 3.6) showed that by using the MFC manufacturer's conversion from reading output (V) to flow (mL min^{-1}), there was a deviation in slope for the samples requiring dilution. Using the Solver function in Microsoft Excel, we calculated the correct flow and offset of the flow controllers and meters using the calibrated standards (yellow symbols). This calibration process is readily implemented in the field, and the new slopes and offsets can be substituted easily into the measurement and control code.

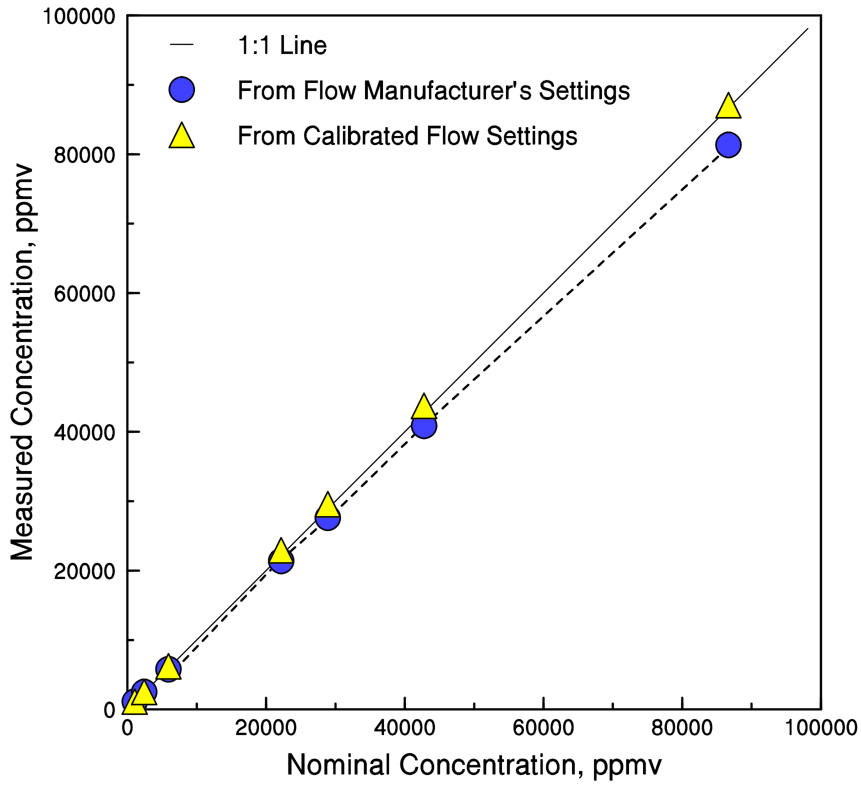

Figure 3.6. Test of Staged-Dilution Accuracy Using CO_2 Standards Prepared in N_2 and Introduced at 10 psi. The blue symbols are the raw readings, and the yellow symbols are the corrected readings.

3.3 Full-Scale Field-Monitoring Version of Measurement and Control System

During the development and testing of the of the portable multi-port real-time CO_2-detection system, we found the system to be a robust, accurate, and useful tool in understanding the dynamics of well injections at the ZERT site in Bozeman, Montana. However, the system was limited by having only seven sampling chambers, requiring a considerable amount of operator interaction to record data, recharge and replace the deep-cycle battery power source, and replace the N_2 gas cylinders that provide both reference and dilution capabilities to the system. The aim of the full-scale field-monitoring version was to create a system that would be capable of continuous unattended subsurface monitoring at remote sites. Our specific goals were to produce a monitoring system that could be installed easily at remote sites, sample from an ordered dense grid covering a moderate area, operate at sites without available power, be monitored and controlled from offsite continuously in real time, and operate for extended periods between N_2 refills.

The most important changes involved increasing the number of chambers and decreasing the need for frequent operator interactions with the system. Increasing the number of chambers to monitor a moderately sized area in a grid-wise manner, essentially moving from a one-dimensional monitor to a two-dimensional one, was determined to be highly beneficial to understanding subsurface characteristics for transport and to assist in locating small areas of high flux. A modular solution was taken to address the need to increase the sampling chambers from seven to twenty-seven, allowing for the creation of a 5×5 grid with additional soil and ambient-air reference channels. This was accomplished using valved direct-current (DC) relays that were addressable and capable of being daisy-chained, together with valve manifolds that were compact and had exhausts that could easily be tied together. Using addressable and chainable relays allows for future expandability with minimum of changes to system configuration or control software. The relay drivers chosen for this application were Campbell Scientific SDM–CD16AC. These relays have 16 relay ports for device control and can be chained 15 deep for a total of 240 ports or sampling chambers. In the current configuration, two SDM-CD16AC relays are employed, utilizing 27 of the 32 ports for sample valve control. The new manifolds to house the valves are LFMX0510533B and LFMX0510538B manifolds (3- and 8-port manifolds, respectively; Lee Co., Westbrook, CT). These manifolds accept the same microvalves as the custom Campbell Scientific brass manifold at a fraction of the cost and consume very little space in the control and measurement system housing, leaving room for future expansion.

The operator interaction with the previous system involved three activities: 1) charging and rotating deep-cycle batteries every 12 h, 2) transferring data to external storage before the datalogger would overwrite the onboard storage, and 3) replacing cylinders of N_2 every several days (dependent on subsurface concentrations and amount of dilution gas required). Because this level of operator interaction was significant, it would not be feasible for long-term studies. We addressed the first operator-interaction activity by assembling a renewable power system with a large electrical storage capacity, the details of which are described in Section 4.

With respect to the second operator-interaction activity, we developed a two-part solution involving both hardware and software. The Campbell Scientific CR23X datalogger (Campbell Scientific, Logan, UT) stores 5e5 values in 1 MB of flash memory. With the previous system, this translated into 6.5 h of data before an operator would have to perform a memory dump to external memory to prevent overwriting of the data by the datalogger. We connected an Airlink Raven 110 cellular data modem (Sierra Wireless, Richmond, BC, Canada) and a Campbell Scientific 18285 1-dBd Omnidirectional Antenna (Campbell Scientific, Logan, UT) to the datalogger RS232 port, thus allowing data to be pushed or pulled to an Internet Protocol address at 384 kbps. To take advantage of all of the capabilities provided by the cellular data modem, we installed Loggernet 3.1 software (Campbell Scientific, Logan, UT) on the computers used to communicate with the datalogger. With this software, all control programming, communications, and data retrieval can be done remotely, thereby eliminating the need for an on-site presence. However, this approach requires cellular service in the area, the signal of which can be drastically improved if necessary by the use of a Campbell Scientific 14454 9 dBd YAGI unidirectional antenna also available for use with the system.

For the 2008 ZERT injection, we pulled data from the system every 10 min and appended it to a file on the operator's computer. The data file on the computer can contain an unlimited amount of data. However, if viewing data in a spreadsheet, files of less than 18 h of data are most practical to view, due to the limited number of rows available in a spreadsheet.

The third operator-interaction activity involved frequent changing of gas cylinders that supplied the N_2 used in the dilution stage and as a reference gas. Initially we used a type K pressurized cylinder containing approximately 6500 L of N_2. For a typical injection experiment at the ZERT site, this size N_2 cylinder would need to be replaced every 2 to 3 days. To address the need for a larger volume of N_2 than provided by the K-type tank, a Dura-Cyl medium-pressure liquid N_2 cylinder (Chart Industries, Inc., Garfield Heights, OH) containing 209 L of liquid N_2 (yielding approximately 135,000 L of N_2 gas at ambient pressure) was employed. The use of a liquid N_2 cylinder extended the gas maintenance interval by twenty-fold from 2–3 days to more than a month.

4.0 Power System

The power system was designed to provide off-grid power to the measurement and control system throughout the year at the ZERT site. Energy consumption for the complete measurement and control system and subcomponents of that system is detailed in Table 4.1. Total measurement and control system power consumption was determined to be 73.64 A-h. Assuming 80% efficiency, a power supply system would need to provide a minimum of 88.4 ampere-hours (A-h) of power at 12 V. We designed a power supply system that included three 125-W Mitsubishi PV-TE125MF5N solar panels (Mitsubishi Electric and Electronics USA, Cypress, CA), two 400-W Air Industrial wind turbines (Southwest Wind Power, Flagstaff, AZ), and a bank of six Lifeline GPL-4DA 210-A-h deep-cycle 12-V batteries (Lifeline Battery, Azusa, CA).

Table 4.1. Power Consumption of System in Ampere-Hours

Device	Device Current (A-h)
Licor LI-7000 CO_2 gas analyzer	36
SKC pump	9
Omega mass flow controller	6.4
Tom's Aqua Lifter 20 pump	6
Campbell Scientific SDM16AC relay x 2	4.8
Aalborg mass flow meter	4.8
Omega mass flow meter	4.8
Campbell Scientific CR23X datalogger	1.2
Sierra Wireless Airlink Raven	0.64
Total Device Current (A-h)	**73.64**

The system was sized to work solely on solar power throughout the year at the ZERT site in Bozeman, Montana. Using the worst-case equivalent sun hours (i.e., the minimum sun hours for the worst month of the year) for Bozeman (3 h), it was determined that three 125-W 12-V solar panels would be able to deliver an adequate amount of power to the measurement and control system, taking into account 20% system loss (125 W/12 V × 3 h = 93.75 A-h = minimum solar output > 88.4 A-h = adjusted system power need). To supply consistent power (e.g., at night, in winter) to the measurement system, a reserve power battery bank was determined a necessary component of the power system. Given the latitude of the ZERT site (45.68 degrees N), it was determined that a 14-day reserve would be adequate for the system.[1] A battery bank of six 210-A-h deep-cycle batteries (1260 A-h total, 14-day reserve) was attached to the solar array through a Morningstar Tristar solar controller (Morningstar Corp., Washington Crossing, PA). This battery bank feeds 12 V DC into a Xantrex ProWatt 1750 Inverter that converts 12 V DC into the 120-V AC power (at 80% efficiency) that powers the measurement and control system (Xantrex Co, Burnaby, BC, Canada).

[1] http://www.southwestpv.com/Catalog/Home%20Power/SYS_DESIGN.HTM.

To allow for future needs of the measurement and control system, occasional use of power for non-system activities (e.g., power tools, lights), or deployment to a site incapable of providing enough power from the current solar array, two 400-W Air Industrial Wind Turbines mounted on 25-ft towers (RV Mounting Tower, Earthtech Products, Merrick, NY) were tied into the system with individual Tristar Controllers and an external heat load for over-power conditions. The specialized towers make it possible for one person to set up the wind turbines by securing the base under the trailer wheel and rotating the tower into the locked position (Figure 4.1). All of the controls, breakers, battery cases, batteries, heat loads, and power measurement instruments were located in a 6-ft ×-10 ft single-axle trailer (CargoMate, Independence, OR) (Figure 4.1 and Figure 4.2). The trailer can transport all of the hard-mounted electronics, the remainder of the power system (turbines, turbine towers, solar array), the measurement and control system, chambers, chamber tubing, and associated tools with room to store a N_2 dewar if appropriate safety controls are taken.

Figure 4.1. Power Supply System: Wind Turbines, Turbine Towers, Solar Array, and Trailer as Deployed at ZERT Site in 2008

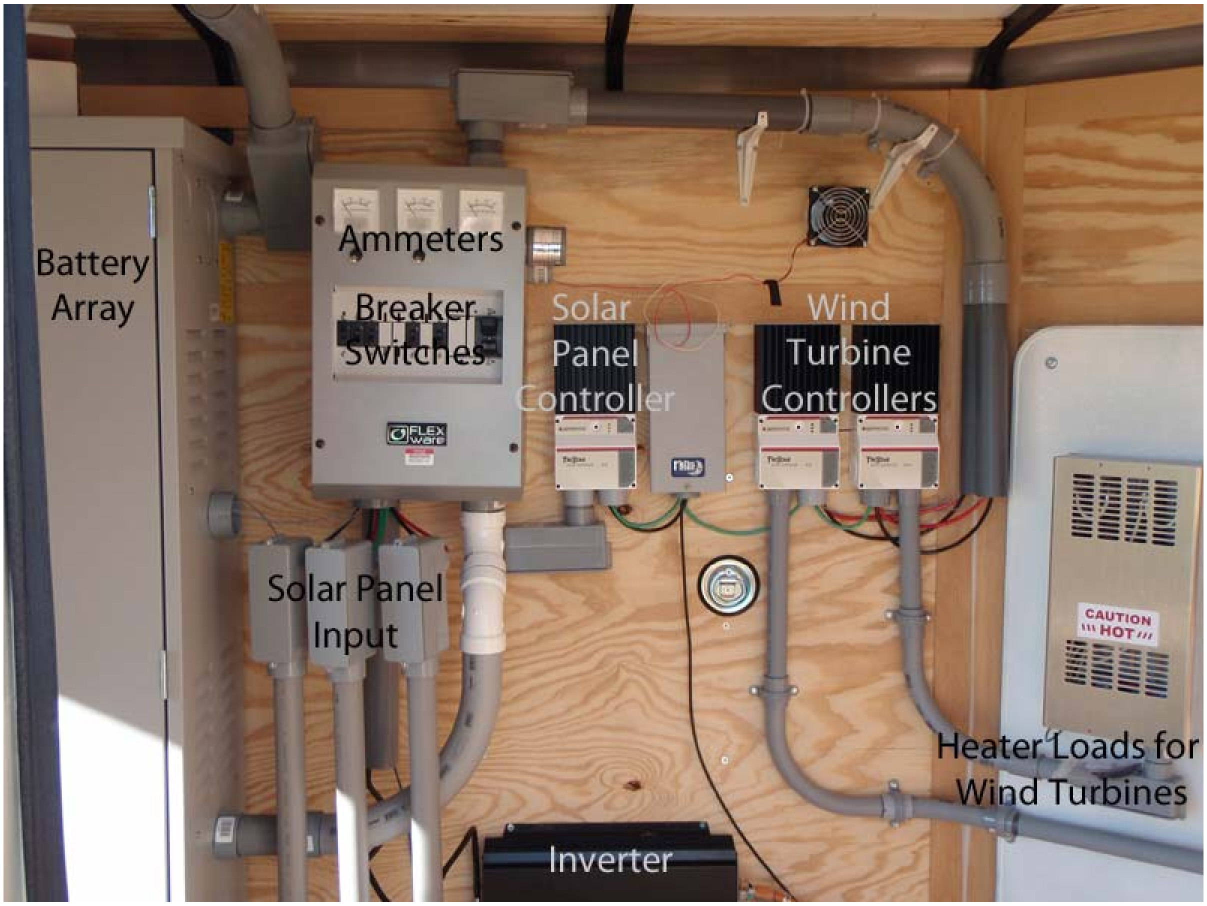

Figure 4.2. Interior View, Power Supply Trailer, Detailing Orientation of Power Supply Components Housed Inside Trailer

5.0 Field Test at ZERT Site, FY 2008

5.1 Experimental Layout

The measurement and control system and components for the off-grid power supply were delivered to the ZERT field test site near Bozeman, Montana, during the third week of June 2008. Limited power availability on the site required that we supply our own power in order to participate in the first test injection scheduled for the second week of July. However, significant delays (10 weeks) in shipping of the power system components prevented assembly and testing beforehand, and the next several weeks were spent assembling the power system onsite. We did not complete assembly in time to participate in the first injection and were fortunate that a sufficient supply of bulk CO_2 remained afterward to allow the ZERT project to schedule a second injection specifically for testing our system.

The 100-m-long horizontal well at the ZERT site used for this experiment is buried approximately 2 m below the surface and divided into six zones by packers that allow independent control of flow rates and gas mixtures in each zone (Figure 5.1). The well is oriented along a northeast–southwest axis, and CO_2 is injected at the northeast end. The water table varies during the year but typically is on the order of 1 m below the surface during mid-summer. As a consequence, CO_2 is injected below the water table, and the pressure differences resulting from small changes in pipe elevation lead to localized emissions or "hot" spots at the higher end of each zone near the packer. In this test, CO_2 was injected only into Zone 3.

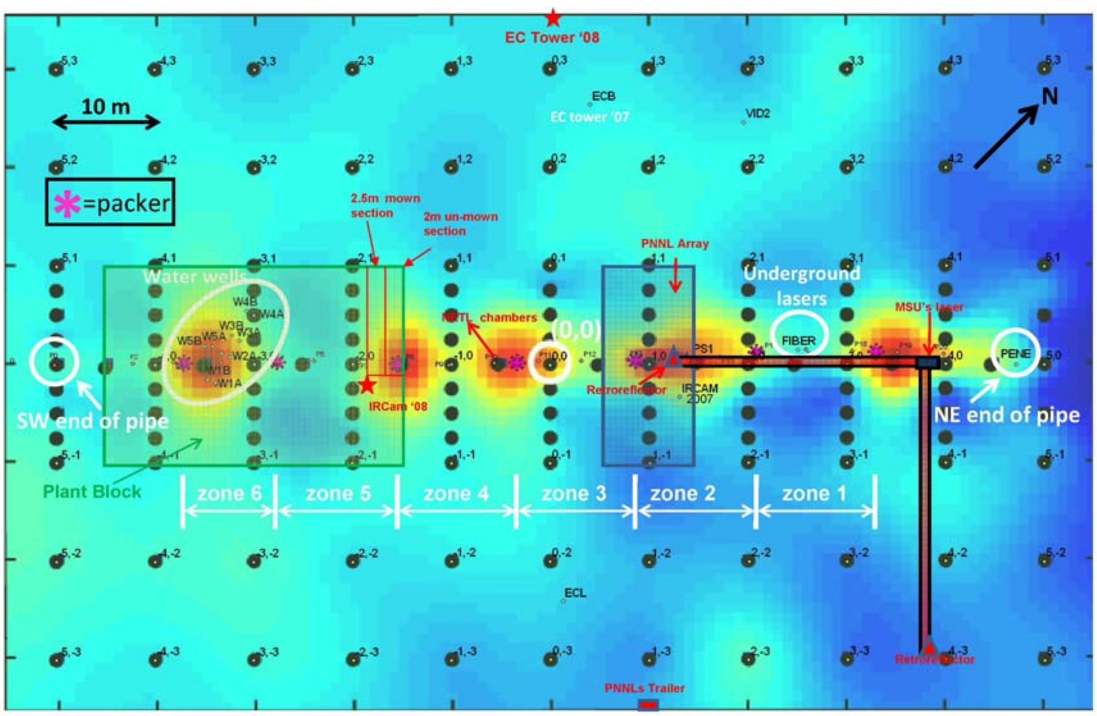

Figure 5.1. ZERT Site Plan View Showing Position of PNNL Experiment (Conducted During Second Injection) Relative to Other Experiments Conducted During First Injection. Also shown in red and orange are the areas in which high CO_2 fluxes were observed during the previous year's injection (data of J. L. Lewicki; map drawn by L. Dobeck).

Based on the results from the previous year's tests, we centered our sampling array directly over a hot spot located near the boundary between zones 2 and 3. Twenty-seven surface-flux chambers were installed to yield a 5×5 sampling array with two reference chambers. A leaking gas valve manifold in the measurement system, however, limited us to twenty chambers for this experiment; their locations are shown in Figure 5.2 and Figure 5.3.

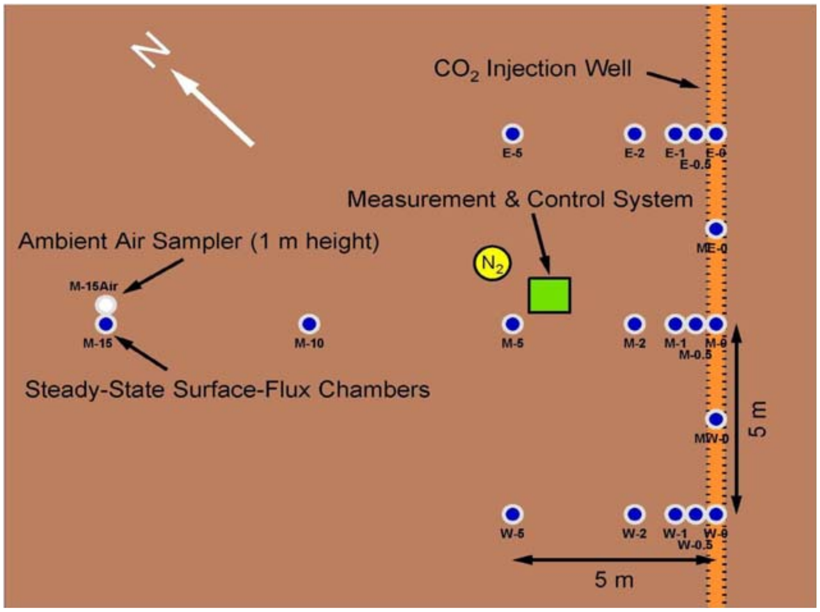

Figure 5.2. Plan View, Surface-Flux Chamber Array and Location of Measurement and Control System with Liquid N_2 Supply

Figure 5.3. Experimental Layout Looking Northeast. Horizontal well is directly beneath rightmost row of flux chambers.

5.2 Injection and Concentration Data

The second injection was started at 12:55 PM on 27 August 2008 (ordinal day 240.54), and continued for nearly 13 days (308.2 h), ending at 9:00 AM on 9 September 2008 (ordinal day 253.38). An injection rate of 52.1 (±0.4) kg CO_2 d^{-1} was maintained for the first 280.8 h, after which the flow monitor failed. A second monitor that measured pressure (rather than flow) showed that the same conditions were maintained except for a 12-h period between 289.4 and 301.4 h, during which pressure increased by 25% over the value maintained for the rest of the injection. Although a 5% increase in measured flux was observed in one of the chambers during this 12-h period, such a change was within the normal noise limits observed, so it is unlikely that the 12-h deviation had a significant impact on the results. The injection was halted about 7 h after the end of the pressure deviation.

We continuously (at 2.7-h intervals) monitored CO_2 concentrations in the twenty chambers starting about 4 h before the injection and for 33 d post-injection. Because these chambers were operating in steady-state flux mode, these concentration data can be converted directly to flux data using a flow-rate specific constant (ca. 0.0031 μmol m^{-2} s^{-1} $ppmv^{-1}$). A plot of data out to 1000 h for all twenty chambers is shown in Figure 5.4. Successive plots (Figure 5.5 through Figure 5.8) focus on subsets of these data.

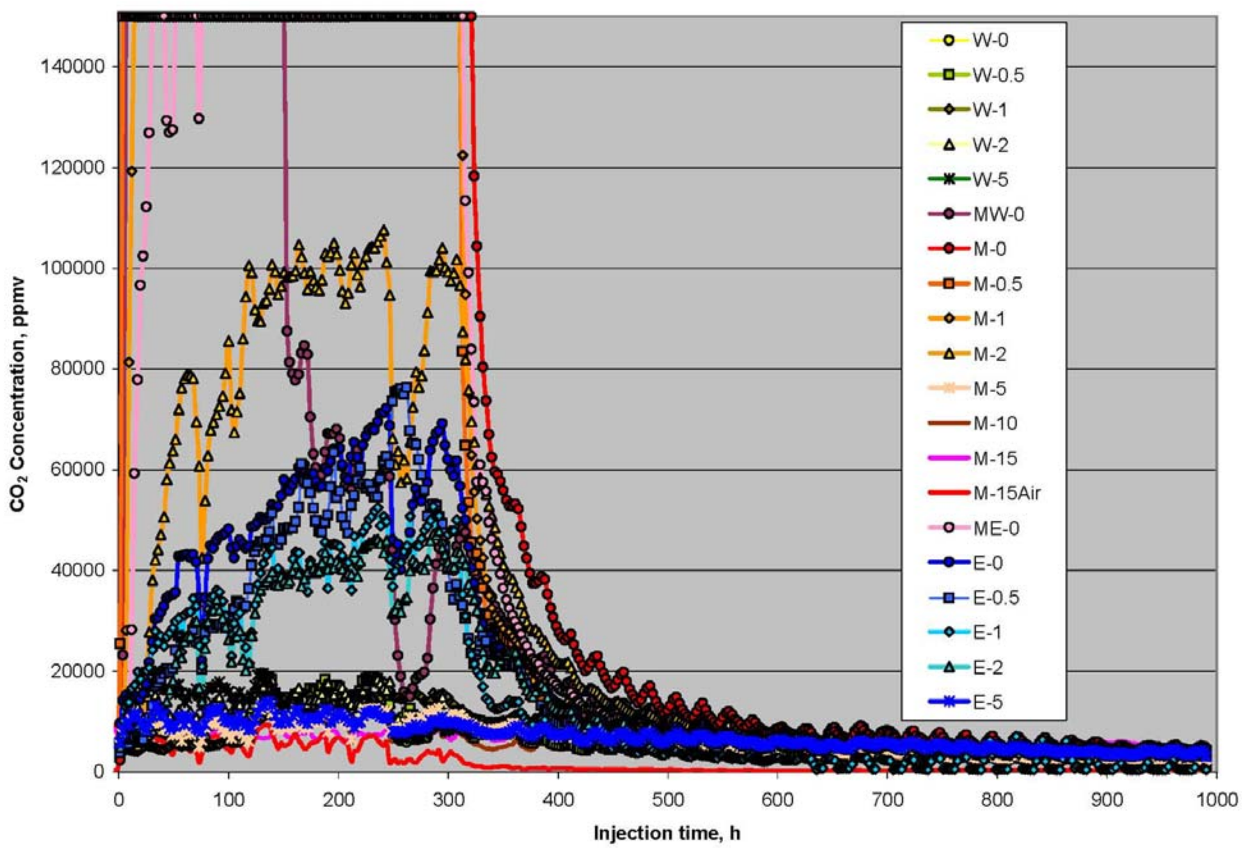

Figure 5.4. CO_2 Concentration Data Collected from Twenty Surface-Flux Chambers During and After Second Injection at ZERT Site. Data collection started on 27 August 2008. Chambers are identified by row (letter) and lateral distance in meters from the horizontal well (number).

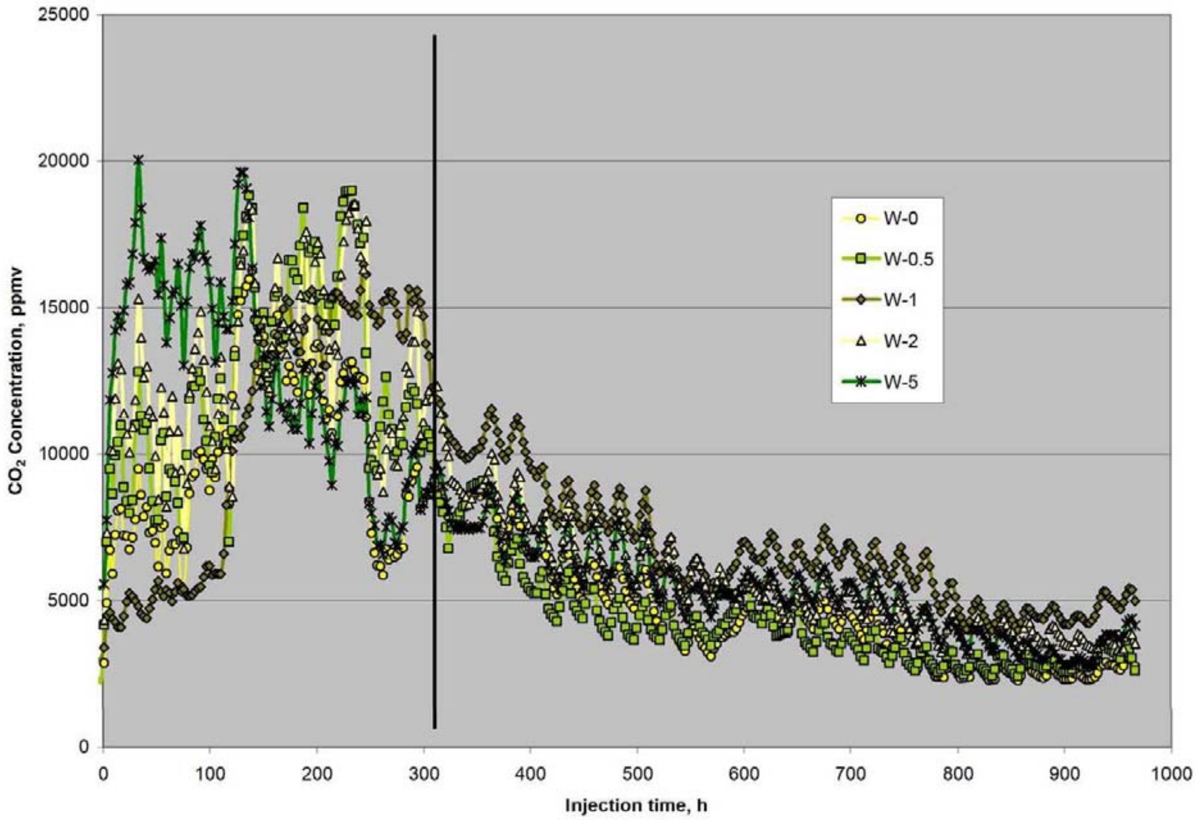

Figure 5.5. CO_2 Concentration Data Collected for West Row (W) of Surface-Flux Chambers. Vertical line indicates end of CO_2 injection. Chambers are identified by row (letter) and lateral distance in meters from the horizontal well (number).

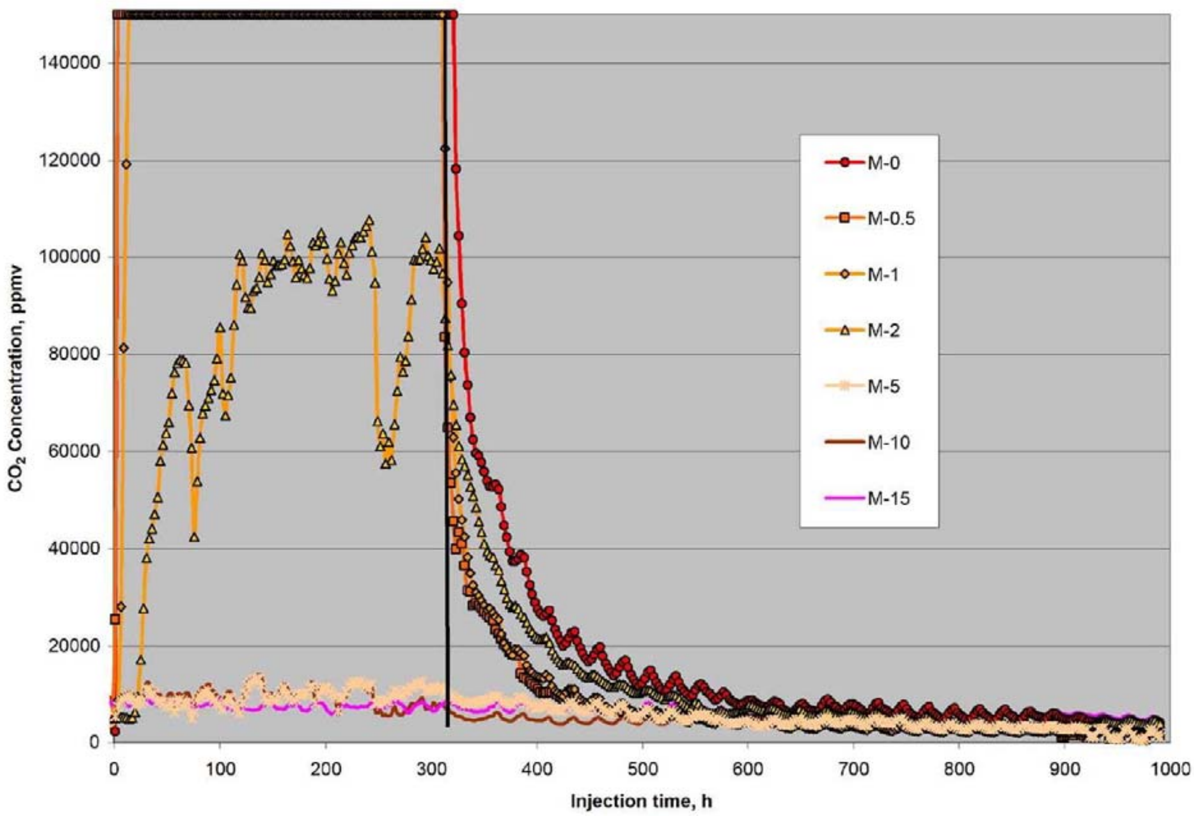

Figure 5.6. CO_2 Concentration Data Collected for Middle Row (M) of Surface-Flux Chambers. Vertical line indicates end of CO_2 injection. Chambers are identified by row (letter) and lateral distance in meters from the horizontal well (number).

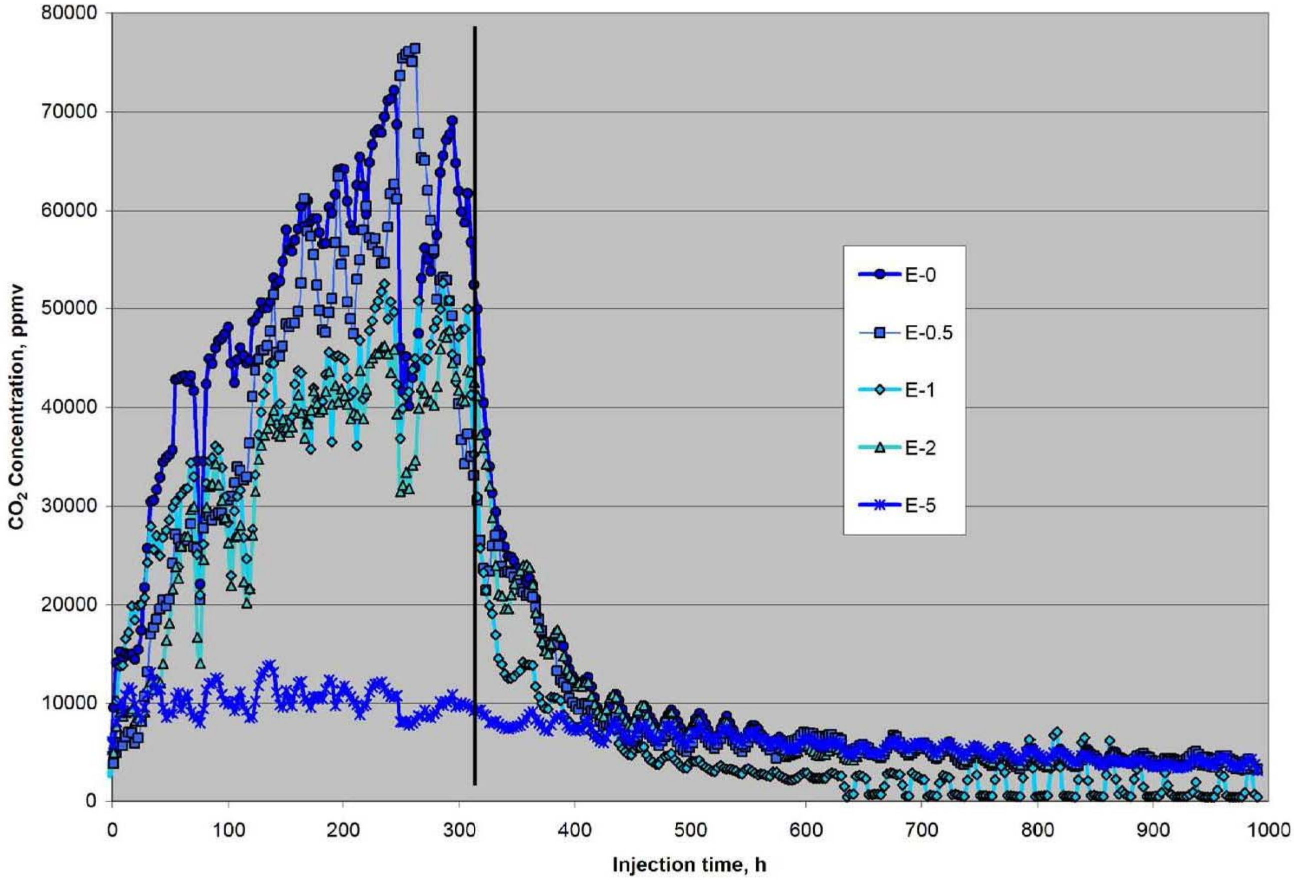

Figure 5.7. CO_2 Concentration Data Collected for East Row (E) of Surface-Flux Chambers. Vertical line indicates end of CO_2 injection. Chambers are identified by row (letter) and lateral distance in meters from the horizontal well (number).

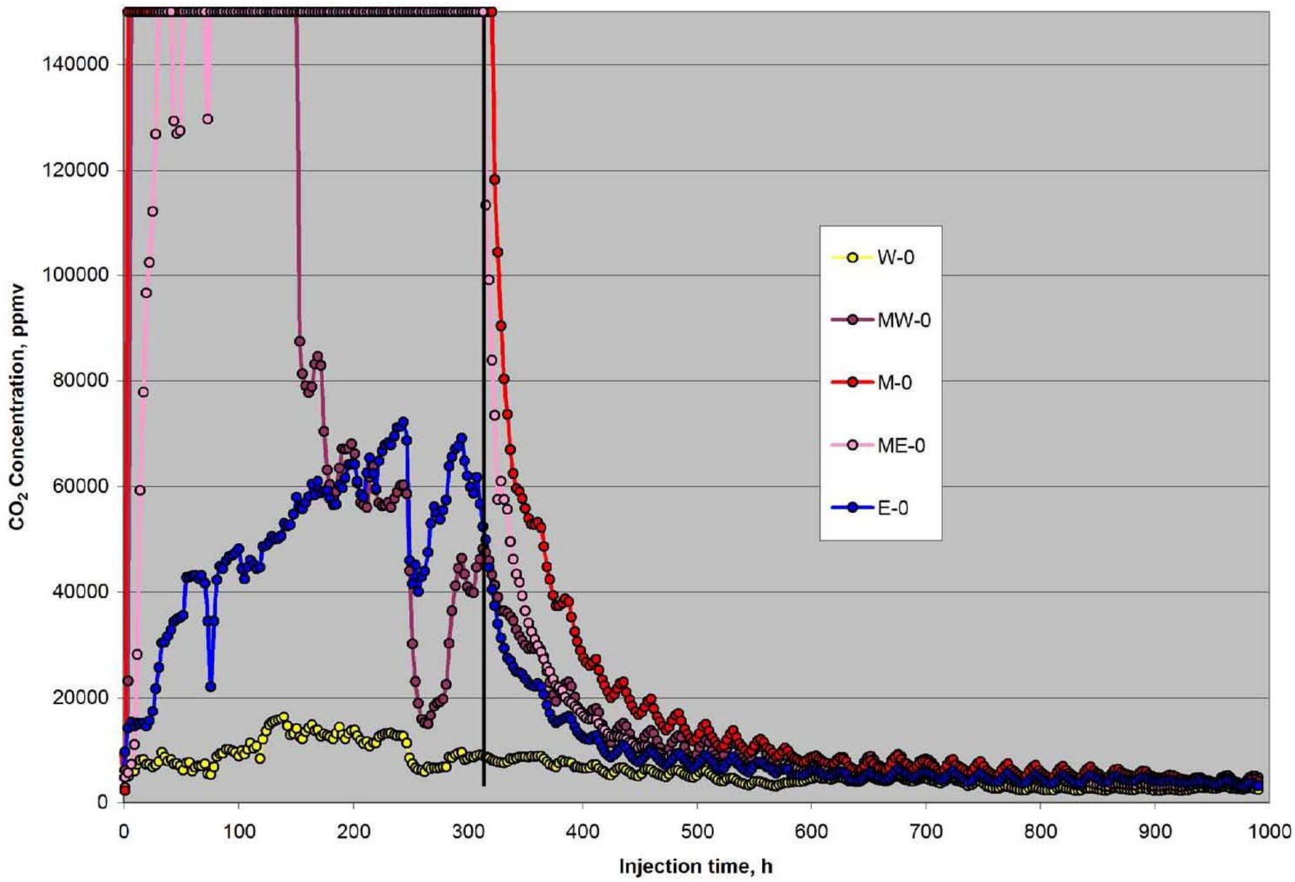

Figure 5.8. CO_2 Concentration Data Collected Surface-Flux Chambers Located Directly Above Horizontal Well. Vertical line indicates end of CO_2 injection. Chambers are identified by row (letter) and lateral distance in meters from the horizontal well (number).

The concentration data in Figure 5.4 to Figure 5.8 show that several chambers reached instrument saturation levels of CO_2 (150,000 ppmv) during the injection period. These chambers were located primarily along the middle row of chambers within 2 m of the horizontal well. The MW-0 and ME-0 chambers also saturated. As would be expected from locating the sampling array over a hot spot, the chambers positioned more than 3 m from this spot (centered at chamber M-0) did not saturate. Although a steady state seemed to be reached for M-2 and some of the W chambers, the CO_2 concentration in the E row continued to increase during the injection, suggesting continued expansion of the plume toward the northeastern end of the sampling array. This result is interesting because the injection occurred only in the southwestern half of the array (i.e., that portion of the horizontal well located in Zone 3). This drift is seen also in the MW-0 data during the injection. Initially (within 7 h), the MW-0 chamber reached saturation, but after 153 h it decreased to about 90,000 ppmv and continued to decline for the remainder of the experiment (Figure 5.8). The northeasterly drift in concentration is consistent with the generally northerly direction of groundwater flow at the ZERT site, which may be a contributing factor.

The concentration data also show significant drops in nearly all the chambers at about 75, 105, and 257 h after injection. As will be discussed in Section 5.3, these drops are likely the result of barometric effects associated with local weather changes.

We took two approaches to help visualize the changes in spatial extent of the plume. In the first, we show the discrete concentration values for each chamber for a particular time arranged in an array that simulates that in the field (Figure 5.9). In the second, we created filled-contour plots for the same time periods using R, a statistical programming language (http://www.r-project.org/) but restricted the spatial range to 0–5 m from the horizontal well (Figure 5.10). Because the contour plots required a full 21×11 data matrix (231 pixels) on a 0.5-m grid spacing and data for only seventeen of these pixels were collected (M-10, M-15, and M-15AIR were excluded), a large number of points needed to be estimated. A two-dimensional Gaussian kernel was used as the smoothing function (essentially a spatial-weighted moving average), and missing values were handled with the Nadaraya/Watson normalization of the kernel (a normalization that diminishes the effects of missing observations). The function was initialized with a 0.5-m spacing of the pixels in the width and height directions and a bandwidth parameter of 1.5 m.

The spatial representations we obtained (Figure 5.9 and Figure 5.10) clearly show a rapid increase to saturation levels within the first 72–168 h of injection for chambers located less than 3 m from the center of the hot spot, as well as the general drift of the plume toward the northeast end of the array (top of plots) with time. Possible evidence for the plume reaching 5 m from the injection well can be seen in the discrete data for the west and east rows in which data rise slightly above background levels.

A rapid system response was observed in the early stages of the injection (Figure 5.11). Within 4 h of the start of injection, the M-0 and M-0.5 chambers had reached instrument saturation levels; the MW-0 and M-1 chambers followed suit at about 7 h and 14 h, respectively. The concentration in the ME-0 chamber rose more slowly and oscillated near saturation from 30 h to 75 h before exceeding 150,000 ppmv for the remainder of the injection.

The rapid response was seen also once the injection ceased. Within 16 h of the injection end, all chamber concentrations were below saturation, and within 133 h, all were below 20,000 ppmv (Figure 5.4 to Figure 5.8). Also, a noticeable diurnal pattern returned to the concentration data once the advective forcing provided by the injection ceased. This pattern presumably reflects the contributions of soil and plant respiration to the surface fluxes measured. Clearly, even in locations where the highest concentrations of CO_2 were observed (e.g., chamber M-0), some living organisms survived. The steady decay of the CO_2 concentrations beneath the diurnal signal continued until background levels were reached 400-600 h after injection ceased.

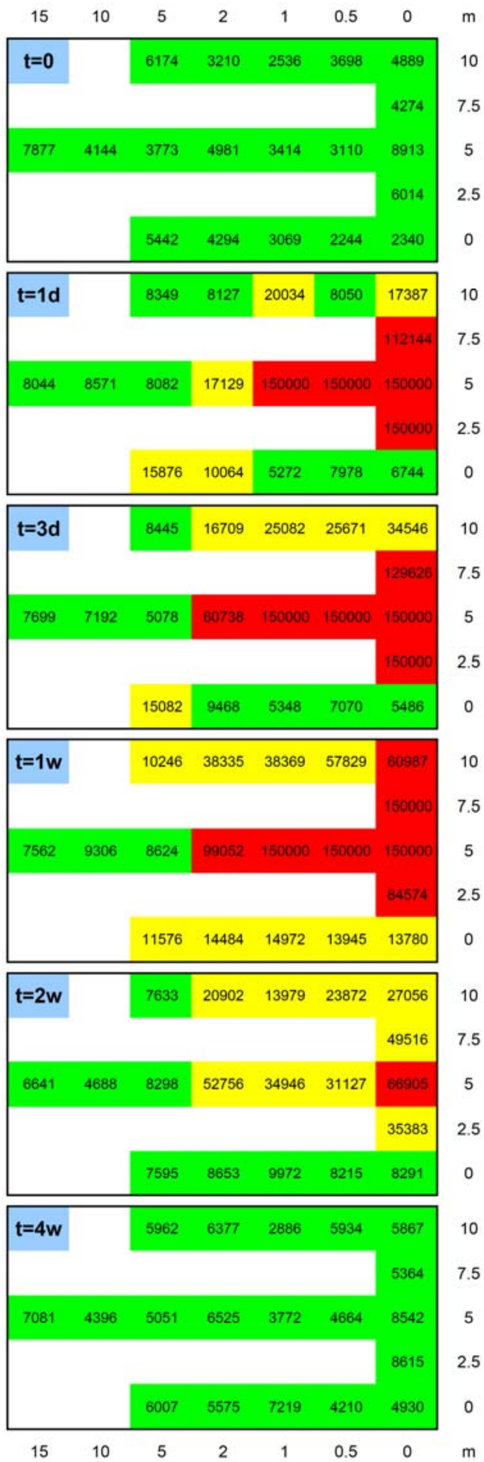

Figure 5.9. Quasi-Spatial Representation of Discrete Chamber Concentration Data at Six Selected Times During the Second Injection Experiment. Values in each rectangle are in parts per million-volumetric of CO_2.

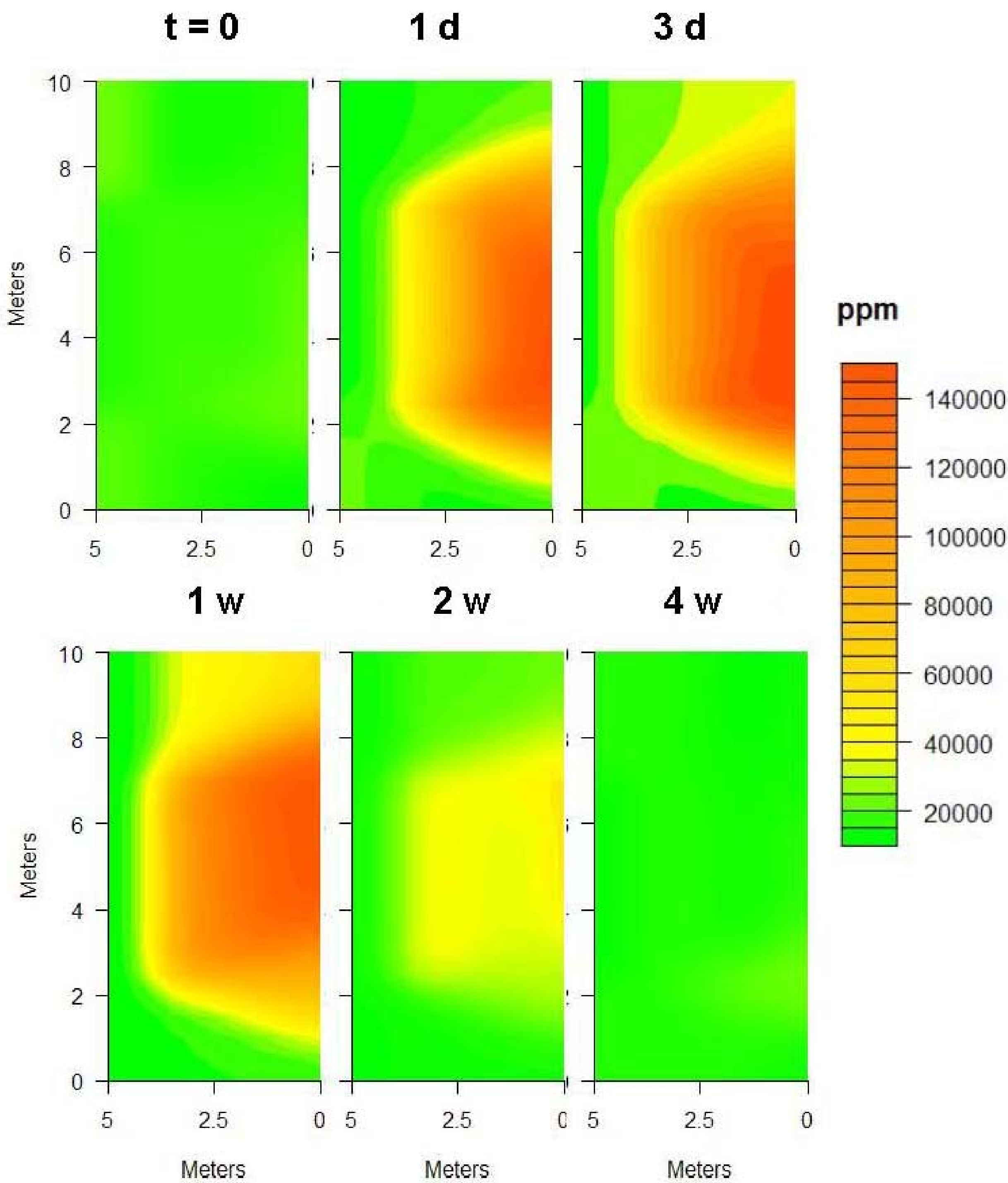

Figure 5.10. Spatially Accurate Two-Dimensional Representation of CO_2 Concentrations Measured Within 5 m of the Horizontal Well During the Second Injection. Data are interpolated from discrete chamber measurements using R statistical software.

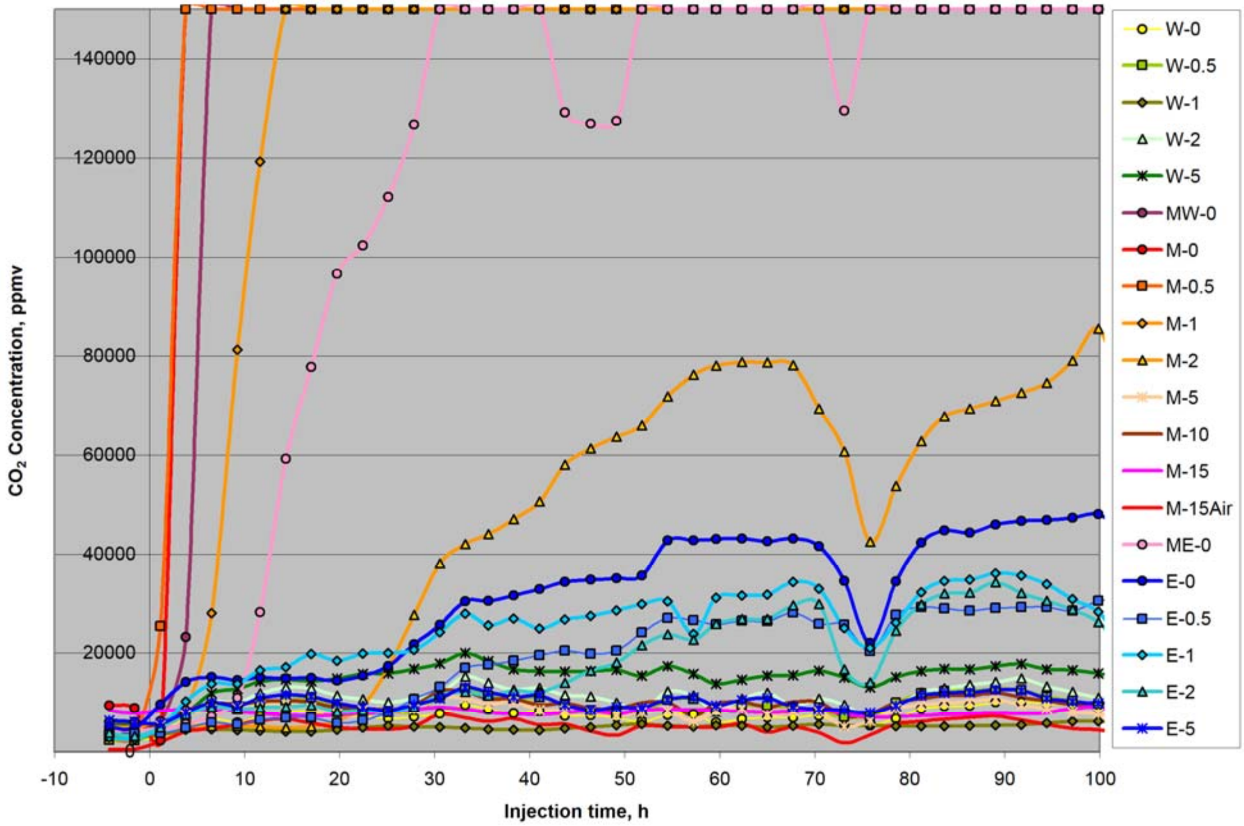

Figure 5.11. CO_2 Concentration Data Collected from twenty Surface-Flux Chambers Immediately Before and During the First 100 h of the Second CO_2 Injection at the ZERT Site. Chambers are identified by row (letter) and lateral distance in meters from the horizontal well (number).

The concentration data for chambers M-10 and M-15 remained at background levels throughout the experiment and retained the diurnal pattern typical of biologically derived CO_2 emissions. The background level for chamber M-15 dropped by about a third as the experiment progressed, in keeping with the overall decline in biological activity with dropping ambient temperature during the fall season (Figure 5.12).

The atmospheric background sample collected at the same location as chamber M-15 but from a chamber suspended 1 m above the ground surface (i.e., chamber M-15Air) should have yielded a similar diurnal pattern (albeit at much lower concentrations) with no impact from the injection. However, the results (Figure 5.12) show much higher concentrations during the injection, falling to normal ambient levels once the injection ceased. The levels observed for chamber M-15Air during the injection are in the range of those expected for normal steady-state soil flux measurements (around 5,000–10,000 ppmv) and clearly do not represent atmospheric conditions. Further evidence for this is the open-path atmospheric concentration data collected directly over the horizontal well in zone 2 (approximately 15-cm height) by Humphries and Repasky during the first injection, which showed typical concentrations near 1000 ppmv and maximum concentrations on the order of 1500 ppmv (K. S. Repasky, Montana State University, personal communication).

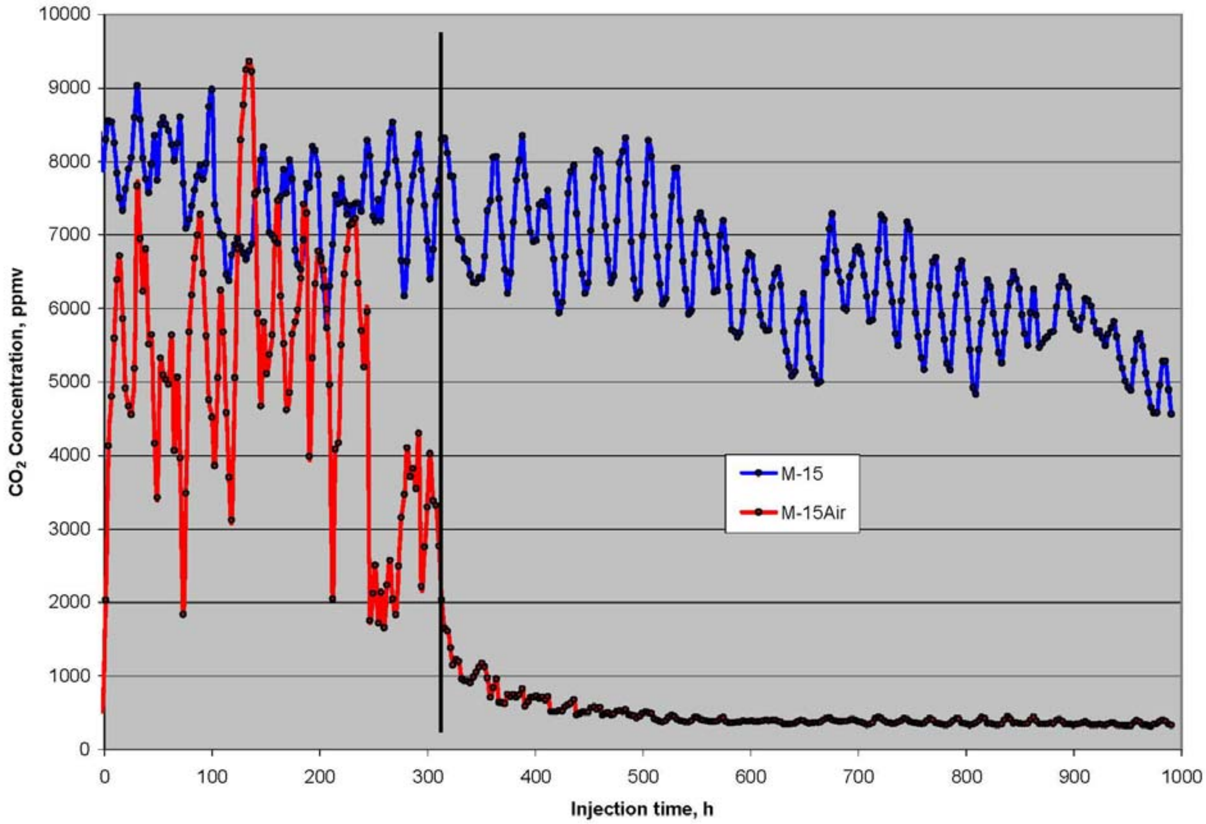

Figure 5.12. CO_2 Concentration Data Collected for Reference Surface-Flux Chamber and Ambient Air 15 m from Horizontal Well. Vertical line indicates end of CO_2 injection.

To explain the chamber M-15Air data, we reexamined other possible sources of CO_2 that could interfere in the analysis. We had eliminated "cross-talk" in earlier versions of the measurement system by having individual pumps for each channel and by flushing the system with 100% N_2 between samples. With our change to a pair of pumps for the entire system (one for exhaust of the chambers not being analyzed, and one for the sample dilution feed) to lower the power consumption of the measurement system, this feature was eliminated. We think there are two possible causes of the high readings. One is sample carryover from the use of a common sample dilution-feed pump. However, we would expect this to be even more of a problem for the chamber M-15 sample because it is analyzed before the M-15A and, thus, closer, in time to the higher-concentration samples. We see no impact of the injection on data for M-15, however, suggesting that carryover is not the likely cause of higher observed concentrations with M-15A. Nevertheless, as a precaution, we have identified a way to automatically flush the sample-handling and dilution system between each sample while retaining the current two-pump configuration and will test it in the next round of instrument enhancements in FY09.

The second possibility is a leak in the valve manifold or tubing. We already know that seven of the channels could not be used due to external air leaks into the sample train. An undetected leak could have been associated with the valve manifold or tubing for the M-15A sample that would allow the take-up of exhaust gas released inside the measurement system box from other samples prior to M-15A analysis, resulting in a contaminated sample. We will be hardening the valve and tubing connections for all channels in the coming year's work, which should eliminate this problem.

5.3 External Factors Affecting CO_2 Concentration Data

As described in Section 5.2, several negative excursions from the expected concentration data were observed simultaneously in essentially all the chambers during the injection. The largest excursions occurred at about 75, 105 and 250–260 h after injection was started and tended to last for tens of hours before the data returned to steady state or otherwise expected patterns. Similar, but positive, excursions were noted by us and the Repasky team during the first injection in summer 2007, and these were hypothesized to be related to changes in soil moisture content stemming from rainfall or dew deposition. With this hypothesis, it was thought that absorption of moisture by the soil particles would decrease the air-filled porosity, thereby increasing the resistance to gas flow in the low-flow regions of a field and promoting higher flow rates in the high-flow regions where moisture absorption would be less likely to occur due to the already high flow rate.

To test the soil-moisture hypothesis in the 2008 field trial, we installed eighteen gypsum-block soil moisture sensors (5201F1 Soilmoisture Gblocks, Soil Moisture Equipment Corporation, Santa Barbara, CA) at a 6-in. depth adjacent to our soil gas-flux chambers in early July 2008. The soil moisture readings from these sensors were obtained manually every 4–7 days using a hand-held meter that registered readings from 0 (dry) to 100 (wet). According to the manufacturer (Soil Moisture Equipment Corporation, 2000), these readings can be converted to soil matric suction (bars). A reading of 70 corresponds to a matric suction of 0.1 bar, that of 19 to 1 bar, that of 4 to 3 bars, and a reading of 1 corresponds to a matric suction of 10 bars (near the permanent wilting point for plants).

Soil moisture measurements were collected over a period of 1800 h (starting at ordinal day 206.65 and ending at ordinal day 282.38) roughly centered on the initiation of the second injection. The results (Figure 5.13) showed a fairly moist soil 800 h before the injection. The soil dried out rapidly, however, and by the time the second injection started, the soil was extremely dry. It remained in that state for the duration of our experiment, thus negating one part of our attempt to address the soil moisture hypothesis. No positive excursions were observed during the second injection of 2008, so the hypothesis remains untested. The sensors remain in place and will be used in the coming field season experiments.

For possible explanations of the negative excursions observed in 2008, we obtained meteorological data from two weather stations located at the ZERT field site (courtesy of J. A. Shaw and J. L. Lewicki). To visually assess relationships between the weather variables and the soil CO_2 excursions, we first isolated the excursions from the "expected" data by fitting a 6th-order polynomial function to the expected data and subtracting the observed from the expected data predicted by the function (Figure 5.14). We then plotted the excursion data on the same time graph as the meteorological variable we were testing and looked for obvious correlations. For this exercise, we selected the data for chamber M-2 as representative for the entire array because the concentrations did not saturate the measurement system and yet were high enough to minimize the contributions of diurnal fluctuations and sampling noise to the overall signal.

The weather variables we tested included relative humidity, temperature, precipitation, wind speed, wind direction, and absolute barometric pressure. Most of these variables had little or no relation to the negative excursion data (Figure 5.15). A clear relationship was seen, however, between wind speed (and, to a lesser extent, change in wind direction) and the observed negative excursions. We believe that the operative variable with respect to wind speed is actually the wind power density (WPD), which has units of watts per square meter, as this more closely measures the ability of the wind to perform work on the soil gas system. The WPD is calculated as

$$WPD = 0.5 \times \rho_{air} \times \upsilon^3 \quad (5.1)$$

where ρ_{air} is the mass density of air in kg m^{-3}, and υ is the wind velocity in m s^{-1}. A doubling of wind velocity thus produces an eight-fold increase in WPD.

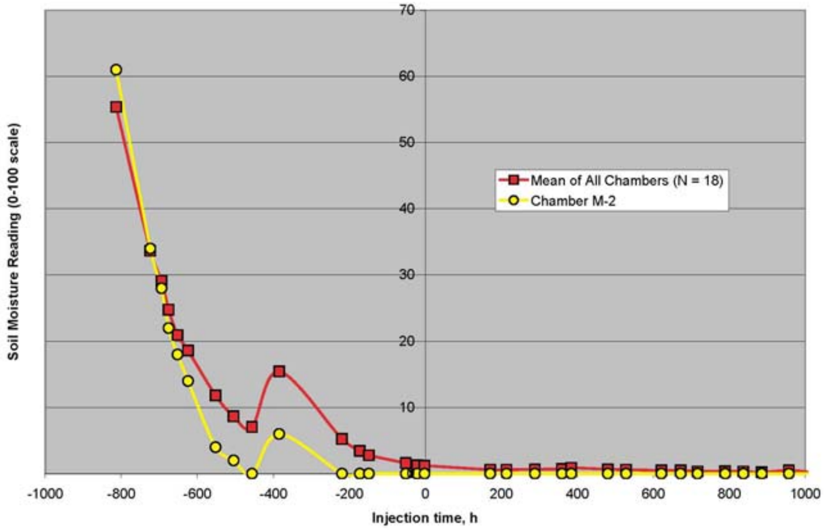

Figure 5.13. Relative Changes in Soil Moisture Content at a 6-in. Depth Before, During, and After Second Injection

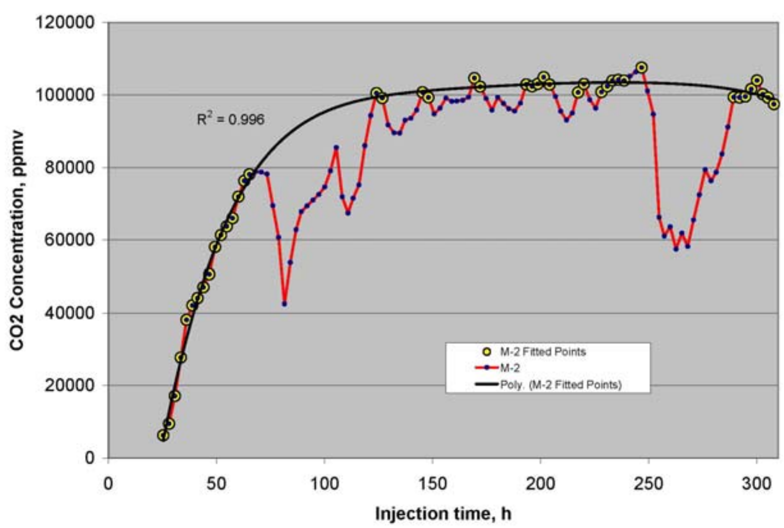

Figure 5.14. Concentration Data for Chamber M-2 Fitted To Obtain a Function Describing the "Expected" Data and Showing the Major Negative Excursions from the Expected Data at 75, 105, and 250–280 h After Injection

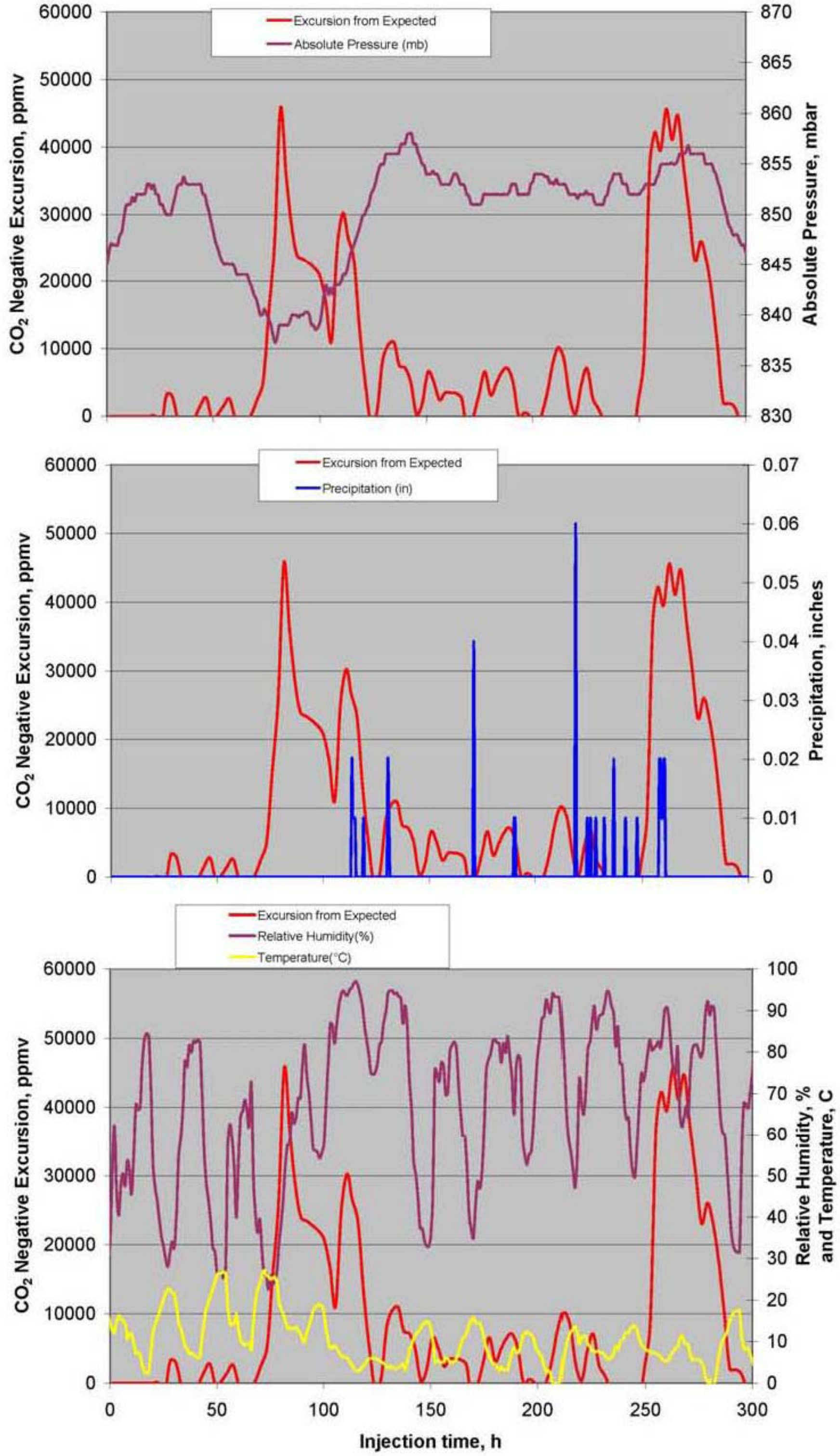

Figure 5.15. Comparison Plots Showing Timing of the Negative Excursions in the CO_2 Concentration Data for Chamber M-2 Relative to the Values for Barometric Pressure (top), Precipitation Amount (middle), and Relative Humidity and Air Temperature (bottom) Collected at the ZERT Site

For wind direction, we calculated the change in wind direction in degrees for a specific time point as the difference between the average of the wind direction 5 h forward from a specific point in time and the average 5 h back. The use of the 5-h differential moving average approach smoothed out variability in the data and helped focus on larger systematic changes. We hypothesized that changes in the wind direction would tend to cause changes in the barometric pumping activity of the wind on the soil, due to the different slope aspect of the soil surface relative to the wind. Wind direction could also affect the venting of the chamber because the 4-in.-long, 1/8-in.-OD vent tubing extended into the air at an angle from the vertical (Figure 5.3).

The results of the comparisons of negative excursion events with wind variables were quite striking. All three major excursions were preceded by or contemporaneous with major bursts of wind power density (Figure 5.16 top). The total energy of the wind (calculated by integrating the area under the power density curve) also seemed to relate well to the size of the excursion event.

The relatively minor excursions did not show much of a correlation with WPD, but the noise in these measurements (2σ) is about 4600 ppmv, so it is unclear whether the minor negative excursions were significantly different from the expected values. Interestingly, however, the frequency of the negative excursions matched nicely with that of the changes in wind direction (Figure 5.16 bottom), suggesting that simply changing the direction of the mass air flow could impact the CO_2 concentrations measured using steady-state methods. We recognize, however, that this periodicity was on the order of 24 h, and some diurnal fluctuations in soil respiration, for example, could have contributed to the minor excursions.

We are uncertain whether the negative excursions that we observed are an artifact of the steady-state flux measurement method or truly represent a process that is occurring in the soil whenever the WPD is high. The evidence supports both possibilities. Data collected using an automated non–steady-state flux chamber (LI-8100, LI-COR Biosciences, Lincoln, NE) located adjacent to our M-2 chamber show a large negative excursion for the 245- to 285-h period comparable to that seen with our chambers (Dr. Laura Dobeck, Montana State University, personal communication). These results suggest that the near-surface portion of the soil reservoir had become depleted due to the high sustained winds and thereby temporarily decreased the measured efflux rates. The LI-8100 chamber was equipped with a novel vent tube (Xu et al. 2006) that minimizes wind effects (transient pressure differentials between chamber interior and ambient air that influence soil gas fluxes) at wind speeds below 7 m s^{-1}. However, the LI-8100 unit did not show negative excursions for the earlier major excursions observed with our chamber that occurred between 73 and 124 h. Moreover, a comparison of flux values obtained by the two chamber types showed the steady-state chamber to have fluxes that were generally five-fold higher than those obtained with the LI-8100.

The combination of wind direction effects, anomalous excursions (i.e., during the 73- to 124-h period), and five-fold higher flux values suggest that our chamber venting system might require modification. For steady-state flow-through flux chambers, pressure differentials of less than a few tenths of a pascal are recommended to avoid artificially enhanced flux results (Kanemasu et al. 1974; Gao and Yates 1998; Rochette and Hutchinson 2005). Reichman and Rolston (2002) obtained accurate data with their chamber at pressure differentials of 0.5–0.8 Pa while noting that soil texture played a significant role in the absolute pressure differential that could be tolerated. The calculated pressure drop (http://www.pressure-drop.com/Online-Calculator/index.html) across the vent tube at the flow rate we used (40 mL min^{-1}) is 8 Pa, which suggests that a relatively substantial vacuum was induced in the chamber under our operating conditions. This vacuum could have caused higher advection from the soil and a correspondingly higher flux rate.

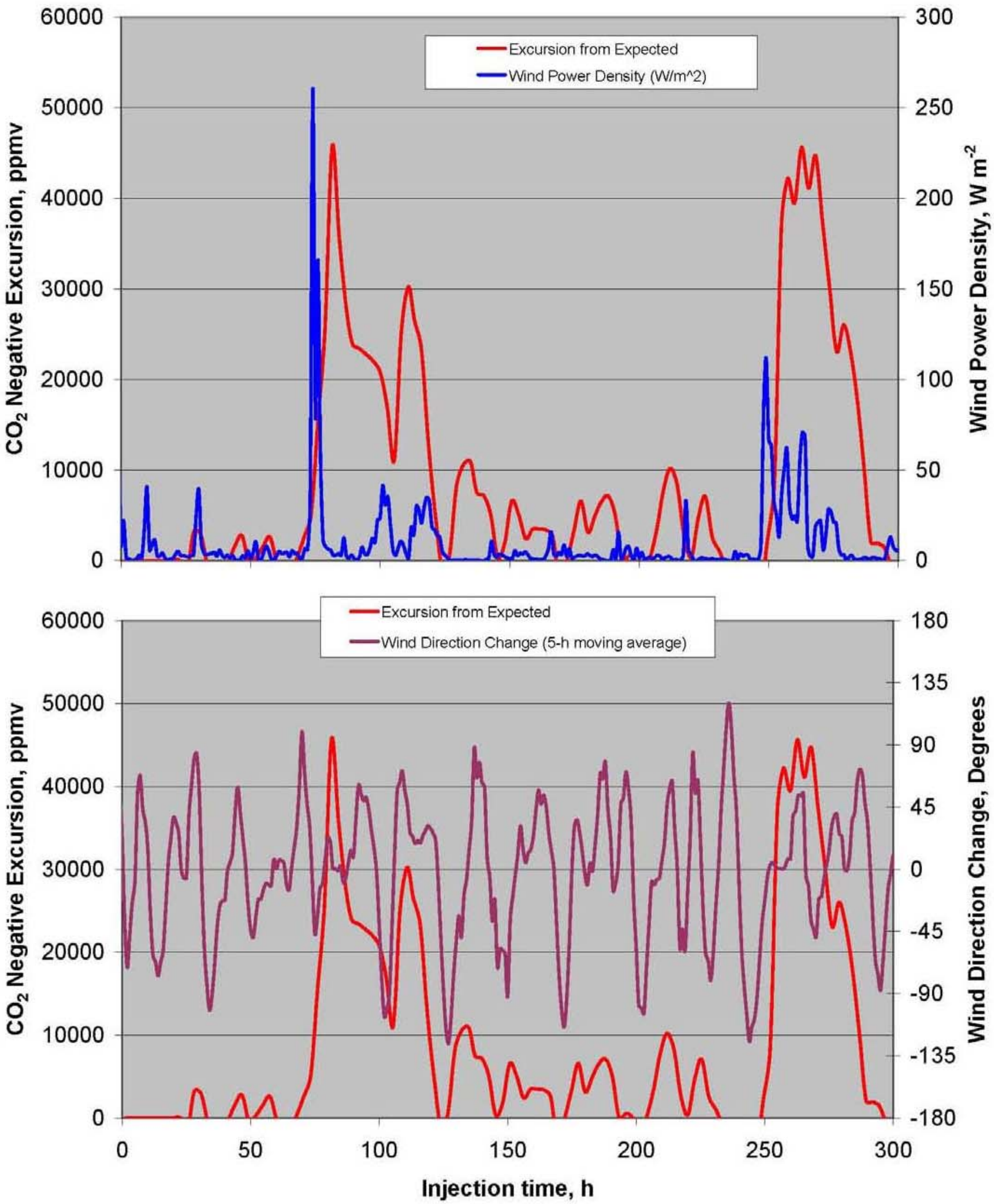

Figure 5.16. Comparison Plots Showing Timing of the Negative Excursions in the CO_2 Concentration Data for Chamber M-2 Relative to the Values for Wind Power Density (top) and Wind Direction Change (bottom) Collected at the ZERT Site

To relieve this pressure drop while also maintaining the ability to buffer transient wind-induced pressure changes, a larger diameter tube is required. For wind speeds of 4 m s^{-1}, Hutchinson and Mosier (1981) calculated that a tube diameter of 3.6 mm and length of 5.8 cm would be needed for a 1.4-L volume chamber. The calculated pressure drop with this sized tube for our flow rate is well below 1 Pa. With the use of vent tubing, however, also comes the risk of pressure changes induced by the Venturi effect at certain wind directions. Xu et al. (2006) eliminated this problem at wind speeds of less than 7 m s^{-1} by a unique split "flying-saucer" vent design oriented normal to the ground and open on all sides, and this design was used to vent the LI-8100 unit. We will explore similar options in modifications to our chamber vent design in the coming year.

6.0 Future Directions

Our interpretation of the results obtained during the second CO_2 test injection in 2008 leads to the following work priorities in FY2009 contingent on funding availability:

- *Chamber Modifications* – The negative pressure inside the chambers resulting from the constricted ambient-air intake tube will need to be reduced to about 0.5 Pa while retaining the ability to minimize Venturi effects from winds. We will explore the use of the vents that behave similarly to those described by Xu et al. (2006) on our chambers, as well as larger-diameter, longer vent tubes based on the calculations in Hutchinson and Mosier (1981). We will use a "flux bucket" fabricated in 2008, based on one described by Evans et al. (2001) to calibrate our flux measurements with those of other flux-monitoring instruments and to explore the impacts of wind and collar depth on our data.
- *Dilution Range* – Assuming that our 2008 flux data are about five times higher than actual (due to the negative pressure inside our chambers), and that the data collected by the LI-8100 system are accurate, we still would need to substantially increase our dilution range to measure fluxes directly over the injection pipe. For example, a maximum flux of about 2500 μmol m^{-2} s^{-1} was measured by the LI-8100 system, which would correspond to a steady-state concentration of more than 800,000 ppmv using our chambers and flow parameters. To expand the current dilution range accurately would require a two-stage dilution system, with each stage capable of one-, five-, and twenty-fold dilution, to yield a maximum dilution of 400-fold and allow us to measure the entire CO_2 concentration range (0–100%). We will add valving and mass-flow controllers to our system so that the full range becomes accessible to our measurements.
- *Data Reduction and Visualization* – The massive amounts of data generated require development of software to process and visualize the data in a more efficient, timely, and spatially organized manner. Further, it will be highly useful to be able to access these data in real time and multiple locations using an Internet-based interface. We will develop the software and interface for use with our system in this summer's experiments.
- *Soil Moisture Experiments* – Due to the very dry soil conditions that occurred during the second test injection, we were not able to test the soil moisture–relative humidity hypothesis in 2008. We anticipate having a fully functional system in time for an injection scheduled during the wetter portion of the summer. In addition, if the weather does not cooperate, we will design an experiment using some form of irrigation to simulate changes in air-filled porosity.
- *Independent and Buried-Chamber Systems* – Although these have lower priority than the previous items, we think it will be important to develop some measurement capabilities that do not require tethering to a central dilution/processing analyzer. Small diffusion-based probes capable of measuring to 200,000 ppmv CO_2 above ground or in the subsurface (noncondensing) are commercially available (e.g., Tang et al. 2003), and we think these could be adapted to transmit output data by radio to a central datalogging system, and from there to the Internet site by cellular modem. Some depth-dependent information would be helpful in delineating the path followed by the CO_2 plume.

7.0 References

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Appendix A

System Control Code

```
;{CR23X}
*Table 1 Program
  01: .25       Execution Interval
(seconds)


;Set up time system and cycle times

1:  Time (P18)
 1: 1         Minutes into current
day (maximum 1440)
 2: 1440      Mod/By
 3: 1         Loc [ time_min  ]

2:  Z=X MOD F (P46)
 1: 1         X Loc [ time_min  ]
 2: 162       F
 3: 2         Z Loc [ time_cycl ]

3:  Time (P18)
 1: 0         Seconds into current
minute (maximum 60)
 2: 60        Mod/By
 3: 1         Loc [ time_min  ]

4:  Z=X*F (P37)
 1: 1         X Loc [ time_min  ]
 2: 0.01667   F
 3: 4         Z Loc [ time_add  ]

5:  Z=X+Y (P33)
 1: 2         X Loc [ time_cycl ]
 2: 4         Y Loc [ time_add  ]
 3: 2         Z Loc [ time_cycl ]
;end time set up


;take readings


6:  Volt (Diff) (P2)
 1: 4         Reps
 2: 15        5000 mV, Fast Range
 3: 8         DIFF Channel
 4: 5         Loc [ co2_in    ]
 5: 1         Mult
 6: 0         Offset

;transfer the licor voltage
function output to another variable

7:  Z=X (P31)
 1: 5         X Loc [ co2_in    ]
 2: 47        Z Loc [ CVtest    ]


8:  Volt (Diff) (P2)
 1: 1         Reps
 2: 15        5000 mV, Fast Range
 3: 12        DIFF Channel
 4: 48        Loc [ FlowDil   ]
 5: 0.3994    Mult
 6: -0.0069   Offset

9:  Volt (Diff) (P2)
 1: 1         Reps
 2: 15        5000 mV, Fast Range
 3: 7         DIFF Channel
 4: 49        Loc [ FlowOut   ]
 5: 0.4004    Mult
 6: 0.0121    Offset
;End Read in

10:  Volt (Diff) (P2)
 1: 1         Reps
 2: 15        5000 mV, Fast Range
 3: 1         DIFF Channel
 4: 50        Loc [ flowsamp  ]
 5: -.01      Mult
 6: 0.0       Offset



;Set up Chamber values
11:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 0         F
 4: 30        Then Do

12:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 6         F
 4: 30        Then Do
```

```
     13:  Z=F (P30)
      1: 1         F
      2: 00        Exponent of 10
      3: 59        Z Loc [ Chamber
]


14:  End (P95)

15:  End (P95)

16:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 6         F
 4: 30        Then Do

17:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 12        F
 4: 30        Then Do


     18:  Z=F (P30)
      1: 2         F
      2: 00        Exponent of 10
      3: 59        Z Loc [ Chamber
]


19:  End (P95)

20:  End (P95)

21:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 12        F
 4: 30        Then Do

22:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 18        F
 4: 30        Then Do


     23:  Z=F (P30)
      1: 3         F
      2: 00        Exponent of 10
      3: 59        Z Loc [ Chamber
]


24:  End (P95)

25:  End (P95)

26:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 18        F
 4: 30        Then Do

27:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 24        F
 4: 30        Then Do


     28:  Z=F (P30)
      1: 4         F
      2: 00        Exponent of 10
      3: 59        Z Loc [ Chamber
]


29:  End (P95)

30:  End (P95)

31:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 24        F
 4: 30        Then Do

32:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 30        F
 4: 30        Then Do


     33:  Z=F (P30)
      1: 5         F
      2: 00        Exponent of 10
      3: 59        Z Loc [ Chamber
]
```

```
34:  End (P95)

35:  End (P95)

36:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 30       F
 4: 30       Then Do

37:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 36       F
 4: 30       Then Do

     38:  Z=F (P30)
      1: 6        F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

39:  End (P95)

40:  End (P95)

41:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 36       F
 4: 30       Then Do

42:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 42       F
 4: 30       Then Do

     43:  Z=F (P30)
      1: 7        F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

44:  End (P95)

45:  End (P95)

46:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 42       F
 4: 30       Then Do

47:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 48       F
 4: 30       Then Do

     48:  Z=F (P30)
      1: 8        F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

49:  End (P95)

50:  End (P95)

51:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 48       F
 4: 30       Then Do

52:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 54       F
 4: 30       Then Do

     53:  Z=F (P30)
      1: 9        F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

54:  End (P95)

55:  End (P95)

56:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 54       F
```

```
 4: 30        Then Do

57:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 60        F
 4: 30        Then Do


     58:  Z=F (P30)
      1: 10       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


59:  End (P95)

60:  End (P95)

61:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 60        F
 4: 30        Then Do

62:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 66        F
 4: 30        Then Do


     63:  Z=F (P30)
      1: 11       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


64:  End (P95)

65:  End (P95)

66:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 66        F
 4: 30        Then Do

67:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 72        F
 4: 30        Then Do


     68:  Z=F (P30)
      1: 12       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


69:  End (P95)

70:  End (P95)

71:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 72        F
 4: 30        Then Do

72:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 78        F
 4: 30        Then Do


     73:  Z=F (P30)
      1: 13       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


74:  End (P95)

75:  End (P95)


76:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 78        F
 4: 30        Then Do

77:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 84        F
 4: 30        Then Do
```

```
     78:  Z=F (P30)
      1: 14       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


79:  End (P95)

80:  End (P95)


81:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 84       F
 4: 30       Then Do

82:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 90       F
 4: 30       Then Do


     83:  Z=F (P30)
      1: 15       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


84:  End (P95)

85:  End (P95)


86:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 90       F
 4: 30       Then Do

87:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 96       F
 4: 30       Then Do


     88:  Z=F (P30)
      1: 16       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


89:  End (P95)

90:  End (P95)

91:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 96       F
 4: 30       Then Do

92:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 102      F
 4: 30       Then Do


     93:  Z=F (P30)
      1: 17       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


94:  End (P95)

95:  End (P95)

96:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 102      F
 4: 30       Then Do

97:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 108      F
 4: 30       Then Do


     98:  Z=F (P30)
      1: 18       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]
```

```
99:  End (P95)

100:  End (P95)

101:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 108      F
 4: 30       Then Do

102:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 114      F
 4: 30       Then Do

     103:  Z=F (P30)
      1: 19       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

104:  End (P95)

105:  End (P95)

106:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 114      F
 4: 30       Then Do

107:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 120      F
 4: 30       Then Do

     108:  Z=F (P30)
      1: 20       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

109:  End (P95)

110:  End (P95)

111:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 120      F
 4: 30       Then Do

112:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 126      F
 4: 30       Then Do

     113:  Z=F (P30)
      1: 21       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

114:  End (P95)

115:  End (P95)

116:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 126      F
 4: 30       Then Do

117:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 132      F
 4: 30       Then Do

     118:  Z=F (P30)
      1: 22       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

119:  End (P95)

120:  End (P95)

121:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
```

```
 3: 132      F
 4: 30       Then Do

122:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 138      F
 4: 30       Then Do

     123:  Z=F (P30)
      1: 23       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

124:  End (P95)

125:  End (P95)

126:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 138      F
 4: 30       Then Do

127:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 144      F
 4: 30       Then Do

     128:  Z=F (P30)
      1: 24       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

129:  End (P95)

130:  End (P95)

131:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 144      F
 4: 30       Then Do

132:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 150      F
 4: 30       Then Do

     133:  Z=F (P30)
      1: 25       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

134:  End (P95)

135:  End (P95)

136:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 150      F
 4: 30       Then Do

137:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 156      F
 4: 30       Then Do

     138:  Z=F (P30)
      1: 26       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]

139:  End (P95)

140:  End (P95)

141:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 156      F
 4: 30       Then Do

142:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 162      F
 4: 30       Then Do
```

```
     143:  Z=F (P30)
      1: 27       F
      2: 00       Exponent of 10
      3: 59       Z Loc [ Chamber
]


144:  End (P95)

145:  End (P95)

;Open valve 1 operation
146:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: .05      F
 4: 30       Then Do

147:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: .1       F
 4: 30       Then Do

     148:  Do (P86)
      1: 002      Call Subroutine 2


149:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 10       Z Loc [ SDM1P_1   ]


150:  End (P95)
151:  End (P95)

152:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: .2       F
 4: 30       Then Do

153:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: .1       F
 4: 30       Then Do

; de-energize valve1
     154:  Do (P86)
      1: 004      Call Subroutine 4


155:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 10       Z Loc [ SDM1P_1   ]


156:  End (P95)
157:  End (P95)

158:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 5.9      F
 4: 30       Then Do

159:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 5.95     F
 4: 30       Then Do

;close valve1

     160:  Do (P86)
      1: 003      Call Subroutine 3


161:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 10       Z Loc [ SDM1P_1   ]


162:  End (P95)
163:  End (P95)


164:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 6        F
 4: 30       Then Do

165:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
```

```
 3: 5.95      F
 4: 30        Then Do

;de-energize valve1

     166:  Do (P86)
      1: 004      Call Subroutine 4


167:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 10        Z Loc [ SDM1P_1   ]



168:  End (P95)
169:  End (P95)

;Open valve 1 operation
170:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: .07       F
 4: 30        Then Do

171:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: .1        F
 4: 30        Then Do

     172:  Do (P86)
      1: 002      Call Subroutine 2


173:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 10        Z Loc [ SDM1P_1   ]



174:  End (P95)
175:  End (P95)

176:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: .2        F
 4: 30        Then Do

177:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: .1        F
 4: 30        Then Do

; de-energize valve1
     178:  Do (P86)
      1: 004      Call Subroutine 4


179:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 10        Z Loc [ SDM1P_1   ]



180:  End (P95)
181:  End (P95)

182:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 5.9       F
 4: 30        Then Do

183:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 5.95      F
 4: 30        Then Do

;close valve1

     184:  Do (P86)
      1: 003      Call Subroutine 3


185:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 10        Z Loc [ SDM1P_1   ]



186:  End (P95)
187:  End (P95)


188:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 6         F
 4: 30        Then Do

189:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 5.95      F
 4: 30        Then Do
```

```
;de-energize valve1

     190:  Do (P86)
      1: 004      Call Subroutine 4


191:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 10       Z Loc [ SDM1P_1   ]



192:  End (P95)
193:  End (P95)


;Open valve 2 operation
194:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 6.07     F
 4: 30       Then Do

195:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 6.1      F
 4: 30       Then Do

     196:  Do (P86)
      1: 002      Call Subroutine 2


197:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 11       Z Loc [ SDM1P_2   ]



198:  End (P95)
199:  End (P95)

200:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 6.2      F
 4: 30       Then Do

201:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 6.1      F
 4: 30       Then Do

; de-energize valve2

     202:  Do (P86)
      1: 004      Call Subroutine 4


203:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 11       Z Loc [ SDM1P_2   ]



204:  End (P95)
205:  End (P95)

206:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 11.9     F
 4: 30       Then Do

207:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 11.95    F
 4: 30       Then Do

;close valve2

     208:  Do (P86)
      1: 003      Call Subroutine 3


209:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 11       Z Loc [ SDM1P_2   ]



210:  End (P95)
211:  End (P95)


212:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 12       F
 4: 30       Then Do

213:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 11.95    F
 4: 30       Then Do

;de-energize valve2
```

```
     214:  Do (P86)
      1: 004      Call Subroutine 4


215:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 11       Z Loc [ SDM1P_2   ]



216:  End (P95)
217:  End (P95)

;End Valve 2 operation



;Open valve 3 operation
218:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 12.07    F
 4: 30       Then Do

219:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 12.1     F
 4: 30       Then Do

     220:  Do (P86)
      1: 002      Call Subroutine 2


221:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 12       Z Loc [ SDM1P_3   ]



222:  End (P95)
223:  End (P95)

224:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 12.2     F
 4: 30       Then Do

225:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 12.1     F
 4: 30       Then Do

; de-energize valve3
     226:  Do (P86)
      1: 004      Call Subroutine 4


227:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 12       Z Loc [ SDM1P_3   ]



228:  End (P95)
229:  End (P95)

230:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 17.9     F
 4: 30       Then Do

231:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 17.95    F
 4: 30       Then Do

;close valve3

     232:  Do (P86)
      1: 003      Call Subroutine 3


233:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 12       Z Loc [ SDM1P_3   ]



234:  End (P95)
235:  End (P95)


236:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 18       F
 4: 30       Then Do

237:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 17.95    F
 4: 30       Then Do

;de-energize valve3
```

```
     238:  Do (P86)
      1: 004      Call Subroutine 4


239:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 12       Z Loc [ SDM1P_3   ]



240:  End (P95)
241:  End (P95)

;End Valve 3 operation




;Open valve 4 operation
242:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 18.07    F
 4: 30       Then Do

243:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 18.1     F
 4: 30       Then Do

     244:  Do (P86)
      1: 002      Call Subroutine 2


245:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 13       Z Loc [ SDM1P_4   ]



246:  End (P95)
247:  End (P95)

248:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 18.2     F
 4: 30       Then Do

249:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 18.1     F
 4: 30       Then Do

; de-energize valve4
     250:  Do (P86)
      1: 004      Call Subroutine 4


251:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 13       Z Loc [ SDM1P_4   ]



252:  End (P95)
253:  End (P95)

254:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 23.9     F
 4: 30       Then Do

255:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 23.95    F
 4: 30       Then Do

;close valve4

     256:  Do (P86)
      1: 003      Call Subroutine 3


257:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 13       Z Loc [ SDM1P_4   ]



258:  End (P95)
259:  End (P95)


260:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 24       F
 4: 30       Then Do

261:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 23.95    F
```

```
 4: 30       Then Do

;de-energize valve4

     262:  Do (P86)
      1: 004      Call Subroutine 4


263:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 13       Z Loc [ SDM1P_4   ]



264:  End (P95)
265:  End (P95)

;End Valve 4 operation





;Open valve 5 operation
266:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 24.07    F
 4: 30       Then Do

267:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 24.1     F
 4: 30       Then Do

     268:  Do (P86)
      1: 002      Call Subroutine 2


269:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 14       Z Loc [ SDM1P_5   ]



270:  End (P95)
271:  End (P95)

272:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 24.2     F
 4: 30       Then Do

273:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 24.1     F
 4: 30       Then Do

; de-energize valve5
     274:  Do (P86)
      1: 004      Call Subroutine 4


275:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 14       Z Loc [ SDM1P_5   ]



276:  End (P95)
277:  End (P95)

278:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 29.9     F
 4: 30       Then Do

279:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 29.95    F
 4: 30       Then Do

;close valve5

     280:  Do (P86)
      1: 003      Call Subroutine 3


281:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 14       Z Loc [ SDM1P_5   ]



282:  End (P95)
283:  End (P95)

284:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 30       F
 4: 30       Then Do
```

```
285:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 29.95    F
 4: 30       Then Do

;de-energize valve5

     286:  Do (P86)
      1: 004      Call Subroutine 4


287:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 14       Z Loc [ SDM1P_5   ]



288:  End (P95)
289:  End (P95)

;End Valve 5 operation







;Open valve 6 operation
290:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 30.07    F
 4: 30       Then Do

291:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 30.1     F
 4: 30       Then Do

     292:  Do (P86)
      1: 002      Call Subroutine 2


293:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 15       Z Loc [ SDM1P_6   ]



294:  End (P95)
295:  End (P95)

296:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 30.2     F
 4: 30       Then Do

297:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 30.1     F
 4: 30       Then Do

; de-energize valve6
     298:  Do (P86)
      1: 004      Call Subroutine 4


299:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 15       Z Loc [ SDM1P_6   ]



300:  End (P95)
301:  End (P95)

302:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 35.9     F
 4: 30       Then Do

303:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 35.95    F
 4: 30       Then Do

;close valve6

     304:  Do (P86)
      1: 003      Call Subroutine 3


305:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 15       Z Loc [ SDM1P_6   ]



306:  End (P95)
307:  End (P95)
```

```
308:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 36        F
 4: 30        Then Do

309:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 35.95     F
 4: 30        Then Do

;de-energize valve6

     310:  Do (P86)
      1: 004      Call Subroutine 4


311:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 15        Z Loc [ SDM1P_6   ]



312:  End (P95)
313:  End (P95)

;End Valve 6 operation






;Open valve 7 operation
314:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 36.07     F
 4: 30        Then Do

315:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 36.1      F
 4: 30        Then Do

     316:  Do (P86)
      1: 002      Call Subroutine 2


317:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 16        Z Loc [ SDM1P_7   ]


318:  End (P95)
319:  End (P95)

320:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 36.2      F
 4: 30        Then Do

321:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 36.1      F
 4: 30        Then Do

; de-energize valve7
     322:  Do (P86)
      1: 004      Call Subroutine 4


323:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 16        Z Loc [ SDM1P_7   ]



324:  End (P95)
325:  End (P95)

326:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 41.9      F
 4: 30        Then Do

327:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 41.95     F
 4: 30        Then Do

;close valve7

     328:  Do (P86)
      1: 003      Call Subroutine 3


329:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 16        Z Loc [ SDM1P_7   ]
```

```
330:  End (P95)
331:  End (P95)

332:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 42       F
 4: 30       Then Do

333:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 41.95    F
 4: 30       Then Do

;de-energize valve7

     334:  Do (P86)
      1: 004      Call Subroutine 4

335:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 16       Z Loc [ SDM1P_7   ]

336:  End (P95)
337:  End (P95)

;End Valve 7 operation

;Open valve 8 operation
338:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 42.07    F
 4: 30       Then Do

339:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 42.1     F
 4: 30       Then Do

     340:  Do (P86)
      1: 002      Call Subroutine 2

341:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 17       Z Loc [ SDM1P_8   ]

342:  End (P95)
343:  End (P95)

344:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 42.2     F
 4: 30       Then Do

345:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 42.1     F
 4: 30       Then Do

; de-energize valve8
     346:  Do (P86)
      1: 004      Call Subroutine 4

347:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 17       Z Loc [ SDM1P_8   ]

348:  End (P95)
349:  End (P95)

350:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 47.9     F
 4: 30       Then Do

351:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 47.95    F
 4: 30       Then Do

;close valve8

     352:  Do (P86)
```

```
     1: 003      Call Subroutine 3


353:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 17       Z Loc [ SDM1P_8   ]



354:  End (P95)
355:  End (P95)


356:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 48       F
 4: 30       Then Do

357:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 47.95    F
 4: 30       Then Do

;de-energize valve8

     358:  Do (P86)
      1: 004      Call Subroutine 4


359:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 17       Z Loc [ SDM1P_8   ]



360:  End (P95)
361:  End (P95)

;End Valve 8 operation


;Open valve 9 operation
362:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 48.07    F
 4: 30       Then Do

363:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 48.1     F
 4: 30       Then Do

     364:  Do (P86)
      1: 002      Call Subroutine 2


365:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 18       Z Loc [ SDM1P_9   ]


366:  End (P95)
367:  End (P95)

368:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 48.2     F
 4: 30       Then Do

369:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 48.1     F
 4: 30       Then Do

; de-energize valve9
     370:  Do (P86)
      1: 004      Call Subroutine 4


371:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 18       Z Loc [ SDM1P_9   ]


372:  End (P95)
373:  End (P95)

374:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 53.9     F
 4: 30       Then Do

375:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 53.95    F
```

```
 4: 30       Then Do

;close valve9

     376:  Do (P86)
      1: 003      Call Subroutine 3


377:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 18       Z Loc [ SDM1P_9   ]



378:  End (P95)
379:  End (P95)


380:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 54       F
 4: 30       Then Do

381:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 53.95    F
 4: 30       Then Do

;de-energize valve9

     382:  Do (P86)
      1: 004      Call Subroutine 4


383:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 18       Z Loc [ SDM1P_9   ]



384:  End (P95)
385:  End (P95)

;End Valve 9 operation





;Open valve 10 operation
386:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 54.07    F
 4: 30       Then Do

387:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 54.1     F
 4: 30       Then Do

     388:  Do (P86)
      1: 002      Call Subroutine 2


389:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 19       Z Loc [ SDM1P_10  ]



390:  End (P95)
391:  End (P95)

392:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 54.2     F
 4: 30       Then Do

393:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 54.1     F
 4: 30       Then Do

; de-energize valve10
     394:  Do (P86)
      1: 004      Call Subroutine 4


395:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 19       Z Loc [ SDM1P_10  ]



396:  End (P95)
397:  End (P95)

398:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 59.9     F
 4: 30       Then Do
```

```
399:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 59.95     F
 4: 30        Then Do

;close valve10

     400:  Do (P86)
      1: 003      Call Subroutine 3


401:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 19        Z Loc [ SDM1P_10  ]


402:  End (P95)
403:  End (P95)


404:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 60        F
 4: 30        Then Do

405:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 59.95     F
 4: 30        Then Do

;de-energize valve10

     406:  Do (P86)
      1: 004      Call Subroutine 4


407:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 19        Z Loc [ SDM1P_10  ]


408:  End (P95)
409:  End (P95)

;End Valve 10 operation

;Open valve 11 operation
410:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 60.07     F
 4: 30        Then Do

411:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 60.1      F
 4: 30        Then Do

     412:  Do (P86)
      1: 002      Call Subroutine 2


413:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 20        Z Loc [ SDM1P_11  ]


414:  End (P95)
415:  End (P95)

416:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 60.2      F
 4: 30        Then Do

417:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 60.1      F
 4: 30        Then Do

; de-energize valve11
     418:  Do (P86)
      1: 004      Call Subroutine 4


419:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 20        Z Loc [ SDM1P_11  ]


420:  End (P95)
421:  End (P95)

422:  If (X<=>F) (P89)
```

```
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 65.9     F
 4: 30       Then Do

423:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 65.95    F
 4: 30       Then Do

;close valve11

     424:  Do (P86)
      1: 003      Call Subroutine 3


425:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 20       Z Loc [ SDM1P_11  ]



426:  End (P95)
427:  End (P95)


428:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 66       F
 4: 30       Then Do

429:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 65.95    F
 4: 30       Then Do

;de-energize valve11

     430:  Do (P86)
      1: 004      Call Subroutine 4


431:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 20       Z Loc [ SDM1P_11  ]



432:  End (P95)
433:  End (P95)

;End Valve 11 operation

;Open valve 12 operation
434:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 66.07    F
 4: 30       Then Do

435:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 66.1     F
 4: 30       Then Do

     436:  Do (P86)
      1: 002      Call Subroutine 2


437:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 21       Z Loc [ SDM1P_12  ]



438:  End (P95)
439:  End (P95)

440:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 66.2     F
 4: 30       Then Do

441:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 66.1     F
 4: 30       Then Do

; de-energize valve12
     442:  Do (P86)
      1: 004      Call Subroutine 4


443:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 21       Z Loc [ SDM1P_12  ]
```

```
444:  End (P95)
445:  End (P95)

446:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 71.9     F
 4: 30       Then Do

447:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 71.95    F
 4: 30       Then Do

;close valve12

     448:  Do (P86)
      1: 003      Call Subroutine 3


449:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 21       Z Loc [ SDM1P_12  ]



450:  End (P95)
451:  End (P95)


452:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 72       F
 4: 30       Then Do

453:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 71.95    F
 4: 30       Then Do

;de-energize valve12

     454:  Do (P86)
      1: 004      Call Subroutine 4


455:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 21       Z Loc [ SDM1P_12  ]

456:  End (P95)
457:  End (P95)

;End Valve 12 operation



;Open valve 13 operation
458:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 72.07    F
 4: 30       Then Do

459:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 72.1     F
 4: 30       Then Do

     460:  Do (P86)
      1: 002      Call Subroutine 2


461:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 22       Z Loc [ SDM1P_13  ]


462:  End (P95)
463:  End (P95)

464:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 72.2     F
 4: 30       Then Do

465:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 72.1     F
 4: 30       Then Do

; de-energize valve13
     466:  Do (P86)
      1: 004      Call Subroutine 4


467:  Z=F x 10^n (P30)
```

```
 1: 0        F
 2: 0        n, Exponent of 10
 3: 22       Z Loc [ SDM1P_13  ]


468:  End (P95)
469:  End (P95)

470:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 77.9     F
 4: 30       Then Do

471:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 77.95    F
 4: 30       Then Do

;close valve13

     472:  Do (P86)
      1: 003      Call Subroutine 3


473:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 22       Z Loc [ SDM1P_13  ]


474:  End (P95)
475:  End (P95)


476:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 78       F
 4: 30       Then Do

477:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 77.95    F
 4: 30       Then Do

;de-energize valve13

     478:  Do (P86)
      1: 004      Call Subroutine 4


479:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 22       Z Loc [ SDM1P_13  ]


480:  End (P95)
481:  End (P95)

;End Valve 13 operation


;Open valve 14 operation
482:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 78.07    F
 4: 30       Then Do

483:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 78.1     F
 4: 30       Then Do

     484:  Do (P86)
      1: 002      Call Subroutine 2


485:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 23       Z Loc [ SDM1P_14  ]


486:  End (P95)
487:  End (P95)

488:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 78.2     F
 4: 30       Then Do

489:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 78.1     F
```

```
 4: 30       Then Do

; de-energize valve14
     490:  Do (P86)
      1: 004      Call Subroutine 4


491:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 23       Z Loc [ SDM1P_14  ]



492:  End (P95)
493:  End (P95)

494:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 83.9     F
 4: 30       Then Do

495:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 83.95    F
 4: 30       Then Do

;close valve14

     496:  Do (P86)
      1: 003      Call Subroutine 3


497:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 23       Z Loc [ SDM1P_14  ]



498:  End (P95)
499:  End (P95)


500:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 84       F
 4: 30       Then Do

501:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 83.95    F
 4: 30       Then Do

;de-energize valve14

     502:  Do (P86)
      1: 004      Call Subroutine 4


503:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 23       Z Loc [ SDM1P_14  ]



504:  End (P95)
505:  End (P95)

;End Valve 14 operation


;Open valve 15 operation
506:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 84.07    F
 4: 30       Then Do

507:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 84.1     F
 4: 30       Then Do

     508:  Do (P86)
      1: 002      Call Subroutine 2


509:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 24       Z Loc [ SDM1P_15  ]


510:  End (P95)
511:  End (P95)

512:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 84.2     F
 4: 30       Then Do

513:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
```

```
 3: 84.1      F
 4: 30       Then Do

; de-energize valve15
     514:  Do (P86)
      1: 004      Call Subroutine 4


515:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 24       Z Loc [ SDM1P_15  ]



516:  End (P95)
517:  End (P95)

518:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 89.9     F
 4: 30       Then Do

519:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 89.95    F
 4: 30       Then Do

;close valve15

     520:  Do (P86)
      1: 003      Call Subroutine 3


521:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 24       Z Loc [ SDM1P_15  ]



522:  End (P95)
523:  End (P95)


524:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 90       F
 4: 30       Then Do

525:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 89.95    F
 4: 30       Then Do

;de-energize valve15

     526:  Do (P86)
      1: 004      Call Subroutine 4


527:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 24       Z Loc [ SDM1P_15  ]



528:  End (P95)
529:  End (P95)

;End Valve 15 operation



;Open valve 16 operation
530:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 90.07    F
 4: 30       Then Do

531:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 90.1     F
 4: 30       Then Do

     532:  Do (P86)
      1: 002      Call Subroutine 2


533:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 25       Z Loc [ SDM1P_16  ]



534:  End (P95)
535:  End (P95)

536:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
```

```
 3: 90.2      F
 4: 30        Then Do

537:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 90.1      F
 4: 30        Then Do

; de-energize valve16
     538:  Do (P86)
      1: 004      Call Subroutine 4


539:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 25        Z Loc [ SDM1P_16  ]



540:  End (P95)
541:  End (P95)

542:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 95.9      F
 4: 30        Then Do

543:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 95.95     F
 4: 30        Then Do

;close valve16

     544:  Do (P86)
      1: 003      Call Subroutine 3


545:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 25        Z Loc [ SDM1P_16  ]



546:  End (P95)
547:  End (P95)


548:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 96        F
 4: 30        Then Do

549:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 95.95     F
 4: 30        Then Do

;de-energize valve16

     550:  Do (P86)
      1: 004      Call Subroutine 4


551:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 25        Z Loc [ SDM1P_16  ]



552:  End (P95)
553:  End (P95)

;End Valve 16 operation

;Open valve 17 operation
554:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 96.07     F
 4: 30        Then Do

555:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 96.1      F
 4: 30        Then Do

     556:  Do (P86)
      1: 002      Call Subroutine 2


557:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 26        Z Loc [ SDM2P_1   ]
```

```
558:  End (P95)
559:  End (P95)

560:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 96.2      F
 4: 30        Then Do

561:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 96.1      F
 4: 30        Then Do

; de-energize valve17
     562:  Do (P86)
      1: 004      Call Subroutine 4


563:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 26        Z Loc [ SDM2P_1   ]



564:  End (P95)
565:  End (P95)

566:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 101.9     F
 4: 30        Then Do

567:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 101.95    F
 4: 30        Then Do

;close valve17

     568:  Do (P86)
      1: 003      Call Subroutine 3


569:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 26        Z Loc [ SDM2P_1   ]

570:  End (P95)
571:  End (P95)


572:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 102       F
 4: 30        Then Do

573:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 101.95    F
 4: 30        Then Do

;de-energize valve17

     574:  Do (P86)
      1: 004      Call Subroutine 4


575:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 26        Z Loc [ SDM2P_1   ]



576:  End (P95)
577:  End (P95)

;End Valve 17 operation



;Open valve 18 operation
578:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 102.07    F
 4: 30        Then Do

579:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 102.1     F
 4: 30        Then Do

     580:  Do (P86)
      1: 002      Call Subroutine 2
```

```
581:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 27       Z Loc [ SDM2P_2   ]


582:  End (P95)
583:  End (P95)

584:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 102.2    F
 4: 30       Then Do

585:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 102.1    F
 4: 30       Then Do

; de-energize valve18
     586:  Do (P86)
      1: 004      Call Subroutine 4


587:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 27       Z Loc [ SDM2P_2   ]


588:  End (P95)
589:  End (P95)

590:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 107.9    F
 4: 30       Then Do

591:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 107.95   F
 4: 30       Then Do

;close valve18

     592:  Do (P86)
      1: 003      Call Subroutine 3


593:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 27       Z Loc [ SDM2P_2   ]


594:  End (P95)
595:  End (P95)

596:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 108      F
 4: 30       Then Do

597:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 107.95   F
 4: 30       Then Do

;de-energize valve18

     598:  Do (P86)
      1: 004      Call Subroutine 4


599:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 27       Z Loc [ SDM2P_2   ]


600:  End (P95)
601:  End (P95)

;End Valve 18 operation


;Open valve 19 operation
602:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 108.07   F
 4: 30       Then Do

603:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
```

```
 3: 108.1    F
 4: 30       Then Do

     604:  Do (P86)
      1: 002      Call Subroutine 2


605:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 28       Z Loc [ SDM2P_3   ]



606:  End (P95)
607:  End (P95)

608:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 108.2    F
 4: 30       Then Do

609:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 108.1    F
 4: 30       Then Do

; de-energize valve19
     610:  Do (P86)
      1: 004      Call Subroutine 4


611:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 28       Z Loc [ SDM2P_3   ]



612:  End (P95)
613:  End (P95)

614:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 113.9    F
 4: 30       Then Do

615:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 113.95   F
 4: 30       Then Do

;close valve19

     616:  Do (P86)
      1: 003      Call Subroutine 3


617:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 28       Z Loc [ SDM2P_3   ]



618:  End (P95)
619:  End (P95)

620:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 114      F
 4: 30       Then Do

621:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 113.95   F
 4: 30       Then Do

;de-energize valve19

     622:  Do (P86)
      1: 004      Call Subroutine 4


623:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 28       Z Loc [ SDM2P_3   ]



624:  End (P95)
625:  End (P95)

;End Valve 19 operation
```

```
;Open valve 20 operation
626:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 114.07   F
 4: 30       Then Do

627:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 114.1    F
 4: 30       Then Do

     628:  Do (P86)
      1: 002      Call Subroutine 2


629:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 29       Z Loc [ SDM2P_4   ]



630:  End (P95)
631:  End (P95)

632:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 114.2    F
 4: 30       Then Do

633:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 114.1    F
 4: 30       Then Do

; de-energize valve20
     634:  Do (P86)
      1: 004      Call Subroutine 4


635:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 29       Z Loc [ SDM2P_4   ]



636:  End (P95)
637:  End (P95)

638:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 119.9    F
 4: 30       Then Do

639:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 119.95   F
 4: 30       Then Do

;close valve20

     640:  Do (P86)
      1: 003      Call Subroutine 3


641:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 29       Z Loc [ SDM2P_4   ]



642:  End (P95)
643:  End (P95)


644:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 120      F
 4: 30       Then Do

645:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 119.95   F
 4: 30       Then Do

;de-energize valve20

     646:  Do (P86)
      1: 004      Call Subroutine 4


647:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 29       Z Loc [ SDM2P_4   ]



648:  End (P95)
649:  End (P95)

;End Valve 20 operation
```

```
;Open valve 21 operation
650:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 120.07   F
 4: 30       Then Do

651:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 120.1    F
 4: 30       Then Do

     652:  Do (P86)
      1: 002      Call Subroutine 2


653:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 30       Z Loc [ SDM2P_5   ]



654:  End (P95)
655:  End (P95)

656:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 120.2    F
 4: 30       Then Do

657:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 120.1    F
 4: 30       Then Do

; de-energize valve21
     658:  Do (P86)
      1: 004      Call Subroutine 4


659:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 30       Z Loc [ SDM2P_5   ]



660:  End (P95)
661:  End (P95)

662:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 125.9    F
 4: 30       Then Do

663:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 125.95   F
 4: 30       Then Do

;close valve21

     664:  Do (P86)
      1: 003      Call Subroutine 3


665:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 30       Z Loc [ SDM2P_5   ]



666:  End (P95)
667:  End (P95)


668:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 126      F
 4: 30       Then Do

669:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 125.95   F
 4: 30       Then Do

;de-energize valve21

     670:  Do (P86)
      1: 004      Call Subroutine 4


671:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
```

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 3: 30        Z Loc [ SDM2P_5   ]


672:  End (P95)
673:  End (P95)

;End Valve 21 operation


;Open valve 22 operation
674:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 126.07    F
 4: 30        Then Do

675:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 126.1     F
 4: 30        Then Do

     676:  Do (P86)
      1: 002      Call Subroutine 2


677:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 31        Z Loc [ SDM2P_6   ]


678:  End (P95)
679:  End (P95)

680:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 126.2     F
 4: 30        Then Do

681:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 126.1     F
 4: 30        Then Do

; de-energize valve22
     682:  Do (P86)
      1: 004      Call Subroutine 4

683:  Z=F x 10^n (P30)
 1: 0         F
 2: 0         n, Exponent of 10
 3: 31        Z Loc [ SDM2P_6   ]


684:  End (P95)
685:  End (P95)

686:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 131.9     F
 4: 30        Then Do

687:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 131.95    F
 4: 30        Then Do

;close valve22

     688:  Do (P86)
      1: 003      Call Subroutine 3


689:  Z=F x 10^n (P30)
 1: 1         F
 2: 0         n, Exponent of 10
 3: 31        Z Loc [ SDM2P_6   ]


690:  End (P95)
691:  End (P95)


692:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 4         <
 3: 132       F
 4: 30        Then Do

693:  If (X<=>F) (P89)
 1: 2         X Loc [ time_cycl ]
 2: 3         >=
 3: 131.95    F
 4: 30        Then Do

;de-energize valve22

     694:  Do (P86)
```

```
     1: 004      Call Subroutine 4


695:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 31       Z Loc [ SDM2P_6   ]



696:  End (P95)
697:  End (P95)

;End Valve 22 operation









;Open valve 23 operation
698:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 132.07   F
 4: 30       Then Do

699:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 132.1    F
 4: 30       Then Do

     700:  Do (P86)
      1: 002      Call Subroutine 2


701:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 32       Z Loc [ SDM2P_7   ]



702:  End (P95)
703:  End (P95)

704:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 132.2    F
 4: 30       Then Do

705:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 132.1    F
 4: 30       Then Do

; de-energize valve23
     706:  Do (P86)
      1: 004      Call Subroutine 4



707:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 32       Z Loc [ SDM2P_7   ]



708:  End (P95)
709:  End (P95)

710:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 137.9    F
 4: 30       Then Do

711:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 137.95   F
 4: 30       Then Do

;close valve23

     712:  Do (P86)
      1: 003      Call Subroutine 3


713:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 32       Z Loc [ SDM2P_7   ]



714:  End (P95)
715:  End (P95)


716:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 138      F
 4: 30       Then Do

717:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
```

```
 2: 3        >=
 3: 137.95   F
 4: 30       Then Do

;de-energize valve23

     718:  Do (P86)
      1: 004      Call Subroutine 4


719:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 32       Z Loc [ SDM2P_7   ]


720:  End (P95)
721:  End (P95)

;End Valve 23 operation


;Open valve 24 operation
722:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 138.07   F
 4: 30       Then Do

723:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 138.1    F
 4: 30       Then Do

     724:  Do (P86)
      1: 002      Call Subroutine 2


725:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 33       Z Loc [ SDM2P_8   ]


726:  End (P95)
727:  End (P95)

728:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 138.2    F
 4: 30       Then Do

729:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 138.1    F
 4: 30       Then Do

; de-energize valve24
     730:  Do (P86)
      1: 004      Call Subroutine 4


731:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 33       Z Loc [ SDM2P_8   ]


732:  End (P95)
733:  End (P95)

734:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 143.9    F
 4: 30       Then Do

735:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 143.95   F
 4: 30       Then Do

;close valve24

     736:  Do (P86)
      1: 003      Call Subroutine 3


737:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 33       Z Loc [ SDM2P_8   ]


738:  End (P95)
739:  End (P95)


740:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 144      F
 4: 30       Then Do
```

```
741:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 143.95   F
 4: 30       Then Do

;de-energize valve24

     742:  Do (P86)
      1: 004      Call Subroutine 4


743:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 33       Z Loc [ SDM2P_8   ]



744:  End (P95)
745:  End (P95)

;End Valve 24 operation

;Open valve 25 operation
746:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 144.07   F
 4: 30       Then Do

747:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 144.1    F
 4: 30       Then Do

     748:  Do (P86)
      1: 002      Call Subroutine 2


749:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 34       Z Loc [ SDM2P_9   ]

750:  End (P95)
751:  End (P95)

752:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 144.2    F
 4: 30       Then Do

753:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 144.1    F
 4: 30       Then Do

; de-energize valve25
     754:  Do (P86)
      1: 004      Call Subroutine 4


755:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 34       Z Loc [ SDM2P_9   ]



756:  End (P95)
757:  End (P95)

758:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 149.9    F
 4: 30       Then Do

759:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 149.95   F
 4: 30       Then Do

;close valve25

     760:  Do (P86)
      1: 003      Call Subroutine 3


761:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 34       Z Loc [ SDM2P_9   ]


762:  End (P95)
```

```
763:  End (P95)

764:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 150      F
 4: 30       Then Do

765:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 149.95   F
 4: 30       Then Do

;de-energize valve25

     766:  Do (P86)
      1: 004      Call Subroutine 4

767:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 34       Z Loc [ SDM2P_9   ]

768:  End (P95)
769:  End (P95)

;End Valve 25 operation

;Open valve 26 operation
770:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 150.07   F
 4: 30       Then Do

771:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 150.1    F
 4: 30       Then Do

     772:  Do (P86)
      1: 002      Call Subroutine 2

773:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 35       Z Loc [ SDM2P_10  ]

774:  End (P95)
775:  End (P95)

776:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 150.2    F
 4: 30       Then Do

777:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 150.1    F
 4: 30       Then Do

; de-energize valve26
     778:  Do (P86)
      1: 004      Call Subroutine 4

779:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 35       Z Loc [ SDM2P_10  ]

780:  End (P95)
781:  End (P95)

782:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 155.9    F
 4: 30       Then Do

783:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 155.95   F
 4: 30       Then Do

;close valve26

     784:  Do (P86)
      1: 003      Call Subroutine 3

785:  Z=F x 10^n (P30)
```

```
 1: 1        F
 2: 0        n, Exponent of 10
 3: 35       Z Loc [ SDM2P_10  ]


786:  End (P95)
787:  End (P95)


788:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 156      F
 4: 30       Then Do

789:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 155.95   F
 4: 30       Then Do

;de-energize valve26

     790:  Do (P86)
      1: 004      Call Subroutine 4


791:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 35       Z Loc [ SDM2P_10  ]


792:  End (P95)
793:  End (P95)

;End Valve 26 operation


;Open valve 27 operation
794:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 156.07   F
 4: 30       Then Do

795:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 156.1    F
 4: 30       Then Do

     796:  Do (P86)
      1: 002      Call Subroutine 2

797:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 36       Z Loc [ SDM2P_11  ]


798:  End (P95)
799:  End (P95)

800:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 156.2    F
 4: 30       Then Do

801:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 156.1    F
 4: 30       Then Do

; de-energize valve27
     802:  Do (P86)
      1: 004      Call Subroutine 4


803:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 36       Z Loc [ SDM2P_11  ]


804:  End (P95)
805:  End (P95)

806:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 161.9    F
 4: 30       Then Do

807:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 161.95   F
 4: 30       Then Do

;close valve27

     808:  Do (P86)
      1: 003      Call Subroutine 3
```

```
809:  Z=F x 10^n (P30)
 1: 1        F
 2: 0        n, Exponent of 10
 3: 36       Z Loc [ SDM2P_11  ]


810:  End (P95)
811:  End (P95)


812:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 4        <
 3: 162      F
 4: 30       Then Do

813:  If (X<=>F) (P89)
 1: 2        X Loc [ time_cycl ]
 2: 3        >=
 3: 161.95   F
 4: 30       Then Do

;de-energize valve27

     814:  Do (P86)
      1: 004      Call Subroutine 4


815:  Z=F x 10^n (P30)
 1: 0        F
 2: 0        n, Exponent of 10
 3: 36       Z Loc [ SDM2P_11  ]


816:  End (P95)
817:  End (P95)

;End Valve 27 operation


;purge sample flow controller-
taken out until
;wired into SDM as aopposed to
direct connect to V_hi
;689:  Do (P86)
; 1: 45       Set Port 5 High


;scale variables
818:  Z=X*F (P37)
 1: 6        X Loc [ Tin       ]
 2: .011     F
 3: 6        Z Loc [ Tin       ]

819:  Z=X+F (P34)
 1: 6        X Loc [ Tin       ]
 2: 0        F
 3: 6        Z Loc [ Tin       ]


820:  Z=X*F (P37)
 1: 5        X Loc [ co2_in    ]
 2: .6       F
 3: 5        Z Loc [ co2_in    ]

821:  Z=X+F (P34)
 1: 5        X Loc [ co2_in    ]
 2: 0        F
 3: 5        Z Loc [ co2_in    ]

822:  Z=X*F (P37)
 1: 7        X Loc [ H2Oin     ]
 2: .014     F
```

```
 3: 7        Z Loc [ H2Oin     ]

823:  Z=X+F (P34)
 1: 7        X Loc [ H2Oin     ]
 2: 0        F
 3: 7        Z Loc [ H2Oin     ]

824:  Z=X*F (P37)
 1: 8        X Loc [ Pin       ]
 2: .03058   F
 3: 8        Z Loc [ Pin       ]

825:  Z=X+F (P34)
 1: 8        X Loc [ Pin       ]
 2: 58.564   F
 3: 8        Z Loc [ Pin       ]

826:  If (X<=>F) (P89)
 1: 51       X Loc [ F_Volt    ]
 2: 1        =
 3: 0        F
 4: 30       Then Do

     827:  Z=F (P30)
      1: 0.0      F
      2: 00       Exponent of 10
      3: 48       Z Loc [ FlowDil
]

828:  End (P95)


829:  Z=X/Y (P38)
 1: 49       X Loc [ FlowOut   ]
 2: 50       Y Loc [ flowsamp  ]
 3: 55       Z Loc [ DILconst  ]


830:  Z=X*F (P37)
 1: 55       X Loc [ DILconst  ]
 2: 0.001    F
 3: 56       Z Loc [ DILscalar ]


831:  Z=X*Y (P36)
 1: 5        X Loc [ co2_in    ]
 2: 56       Y Loc [ DILscalar ]
 3: 57       Z Loc [ CO2norm   ]

832:  Z=X*Y (P36)
 1: 5        X Loc [ co2_in    ]
 2: 55       Y Loc [ DILconst  ]
 3: 58       Z Loc [ FlowOut2  ]

; end scale variables

833:  If time is (P92)
 1: 4     -- Minutes (Seconds --)
into a
 2: 5        Interval (same units
as above)
 3: 30       Then Do


834:  Do (P86)
 1: 10       Set Output Flag High
(Flag 0)


835:  Set Active Storage Area
(P80)^7165
 1: 1        Final Storage Area 1
 2: 101      Array ID

836:  Real Time (P77)^25091
 1: 11       Hour/Minute,Seconds
(midnight = 0000)

837:  Resolution (P78)
 1: 1        High Resolution

838:  Sample (P70)^23897
 1: 1        Reps
 2: 1        Loc [ time_min  ]

839:  Sample (P70)^1564
 1: 1        Reps
 2: 65       Loc [ time_cyc2 ]

840:  Sample (P70)^4171
 1: 1        Reps
 2: 59       Loc [ Chamber   ]


841:  Sample (P70)^4459
 1: 1        Reps
 2: 5        Loc [ co2_in    ]


842:  Sample (P70)^11467
 1: 1        Reps
 2: 48       Loc [ FlowDil   ]

843:  Sample (P70)^3149
 1: 1        Reps
 2: 49       Loc [ FlowOut   ]

844:  Sample (P70)^19604
```

```
 1: 1         Reps
 2: 50        Loc [ flowsamp  ]


845:  Sample (P70)^4944
 1: 1         Reps
 2: 56        Loc [ DILscalar ]

846:  Sample (P70)^9719
 1: 1         Reps
 2: 55        Loc [ DILconst  ]

847:  Sample (P70)^1936
 1: 1         Reps
 2: 57        Loc [ CO2norm   ]

848:  Sample (P70)^29257
 1: 1         Reps
 2: 58        Loc [ FlowOut2  ]

849:  Sample (P70)^22202
 1: 1         Reps
 2: 51        Loc [ F_Volt    ]


850:  Sample (P70)^15552
 1: 1         Reps
 2: 6         Loc [ Tin       ]

851:  Sample (P70)^1768
 1: 1         Reps
 2: 7         Loc [ H2Oin     ]

852:  Sample (P70)^9842
 1: 1         Reps
 2: 8         Loc [ Pin       ]


853:  Sample (P70)^13983
 1: 1         Reps
 2: 3         Loc [ CAO2      ]


854:  Do (P86)
 1: 20        Set Output Flag Low
(Flag 0)


855:  End (P95)

*Table 2 Program
  01: 0.01      Execution Interval
(seconds)

;Set up time system and cycle times

1:  Time (P18)
 1: 1         Minutes into current
day (maximum 1440)
 2: 1440      Mod/By
 3: 1         Loc [ time_min  ]

2:  Z=X MOD F (P46)
 1: 1         X Loc [ time_min  ]
 2: 6         F
 3: 65        Z Loc [ time_cyc2 ]

3:  Time (P18)
 1: 0         Seconds into current
minute (maximum 60)
 2: 60        Mod/By
 3: 1         Loc [ time_min  ]

4:  Z=X*F (P37)
 1: 1         X Loc [ time_min  ]
 2: 0.01667   F
 3: 4         Z Loc [ time_add  ]

5:  Z=X+Y (P33)
 1: 65        X Loc [ time_cyc2 ]
 2: 4         Y Loc [ time_add  ]
 3: 65        Z Loc [ time_cyc2 ]
;end time set up

;set ports for clean out

;Setup SDM 16AC port flags

6:  If (X<=>F) (P89)
 1: 65        X Loc [ time_cyc2 ]
 2: 4         <
 3: 0.02      F
 4: 30        Then Do

7:  If (X<=>F) (P89)
 1: 65        X Loc [ time_cyc2 ]
 2: 3         >=
 3: 0         F
 4: 30        Then Do


;Initialize SDM array


     8:  Do (P86)
```

```
      1: 005      Call Subroutine 5

9:  End (P95)
10:  End (P95)

;Setup SDM 16AC port flags

11:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 4        <
 3: 0.04     F
 4: 30       Then Do

12:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 3        >=
 3: 0.02     F
 4: 30       Then Do

;Initialize SDM array



     13:  Do (P86)
      1: 001      Call Subroutine 1

14:  End (P95)
15:  End (P95)

;Execute valve operation

16:  SDM-CD16 / SDM-CD16AC (P104)
 1: 2        Reps
 2: 00       SDM Address
 3: 10       Loc [ SDM1P_1   ]

;Start clean out sample 1

17:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 4        <
 3: .1       F
 4: 30       Then Do

18:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 3        >=
 3: .06      F
 4: 30       Then Do

     19:  Z=F (P30)
      1: 5        F
      2: 03       Exponent of 10
      3: 51       Z Loc [ F_Volt
]

     20:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

21:  End (P95)
22:  End (P95)

;end clean out sample 1

;Initial dilution prep between
switching samples (first 2.25 min)


;close down dilution to get
preliminary read on sample conc

23:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 3        >=
 3: .1       F
 4: 30       Then Do

24:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 4        <
 3: 0.25     F
 4: 30       Then Do

     25:  Z=F (P30)
      1: 0.0      F
      2: 00       Exponent of 10
      3: 51       Z Loc [ F_Volt
]

     26:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

27:  End (P95)

28:  End (P95)
;end priliminary read sample



;Dilution stage 1 for sample 1

29:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 3        >=
 3: .25      F
 4: 30       Then Do

30:  If (X<=>F) (P89)
```

```
 1: 65        X Loc [ time_cyc2 ]
 2: 4         <
 3: 0.75      F
 4: 30        Then Do

31:  If (X<=>F) (P89)
 1: 5         X Loc [ co2_in    ]
 2: 3         >=
 3: 4800      F
 4: 30        Then Do


     32:  Z=F (P30)
      1: 1.2      F
      2: 3        Exponent of 10
      3: 51       Z Loc [ F_Volt
]

     33:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

34:  End (P95)

35:  End (P95)

36:  End (P95)
;Dilution stage 1 for sample 1




;Dilution stage 2 for sample 1

37:  If (X<=>F) (P89)
 1: 65        X Loc [ time_cyc2 ]
 2: 3         >=
 3: .75       F
 4: 30        Then Do

38:  If (X<=>F) (P89)
 1: 65        X Loc [ time_cyc2 ]
 2: 4         <
 3: 1.25      F
 4: 30        Then Do

39:  If (X<=>F) (P89)
 1: 47        X Loc [ CVtest    ]
 2: 3         >=
 3: 4800      F
 4: 30        Then Do


     40:  Z=F (P30)
      1: 2.4      F
      2: 3        Exponent of 10
      3: 51       Z Loc [ F_Volt
]

     41:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

42:  End (P95)

43:  End (P95)

44:  End (P95)
;Dilution stage 2 for sample 1


;Dilution stage 3 for sample 1

45:  If (X<=>F) (P89)
 1: 65        X Loc [ time_cyc2 ]
 2: 3         >=
 3: 1.25      F
 4: 30        Then Do

46:  If (X<=>F) (P89)
 1: 65        X Loc [ time_cyc2 ]
 2: 4         <
 3: 1.75      F
 4: 30        Then Do

47:  If (X<=>F) (P89)
 1: 47        X Loc [ CVtest    ]
 2: 3         >=
 3: 4800      F
 4: 30        Then Do


     48:  Z=F (P30)
      1: 3.6      F
      2: 3        Exponent of 10
      3: 51       Z Loc [ F_Volt
]

     49:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

50:  End (P95)

51:  End (P95)

52:  End (P95)
;Dilution stage 3 for sample 1
```

```
;Dilution stage 4 for sample 1

53:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 3        >=
 3: 1.75     F
 4: 30       Then Do

54:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 4        <
 3: 2.25     F
 4: 30       Then Do

55:  If (X<=>F) (P89)
 1: 47       X Loc [ CVtest    ]
 2: 3        >=
 3: 4800     F
 4: 30       Then Do


     56:  Z=F (P30)
      1: 4.8      F
      2: 3        Exponent of 10
      3: 51       Z Loc [ F_Volt
]

     57:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

58:  End (P95)

59:  End (P95)

60:  End (P95)
;end Dilution stage 4 for sample 1

;Dilute if CO2 is saturated for
sample 1
61:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 3        >=
 3: 2.25     F
 4: 30       Then Do

62:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 4        <
 3: 6        F
 4: 30       Then Do

63:  If (X<=>F) (P89)
 1: 47       X Loc [ CVtest    ]
 2: 3        >=
 3: 4800     F
 4: 30       Then Do

64:  If (X<=>F) (P89)
 1: 51       X Loc [ F_Volt    ]
 2: 4        <
 3: 4800     F
 4: 30       Then Do


          65:  Z=X+F (P34)
           1: 51       X Loc [
F_Volt    ]
           2: 1200     F
           3: 51       Z Loc [
F_Volt    ]

     66:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

     67:  End (P95)
;end if 1
     68:  End (P95)
;end if 2
69:  End (P95)
;end if 3
70:  End (P95)
;end if 4

;This should increase the dilution
and wait to see if the
;action is effective



;Reduce dilution if CO2 is over
diluted for sample 1
```

```
71:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 3        >=
 3: 2.25     F
 4: 30       Then Do

72:  If (X<=>F) (P89)
 1: 65       X Loc [ time_cyc2 ]
 2: 4        <
 3: 6        F
 4: 30       Then Do

73:  If (X<=>F) (P89)
 1: 47       X Loc [ CVtest    ]
 2: 4        <
 3: 500      F
 4: 30       Then Do

74:  If (X<=>F) (P89)
 1: 51       X Loc [ F_Volt    ]
 2: 3        >=
 3: 1200     F
 4: 30       Then Do

          75:  Z=X+F (P34)
           1: 51       X Loc [
F_Volt    ]
           2: -1200    F
           3: 51       Z Loc [
F_Volt    ]

     76:  Analog Out (P133)
      1: 1        CAO1
      2: 51       mV Loc [ F_Volt
]

     77:  End (P95)
;end if 1
     78:  End (P95)
;end if 2
79:  End (P95)
;end if 3
80:  End (P95)
;end if 4

;This should decrease the dilution
and wait to see if the
;action is effective



81:  Do (P86)
 1: 10       Set Output Flag High
(Flag 0)
```

```
;End Table 2


*Table 3 Subroutines

1:  Beginning of Subroutine (P85)
 1: 01       Subroutine 1
;Initialize SDM arrays to zero
2:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 10       Z Loc [ SDM1P_1   ]

3:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 11       Z Loc [ SDM1P_2   ]

4:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 12       Z Loc [ SDM1P_3   ]

5:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 13       Z Loc [ SDM1P_4   ]

6:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 14       Z Loc [ SDM1P_5   ]

7:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 15       Z Loc [ SDM1P_6   ]

8:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 16       Z Loc [ SDM1P_7   ]

9:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 17       Z Loc [ SDM1P_8   ]

10:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 18       Z Loc [ SDM1P_9   ]
```

```
11:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 19       Z Loc [ SDM1P_10  ]

12:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 20       Z Loc [ SDM1P_11  ]

13:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 21       Z Loc [ SDM1P_12  ]

14:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 22       Z Loc [ SDM1P_13  ]

15:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 23       Z Loc [ SDM1P_14  ]

16:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 24       Z Loc [ SDM1P_15  ]

17:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 25       Z Loc [ SDM1P_16  ]

18:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 26       Z Loc [ SDM2P_1   ]

19:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 27       Z Loc [ SDM2P_2   ]

20:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 28       Z Loc [ SDM2P_3   ]

21:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 29       Z Loc [ SDM2P_4   ]

22:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 30       Z Loc [ SDM2P_5   ]

23:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 31       Z Loc [ SDM2P_6   ]

24:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 32       Z Loc [ SDM2P_7   ]

25:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 33       Z Loc [ SDM2P_8   ]

26:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 34       Z Loc [ SDM2P_9   ]

27:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 35       Z Loc [ SDM2P_10  ]

28:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 36       Z Loc [ SDM2P_11  ]

29:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 37       Z Loc [ SDM2P_12  ]

30:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 38       Z Loc [ SDM2P_13  ]

31:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 39       Z Loc [ SDM2P_14  ]

32:  Z=F x 10^n (P30)
 1: 0        F
 2: 00       n, Exponent of 10
 3: 40       Z Loc [ SDM2P_15  ]

33:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 41       Z Loc [ SDM2P_16  ]
```

```
34:  End (P95)

35:  Beginning of Subroutine (P85)
 1: 02       Subroutine 2

;Power latch open

36:  Z=F x 10^n (P30)
 1: 0.0      F
 2: 00       n, Exponent of 10
 3: 40       Z Loc [ SDM2P_15  ]

37:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 41       Z Loc [ SDM2P_16  ]


38:  End (P95)

39:  Beginning of Subroutine (P85)
 1: 03       Subroutine 3

;Power latch close

40:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 40       Z Loc [ SDM2P_15  ]

41:  Z=F x 10^n (P30)
 1: 0        F
 2: 00       n, Exponent of 10
 3: 41       Z Loc [ SDM2P_16  ]



42:  End (P95)

43:  Beginning of Subroutine (P85)
 1: 04       Subroutine 4

;Valve SS (non-powered)

44:  Z=F x 10^n (P30)
 1: 0        F
 2: 00       n, Exponent of 10
 3: 40       Z Loc [ SDM2P_15  ]

45:  Z=F x 10^n (P30)
 1: 0        F
 2: 00       n, Exponent of 10
 3: 41       Z Loc [ SDM2P_16  ]

46:  End (P95)

47:  Beginning of Subroutine (P85)
 1: 05       Subroutine 5
;Initialize SDM arrays to exhaust

48:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 40       Z Loc [ SDM2P_15  ]

49:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 10       Z Loc [ SDM1P_1   ]

50:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 11       Z Loc [ SDM1P_2   ]

51:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 12       Z Loc [ SDM1P_3   ]

52:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 13       Z Loc [ SDM1P_4   ]

53:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 14       Z Loc [ SDM1P_5   ]

54:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 15       Z Loc [ SDM1P_6   ]

55:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 16       Z Loc [ SDM1P_7   ]

56:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 17       Z Loc [ SDM1P_8   ]

57:  Z=F x 10^n (P30)
 1: 1        F
 2: 00       n, Exponent of 10
 3: 18       Z Loc [ SDM1P_9   ]
```

```
58:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 19        Z Loc [ SDM1P_10  ]

59:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 20        Z Loc [ SDM1P_11  ]

60:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 21        Z Loc [ SDM1P_12  ]

61:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 22        Z Loc [ SDM1P_13  ]

62:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 23        Z Loc [ SDM1P_14  ]

63:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 24        Z Loc [ SDM1P_15  ]

64:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 25        Z Loc [ SDM1P_16  ]

65:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 26        Z Loc [ SDM2P_1   ]

66:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 27        Z Loc [ SDM2P_2   ]

67:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 28        Z Loc [ SDM2P_3   ]

68:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 29        Z Loc [ SDM2P_4   ]

69:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 30        Z Loc [ SDM2P_5   ]

70:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 31        Z Loc [ SDM2P_6   ]

71:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 32        Z Loc [ SDM2P_7   ]

72:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 33        Z Loc [ SDM2P_8   ]

73:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 34        Z Loc [ SDM2P_9   ]

74:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 35        Z Loc [ SDM2P_10  ]

75:  Z=F x 10^n (P30)
 1: 1         F
 2: 00        n, Exponent of 10
 3: 36        Z Loc [ SDM2P_11  ]

76:  End (P95)

End Program


-Input Locations-
1 time_min  1 5 2
2 time_cycl 1 135 2
3 CAO2      1 0 0
4 time_add  1 2 2
5 co2_in    5 7 3
6 Tin       9 3 3
7 H2Oin     9 3 3
8 Pin       17 3 3
9 _________ 0 0 0
10 SDM1P_1   3 1 9
11 SDM1P_2   3 1 6
```

```
12 SDM1P_3   3 1 6
13 SDM1P_4   3 1 6
14 SDM1P_5   3 1 6
15 SDM1P_6   3 1 6
16 SDM1P_7   3 1 6
17 SDM1P_8   3 1 6
18 SDM1P_9   3 1 6
19 SDM1P_10  3 1 6
20 SDM1P_11  3 1 6
21 SDM1P_12  3 1 6
22 SDM1P_13  3 1 6
23 SDM1P_14  3 1 6
24 SDM1P_15  3 1 6
25 SDM1P_16  3 1 6
26 SDM2P_1   3 2 6
27 SDM2P_2   3 2 6
28 SDM2P_3   3 2 6
29 SDM2P_4   3 2 6
30 SDM2P_5   3 2 6
31 SDM2P_6   3 2 6
32 SDM2P_7   3 2 6
33 SDM2P_8   3 2 6
34 SDM2P_9   3 2 6
35 SDM2P_10  3 2 6
36 SDM2P_11  3 2 6
37 SDM2P_12  3 2 1
38 SDM2P_13  3 2 1
39 SDM2P_14  3 2 1
40 SDM2P_15  11 2 5
41 SDM2P_16  19 2 4
42 c2o2_1    1 0 0
43 co2_2     1 0 0
44 co2_3     1 0 0
45 co2_4     1 0 0
46 c2o2_in   1 0 0
47 CVtest    1 5 1
48 FlowDil   1 1 2
49 FlowOut   1 2 1
50 flowsamp  1 2 1
51 F_Volt    1 14 8
52 T2in      1 1 0
53 H22Oin    1 0 0
54 P2in      1 0 0
55 DILconst  1 3 1
56 DILscalar 1 2 1
57 CO2norm   1 1 1
```

```
58 FlowOut2  1 1 1
59 Chamber   1 1 28
60 CO2normhi 1 0 0
61 co2_1     1 0 0
62 co2_2     1 0 0
63 co2_3     1 0 0
64 co2_4     1 0 0
65 time_cyc2 1 76 2
-Program Security-
0
0
0
-Mode 4-
-Final Storage Area 2-
0
-CR10X ID-
0
-CR10X Power Up-
0
-CR10X Compile Setting-
13
-CR10X RS-232 Setting-
-1
-DLD File Labels-
0
-Final Storage Labels-
0,101,7165
1,Hour_Minute_RTM,25091
1,Seconds_RTM
2,time_min~1,23897
3,time_cyc2~65,1564
4,Chamber~59,4171
5,co2_in~5,4459
6,FlowDil~48,11467
7,FlowOut~49,3149
8,flowsamp~50,19604
9,DILscalar~56,4944
10,DILconst~55,9719
11,CO2norm~57,1936
12,FlowOut2~58,29257
13,F_Volt~51,22202
14,Tin~6,15552
15,H2Oin~7,1768
16,Pin~8,9842
17,CAO2~3,13983
```

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