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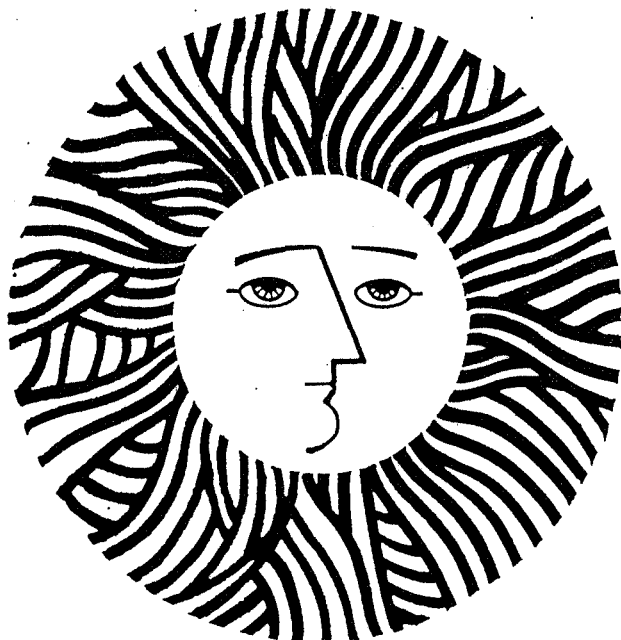
UNIVERSITY OF CALIFORNIA

**ENERGY & ENVIRONMENT
DIVISION**

DESIGN OF A MOBILE LABORATORY FOR VENTILATION STUDIES AND
INDOOR AIR POLLUTION MONITORING

James V. Berk, Craig D. Hollowell, Chin-I Lin,
and James H. Pepper

April 1978



Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48



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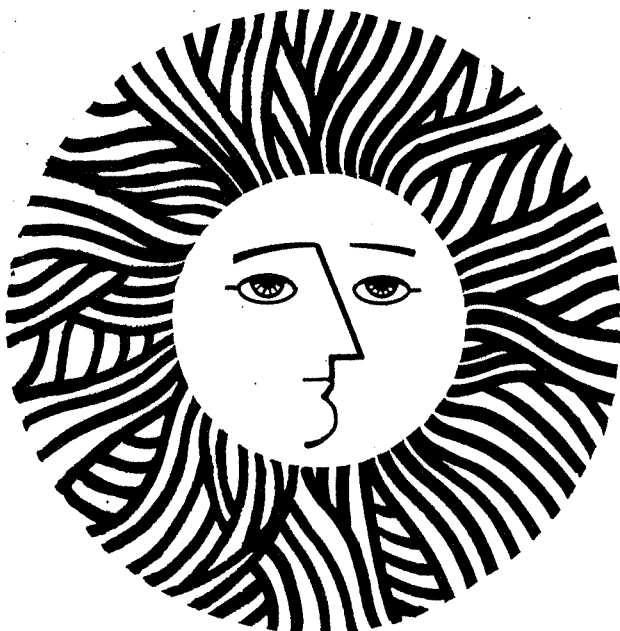
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Preface

The Energy Efficient Buildings (EEB) Program of the Lawrence Berkeley Laboratory (LBL) has designed and fabricated a mobile laboratory for research and development studies of ventilation requirements and energy utilization in residential and commercial buildings.

Developments during the past several years concerning the limited availability of energy have necessitated an examination of our energy consumption and ways of reducing it. Approximately 30% of the total energy consumed in the United States is used to provide comfort, light, and water to buildings. As energy becomes less available and more expensive, measures are being taken to make buildings more energy efficient. These include "tightening up" the building envelopes to reduce leakage and infiltration rates, improving insulation, and reducing ventilation rates. As these measures are implemented and less fresh air is introduced into the buildings, the quality of the indoor air decreases. Ultimately, a balance is sought which will reduce energy consumption as much as possible without compromising the health and comfort of the occupants.

The mobile laboratory is an attempt to utilize state-of-the-art instrumentation to develop an index of air quality in residential and commercial buildings such as schools, hospitals and office buildings. The basic information needed is the methodology for characterization and baseline measurement of a) temperature and humidity levels; b) odor chemical signature, intensity, and physiological sensory response; c) airborne toxic chemicals; and d) biological contaminants. The EEB mobile laboratory is located outside of a building to be studied and air from various locations within the structure is drawn through teflon sampling lines into the laboratory for analysis. By extending sampling lines into the laboratory from several different sites (typically one of which will be used to monitor ambient air) and sequentially sampling these lines, the air quality can be monitored in several rooms simultaneously. In addition, some samples will be collected directly at the sites, using control systems in the laboratory. The duration of monitoring at a particular building will last typically from several weeks to several months, after which the laboratory will be transported to another structure to be studied.

The culmination of the project activity will be a set of recommendations for the ventilation requirements needed in retrofit applications and in new construction. It is expected that these requirements will subsequently be included in the standard building codes of practice issued by local, State, and Federal agencies.

Several individuals contributed towards the completion of the EEB Mobile Laboratory. The assistance of Greg Traynor of LBL was greatly appreciated. Knowledge gained from his efforts in fabricating the Mobile Air Research Laboratory at LBL some three years ago was generously passed on to us and allowed us to circumvent many problems that undoubtedly would have occurred. Ted Fujita's selection of state-of-the-art instrumentation and engineering work in interfacing these instruments to the microprocessor system were significant. Special thanks go to Irv Ko whose assistance in trailer fabrication and debugging of the system were invaluable. A large debt of gratitude is owed to Cal Ward who wrote the system specifications and software for the data acquisition system in addition to contributing helpful suggestions in many other areas.

Many of the design features of this laboratory were patterned after the EPA Semi-trailer Mobile Laboratory built in 1972-73 by Thermo-Systems Inc. of St. Paul, Minnesota. The report of the design of that laboratory EPA 650/4-74-017 by G. J. Sem was extremely helpful both in writing trailer specifications and in preparing this document. Special thanks to Anthony Wisbith and Craig Jones of PEDCO and to Frank Chester of the California Air Resources Board whose considerable experience in the operation of mobile laboratories and helpful suggestions greatly effected the design of this laboratory.

George Morris and Bob Savage of the Fruehauf Division in Oakland, California and their capable crew performed admirably under pressure to deliver the semi-trailer in what must have been record time. It was a pleasure to work with this group of professionals.

Design Considerations

Several types of vehicles were considered in the design of the EEB mobile laboratory. These included semi-trailers, van-type trucks and recreational vehicles, such as the GMC and FMC mobile home units. We visited other mobile laboratories and spoke with the field operators to determine the pros and cons of the various vehicle types. Several factors led to our choice of a semi-trailer as the best for our purposes.

1. The mobile facility had to have a large amount of usable laboratory space. We knew that we would have several racks of electronic equipment. We also anticipated doing some chemistry in the laboratory which would require a lab bench and workspace. The laboratory also had to serve as a cargo carrying unit since we had a considerable amount of apparatus to be transported to and set up in and around the buildings to be studied. Semi-trailers have been designed to maximize their usable space. The rectangular shape is particularly suited to accommodate tall racks of electronic equipment. The height and width of semi-trailers are near the maximum allowable by highway regulations. Vehicles such as the GMC and FMC were rejected because of several factors. The cross-sectional shape is not rectangular. This required tall electronic racks to be placed near the center of the vehicle which severely limited the total amount of rack space available and provided limited and very awkward access to service the electronic equipment. Length is not an option for these vehicles and width and height are considerably less than the maximum legal dimensions. Some other mobile home vehicles were eliminated from consideration because the partitions used for room division were required for structural integrity and could not be removed.

2. The laboratory had to have flexibility to allow for changes in instrumentation and design. Trailer manufacturers routinely make alterations to suit customers needs. It was unclear how much chemistry would have to be done in the field. Floorspace for this had to be available if needed. It was probable that additional electronics would be added to allow for the monitoring of building energy flow and consumption and space had to be available. Vertical walls, a high ceiling and a flat floor without wheel wells imposed the fewest restrictions, thus allowing us to choose a floorplan and laboratory layout most convenient for our needs at the time.
3. The laboratory was to be constructed using standard techniques and equipment whenever possible. The semi-trailer industry has been well established for many years. Such items as air suspension ride for safe transport of delicate instruments and refrigerator systems for maintaining a constant indoor environment are routine in the industry. Service, maintenance and replacement parts are available nationwide. It was felt that standardization would result in lower initial costs and faster repairs.
4. The mobile laboratory had to be durable. Semi-trailers have proven reliability. They are depended on to deliver perishable materials and to meet delivery deadlines. In addition to being durable, the laboratory hardware itself had to be easily set up and taken down. It was felt that a crew of two people had to be able to take down the equipment in one day prior to travel and to set it up again within two days upon arrival at the new site.
5. The mobile laboratory had to be cost-effective. Discussion with field engineers in other mobile labs made us aware of the importance of having a comfortable, well designed laboratory. We knew morale problems could arise during prolonged field operations. With a semi-trailer all money is spent on the laboratory itself. With vehicles such as a van or mobile home, a large fraction of the total cost is for such things as the cab, engine and drive train. Money not spent on these items can be used

to enhance the quality of the work area. Since the vehicle does not have to be moved more than once per month, we found it economical to purchase a trailer and pay for trailer towing service from a private company as needed rather than to consider purchasing a tractor or vehicle which we could drive ourselves.

Trailer Specifications

Initial contact with trailer manufacturers revealed that the purchase of a new vehicle with specialized requirements such as air suspension ride require a minimum waiting period of about four months. In addition, the extensive modifications that were needed to convert the trailer to a laboratory were to require many additional weeks. Since the urgency of our program did not permit a six month wait for the laboratory, a decision was made to purchase a used semi-trailer in good condition and have it refurbished and altered to satisfy our needs in a considerably shorter time period. A list of specifications was prepared detailing the basic size requirements and desired features. It was felt that most of these modifications could be made more efficiently by the trailer company since they had considerable expertise and experience in trailer modification. Much of the interior work was done at LBL where it was felt we could best do much of the finishing work. One factor that had to be considered was the order in which the modifications were made. We felt that LBL would be competent to perform the installation of the electrical system including conduit but it would not be practical to do this after the foam insulation and false ceiling were installed, so this work was done at the manufacturer's facilities rather than at LBL. The following list includes trailer specifications performed by the manufacturer. See figures 1 - 5.

1. Overall size

The preferred size was 27' length x 8' width x 13' height. This is a standard size for semi-trailers. Although a longer trailer would have provided more usable laboratory space, it was felt that reduced maneuverability and the other problems associated with parking such a large vehicle adjacent to buildings, including residential dwellings, outweighed the advantages. The height is within 6" of the maximum allowed in most states and its width is the maximum. The vehicle

selected had the following capacities:

GVWR - 38,000 lbs (gross vehicle weight rating)

GAWR - 1 @ 20,000 lbs with 1000/22F tires (gross axle weight rating)

Trailer Model - FBP9-1-27 Fruehauf

Year of Manufacture - 1973

2. Air suspension ride

Because of the delicate electronics cargo, it was considered advisable to provide an air suspension system for the trailer axle. The trailer was retrofitted with Neway Air Ride AR70-14 complete with an AC 6000 Kit which had a load rating of 25,000 lbs. It should be noted that a tractor also having air suspension ride must be used to tow the trailer if true air suspension ride is desired. Since most tractors do not have this type of suspension, towing arrangements must be made in advance. The trailer axle was centered 5'9" from the rear of the trailer to allow rear supports and a hydraulic lift gate to be installed behind it.

3. Insulation

Polyurethane foam insulation was applied to the floor, ceiling, and all walls to a thickness of 2.5". A controlled thermal environment is necessary for stable operation of much of the electronic equipment. This environment must be kept in both desert summer and midwest winter conditions and requires a very well insulated vehicle. On the ceiling the insulation is located below the aluminum skin roof but above the air conditioning ducts.

4. Floor

The floor consists of 1.375" tongue and groove laminated hardwood attached to I-Beam cross members. On top of this were placed 2 x 4's on 2' centers also running across the width of the truck with the 3.5" side vertical. The floor was then filled in with foam insulation and covered with 1" thick plywood. This floor was covered in turn by a self-padded anti-static electricity carpet (breakdown rating less than 0.2 kV) suitable for computer room installations. This was to prevent static electricity problems which might effect the microprocessor controlled data logger.

5. Doors

The trailer was equipped with standard hinged cargo doors in the rear having a 7'4" high and 7'3" wide opening. In addition, two personnel doors were installed to allow easy access to and from the lab. The large cargo doors are used only for loading and unloading cargo. One personnel door is located in the curbside rear cargo door and has an opening of 6'7" high and 22 1/2" wide. The other is located on the curb side near the front of the trailer and has an opening 6'6" high and 29" wide. These doors are routinely used to enter and exit the trailer and provide emergency exit capability at both the front and rear of the laboratory. A steel ladder is mounted to the roadside cargo door to allow easy access to the roof.

6. Stairs

Two identical sets of aluminum stairs, landings, and hand-rails provide access to the personnel doors. These have 3' x 3' landings, can be set up on sloping ground and are easily dismantled to be stored in an undercompartment during transit from one site to another. Each set is easily assembled with spring loaded clamps and 4 wing nuts.

7. Undercompartment

A steel undercompartment with angle iron reinforcements having an overall size of 8' x 9' x 2 1/2' was located underneath the trailer for storage. Each side has two hinged doors which can be latched and locked. The opening on each side of the trailer is 27" high and 8'7" wide. The front 26" of this compartment is partitioned off with a 3/4" piece of plywood hinged at the bottom to be used as a pump box. Two 3" holes for electrical and air lines connect this compartment to the laboratory above. The size of this compartment is limited by the king pin in front and the axle in the rear.

8. Windows

A total of 5 windows are located in the walls of the trailer. Each is a double pane crank-out type with a screen. The openings are 14" wide and 7" high which is too small to permit unauthorized entry. Each personnel door has one window and there are two others on the curb side and one near the front on the road side. More windows

were not added on the road side as it was felt that lab benches and shelves would block this area. The windows provide some natural light, can be used for fresh air under some circumstances, and aid in communication between the inside and outside of the trailer.

9. Roof

The standard roof consisted of a 40 mil aluminum skin attached to aluminum roof bows on 24" centers. The initial layout of the floorplan called for a bay of 3 standard 19" electronics racks, side by side, 36" deep, extending from floor to ceiling and running across the width of the trailer allowing a walkway on the curb side. It was known that these racks would be heavily loaded with electronics equipment. In preparation for mounting these racks, two of the roof bows were strengthened and two additional ones were added giving a total of 4 reinforced roof bows on 12" centers. The underside of the ceiling was then insulated by applying the polyurethane foam. The exterior roof was covered with 1/8" aluminum diamond plate. The six sheets used were welded along the seams and bolted along the perimeter at one foot intervals to the original roof. Silicone rubber was inserted as a seal along the edges between the skin roof and diamond plate and on the bolts themselves before the bolts were tightened. In addition, 2" wide aluminum angle pieces were welded around the perimeter, set in approximately 2" to cover the exposed bolt heads and edge of the roof. This addition was made to minimize the chances of water entry into the ceiling area under the diamond plate. The angle bracket was left off the rear edge and the rear bolt holes were welded shut. This allowed water which collected on the roof to drain from the rear.

Three access ports were installed in the roof to allow sampling tubes and electrical lines to enter the laboratory from the top. Each port consists of a 10" diameter aluminum tube which extends 1" above and 3" below the roof line and is equipped with a latched cover with a water tight seal. These ports are standard trailer hardware. Each is welded around the exterior perimeter to the diamond plate and sealed with an epoxy type material around the interior perimeter. Two hatch covers exist for each port. One is fitted with holes to allow sampling

and electrical lines to penetrate and the other is solid to be used during transport or if a particular port isn't being used. The modifications to the roof allow personnel to walk on the roof to install and remove electrical and sampling lines and to access a meteorological station. A 9" x 14" base plate with clamp is mounted near the roof center to support a weather tower mast. A 20' mast can be easily installed in this clamp with guy wires attached at the 10' and 20' levels to all four corners where eyebolts are located. The top of the weather tower is 10 meters above ground level.

10. Support legs

The trailer is equipped with 4 individually adjustable leveling supports. These include the standard supports near the front of the trailer plus an additional pair at the rear. These give additional stability to the trailer as personnel move about and as equipment is loaded and unloaded. They also minimize the effects of the wind. The supports are manually operated and have two different gear ratios to allow high and low mechanical advantages. By properly adjusting these, the trailer can be leveled on sloping ground.

11. Air conditioning

Two air conditioning units, Trane model 36WA, each having 3 ton cooling capacity and 10 kw heating capacity provide a controlled laboratory environment. The units are mounted on the exterior front wall of the trailer and extend forward from the wall only 21" so as to not interfere with the tractor used in transport. Because of the outstanding insulating qualities of the 2.5" polyurethane foam and because most of the heat generating pumps are located below in the pump box, one of these units is normally adequate to maintain the laboratory environment at $72^{\circ} \pm 2^{\circ}\text{F}$ in all but extreme weather conditions. Operation of a single unit saves power and provides backup in case a unit is in need of repair and allows operation when limited external power is available. The units are operable from 220 volt single phase power, the most commonly available power for such systems. The two units are controlled by separate thermostats located on the curb side

wall near the center of the trailer. Both units supply air through their respective 8" x 28" openings into a single large plenum 8" high x 28" deep x 7 1/2' wide (the full inside width of the trailer). From this plenum two 4" x 24" ducts extend toward the rear of the trailer. The ducts are separated from each other by 2' so as to not interfere with the two access ports located along the center line of the roof. Individually adjustable air registers are located along these ducts in order to distribute the air throughout the trailer. The road side duct terminates before reaching the access port in the road side rear corner of the lab. The return air exits through two registers mounted on the front wall. Each is approximately 18" x 30" and serves as a fresh air register when the air conditioning system is off.

12. Miscellaneous specifications

The trailer was fitted with a 2000 lb. capacity hydraulic lift gate which extends across the entire width of the trailer. It is needed for loading and unloading heavy equipment such as the dichotomous air samplers. The lift gate is operable from a 12 volt DC battery. To keep the battery charged, two measures were taken. First, a trickle charger was installed which allows recharging of the battery whenever AC power is connected. Second, a converter was installed which converts 115 volts AC to 12 volts DC and allows the lift gate to use AC power whenever electrical power is connected to the trailer.

The laboratory has a false ceiling consisting of metal support brackets and 2' x 4' acoustical tile sheets. The false ceiling is suspended approximately 6" below the polyurethane foam which was applied to the underside of the metal roof. The false ceiling permitted the installation of fluorescent light fixtures which fit directly into 2' x 4' and 2' x 2' areas between sections of acoustical tile. The false ceiling allows sampling lines and electrical lines to interconnect various parts of the laboratory without being visible. For example, lines from the cylinders of calibration gases near the curb side rear end extend directly upward into the false ceiling area and then across to the main instrument racks near the road side front end without

interfering with the laboratory work space. The fluorescent lights are located so as not to obstruct the 2' space down the trailer center. Consideration was given to putting in a false floor similar to those in computer rooms but the prohibitively high cost and problems associated with the motion of the primary floor during transportation resulted in it being eliminated from our specifications.

The interior walls are outfitted with "E-track" hardware. This hardware consists of two slotted steel rails which extend around the interior perimeter of the laboratory, one at floor level and one at a height of 39" above the floor. Brackets, compatible with the "E-track" hardware allow unmounted equipment to be secured to the walls of the trailer during transport. The rails are fitted securely to the trailer cross members in the walls and rear door. The brackets can be used to partition the trailer with 2 x 4's and to tie down equipment with nylon straps, similar to automobile safety belts. The track and brackets are standard items on many moving vans. The cylinders of calibration and tracer gases are chained to a unistrut bar which is attached to the "E-track" using standard brackets.

The interior walls of the laboratory are finished with 3/16" wood paneling treated to meet Underwriters Laboratories tests for a flame spread factor of 200 or less. They are light in color to brighten the appearance of the lab. It was anticipated that these panels would have to be removed periodically to allow additional wires and conduit to be installed in the walls. To facilitate this, the panels were attached to the walls with Scotchmate fabric rather than bolts or screws. This fabric consists of one strip of loops and another strip of hooks which are glued to the panels and wall cross members respectively. The panels are installed by applying direct pressure and removed by peeling them off. The fabric is routinely used in the garment industry and eliminates the need to cover visible screw heads with molding strips.

The trailer is equipped with a halon gas fire protection system. The system contains a cylinder of halon 1301 gas which is released into the trailer in the event of a fire. The fire detector is a heat actuated device which responds to a rapid increase in temperature. Halon systems

are commonly installed in computer rooms where water damage is not desirable. The system, which can also be activated manually, dispenses the halon gas from a nozzle located near the ceiling midway along the curb side wall. The halon apparatus is interfaced to the air conditioning system so that the latter is disabled prior to discharge of the halon gas. This is to prevent the venting of the gas before it can suppress the fire.

Electrical Design

In considering the power requirements for the mobile laboratory, several criteria had to be met. First, the total power capability of the system had to be sufficient to provide the present power requirements as well as any anticipated future requirements. Secondly, the installation had to meet the required electrical codes in the areas where the trailer was to be used. Thirdly, the type of power, whether it should be single or three phase, 115 volt, 230 volt or 115/230 volts, had to be chosen. After due consideration, a single phase 115/230 volt was chosen as the ideal system since this power is most readily available throughout the United States.

The initial major power requirements that had to be met were for the air conditioning units, lighting, instrumentation and air pumping stations. Of the above systems, the greatest power consumer is the air conditioning system consisting of two three-ton units capable of simultaneous operation in high temperature environments. For cold areas, the conditioning systems consist of two 10kw heaters, again capable of operating simultaneously. The maximum power requirements of this dual system is about 90 amperes at 230 volts. The total power requirement for the rest of the systems is about 30 amperes. To allow for sufficient expansion, the load panel is capable of handling 200 amperes.

Power is brought into the trailer through a connector mounted on an access box on the front of the trailer. See figure 6. A connector, rather than a hard wired cable, is used to allow the convenience of storing the cable in the undercompartment during traveling. A flexible cable (four 2/0 conductors) fifty feet long is provided for attachment to a power pole which is equipped with a disconnect switch and watt-hour meter. The pole is generally installed by a local contractor to provide an acceptable method of "tying"

into the area's utility power system.

The 200 ampere load panel is located at the front of the trailer, near the air conditioners, to provide minimum line drop and disturbance to the rest of the electrical system. The total load is split to provide a fairly well balanced system on either side of the neutral leg.

The instrumentation racks have two types of available power, raw AC directly from the load panel and conditioned AC from a SOLA regulator transformer. Figure 7. The SOLA transformer is located in the vented undercompartment to keep it cool and keep its audible and radiated noise level to a minimum. The transformer is rated at 2 KVA at 115 volts. All instruments are connected to this source to reduce line transients and maintain a constant voltage to the instruments. The unconditioned AC is used to drive motors and solenoids used in the automated air sampling system.

There were two choices for illumination in the interior of the trailer. Fluorescent was chosen over incandescent because of the lower power consumption and longer life. Noise from the fluorescent lamps does not create any problems. This may be a result of the use of the conditioned line and the line filtering used on all sensitive equipment. Four 2' x 4' fixtures (4 lamps each) and two 2' x 2' fixtures (4 lamps each) provide the total lighting for the laboratory interior.

All electrical wiring of the trailer is in conduit for maximum safety and also to allow for future expansion without removing wall panels, if heavier or additional wiring is needed. Convenience outlets are located throughout the trailer to allow auxiliary equipment to be connected as required. In addition, two weatherproof external outlets are provided for lighting or other external power as needed.

The air pumps are located in the undercompartment area and are individually controlled by low voltage relays with their controlling switches located in the instrument rack in the trailer. These relays control the 115 volt power to the pump motors. Control of up to 16 pumps is available. Figure 8.

The hydraulic lift platform at the rear of the trailer can be powered from either a 12 volt battery or a DC supply operated from 115 volts AC. The battery source is also used to provide emergency power to the DEW Point sensors through a DC to AC converter. The DEW Point sensors require 24 V AC

continuously and, if power fails, must be removed and dried out in an oven for a period of an hour. The emergency back up will allow for short periods of power failure without requiring the removal of the sensors.

Laboratory Interior

The floorplan is shown in Figure 3. The main components of the laboratory are as follows:

1. Front work area
2. Electronics racks
3. Laboratory bench work area
4. Aisle walkway
5. Cylinder storage area
6. Access ports
7. Storage area for transport
8. Miscellaneous components

Figure 4 shows the front work area which contains a desk, file cabinet and storage cabinet. The desk drawers provide space for office supplies and other small items. The two drawer file cabinet provides convenient storage for equipment manuals and other larger items. Both are covered with an extended top to provide a large work surface the full trailer width. During normal operations, the teletype and telephone are located on the road side of this work surface. A storage cabinet with two bookshelves, sliding doors and two open storage compartments is mounted above the desk and it also extends the full width of the trailer. The front work area is illuminated by a desk lamp mounted to the bookshelf in addition to the two 2' x 2' fluorescent fixtures in the ceiling. A 2' x 3' bulletin board and a 2' x 3' chalkless blackboard are located on opposite sides of the work area.

The three electronics racks extend from floor to ceiling and are 36" deep. The extra depth was provided to allow connection of thick wall teflon tubes which cannot be bent along small radii. Each rack is located on two 3/8" wire rope helical shock mounts. Each shock mount can support up to 1000 lbs. weight. Identical shock mounts are used to attach the top of the racks to the reinforced cross members in the roof. The racks are supplied with both regulated and non-regulated electrical AC power. A block diagram of the instrumentation in these racks is shown in Figure 9.

The racks have hinged rear doors and are located so as to provide complete access to both the front and rear of the instruments with several feet of clearance.

The laboratory bench work area is located along the road side wall as shown in Figure 4 . It consists of a 6' high electronics rack, a 6' wide laboratory bench, and storage cabinets mounted on the wall. This area will be used in the collection of organic vapors and other compounds which require grab sampling techniques. Electronics to support these systems are located in the adjacent electronics rack which is shock mounted to the floor and road side wall and has side door access. This rack also contains a zero air generator. The work bench, complete with storage drawers and electrical outlets, will serve both as an equipment repair station and as a small scale chemistry lab as required in our field studies. Mounted above the work bench is a 6' wide x 2' high storage cabinet with sliding doors.

The laboratory is laid out to allow people to move from the front to the rear without interfering with people working in either of the work areas mentioned above. For this reason, the aisle along the curb side of the trailer has been kept clear of any equipment except for the gas cylinders which extend out approximately 10" from the wall. This layout will also keep the curb side windows free from obstructions. The gas cylinders contain calibration gases, halon gas, and tracer gases for infiltration measurements. The cylinders containing tracer gases have to be replaced frequently and, therefore, are located in an area which is easily accessible.

The access ports are located to optimize their usefulness (see Figure 3). The front access port is located 1' in front of the electronics racks so that exterior sampling lines can be easily connected to the sampling systems with easy access from the inside of the trailer. The central port is located almost equidistant between the electronics racks and the work bench area so that exterior lines can be extended through the false ceiling to either location. The port in the road side rear corner is intended for use with the dichotomous air sampling unit which must be located directly under the vertical sampling tube to assure isokinetic sampling. The dichotomous sampler collects the particulate matter in the ambient air.

It was felt that this location would minimize the obstruction of the sampling unit.

The interior layout provides a large open area in the rear 2/3 of the trailer which can be used to store equipment during transport. The dichotomous air samplers, Anderson microbial samplers, gas bubblers and other apparatus that must be located inside of the test rooms are stored in the trailer during transport along with the sampling lines, electrical cables, meteorological instruments and meteorological tower. The open space and "E-track" hardware allow this equipment to be partitioned and secured with a minimum of difficulty.

The laboratory working conditions are improved considerably over conventional mobile laboratory design by locating nearly all pumps in the undercompartment of the trailer; the pumps generate considerable noise and heat. Each pump is mounted to a separate aluminum plate. These plates are easily inserted into a sturdy metal rack located in the front 26" of the undercompartment of the trailer. The pump box consists of the rack of pumps and a large transformer partitioned off from the rest of the undercompartment by a vertical 3/4" plywood slab hinged at the bottom to allow access. The box is vented by having louvers on the road side and an exhaust fan on the curb side. The interior surfaces of this box are lined with sound foam insulation to minimize the noise, both inside of and exterior to the laboratory.

Instrumentation

The mobile laboratory contains sampling, calibrating, and monitoring systems to measure the concentration of several pollutant gases. Figure 10 illustrates the overall system and Figures 11-12, 13-14, 15-16 and 17 schematically show the sampling, calibrating, monitoring, and data acquisition sub-systems respectively. Table 1 lists the air quality instrumentation in the mobile laboratory. The gas parameters, as well as indoor comfort parameters such as temperature and relative humidity at the sampling sites, and outdoor meteorological parameters (temperature, relative humidity, wind speed, wind direction, solar radiation, and precipitation) are monitored continuously. The following paragraphs give a brief description of the operating principles of these instruments.

CO and CO₂

In both the CO and CO₂ monitors, infrared radiation (IR) of selected wavelength is sent through sample and comparison cells. The pollutant absorbs the IR according to its concentration and the transmitted radiation is used to heat a detector which is sealed with a sample of the gas to be monitored. A semi-circular beam chopper alternately blocks the radiation to the sample cell and to the comparison cell. As light from the sample and comparison cells strikes the detector, the gas expands and contracts. Variations which occur at the chopped frequency are detected by making a membrane capacitance measurement.

NO, NO₂, and NO_x

The NO_x instrument operates on the chemiluminescence principal in which chemiluminescence is observed in the reaction $O_3 + NO \rightarrow NO_2 + O_2 + hv$. A specific frequency is detected when excited NO₂ decays to its ground state. The sample is directed into two chambers, one with a NO_x → NO converter (giving an NO_x measurement), and the other without (giving the NO measurement).

O₃

The ozone monitor operates first by passing the sample through a catalytic converter which converts all O₃ into O₂. Then UV light in an O₂ absorbing band is sent through it and a measurement of the transmitted light is made. The same measurement is made without the catalytic converter and the former is subtracted from the latter. Both measurements are made digitally.

SO₂

In the SO₂ monitor pulsed UV light excites SO₂ molecules which emit specific radiation proportional to the amount of SO₂ in the sample. This radiation is detected to determine the concentration of SO₂.

Infiltration

Infiltration rates are monitored continuously using a tracer gas system developed at LBL in which either N₂O or C₂H₆ is injected into a room, mixed with the room air, and monitored. A microprocessor-controlled feedback system regulates the amount of gas injected so as to keep the concentration within a predetermined range. The quantities of gas injected and resulting

concentrations in the respective rooms being monitored are recorded. Analysis of this data at LBL yields continuous infiltration rates.

Meteorological Instruments

Outdoor dry bulb temperature is measured with a standard thermistor probe. The dew point temperature is measured by a moisture sensor consisting of bifilar electrodes wound on a wick covering a hollow bobbin. The wick is impregnated with lithium chloride, a hygroscopic salt whose conductivity increases as it absorbs moisture. Voltage is applied to the electrodes, generating heat as the wick conducts current between them. Moisture evaporates from the wick until a heat-moisture equilibrium is reached. The equilibrium temperature is related to the dew point temperature. It is sensed with thermistors and converted to the dew point temperature. Wind speed is monitored using a light bulb-photocell assembly, a light chopper disc, and a signal booster. As the chopper disc rotates, it chops the light beam and varies the conductance of the photocell. Wind direction is measured by a potentiometer mounted with a solid connector to the idler shaft inside the sensor main housing. Solar radiation is measured using a precision spectral pyranometer which employs a circular multi-junction wire wound thermopile. Its voltage output is proportional to the incident radiation. Precipitation is monitored with a low inertia tipping bucket which receives water from a funnel and collector tube.

Data Acquisition System

The computer system serves three functions. It controls the source of input to the gas analyzers and logs the data from these analyzers and the other experimental instruments. The computer also monitors several of these instruments and their data in order to detect obvious equipment malfunctions. Finally, the computer provides the experimenter with a means of retrieving the recorded data for preliminary examination prior to the actual data reduction at LBL.

The software has been designed to facilitate changes in the instrumentation. Instruments having analog or simple digital outputs may be added to the system in the field without reprogramming the computer's read only memories provided these additions do not exceed the hardware capacity of the system. Similarly, any of the instruments may be removed from the

system without reprogramming these memories.

The system has also been designed to minimize the need for operator intervention. There is sufficient disk space to log data for 2 1/2 days without changing the disks. In the event of a power failure, the system will restart itself using the real time clock (which has a battery backup) to determine where to restart the experimental protocol.

The system hardware consists of an Intel 80/20 microprocessor based computer, a 32 channel Micromux analog to digital converter, a Vadic Modem, an ICOM Dual Floppy disk drive, and a T.I. Silent Typewriter. The computer has 36,000 bytes of memory, 24 parallel I/O ports, and 4 serial I/O ports. The modem provides a means of linking the computer to a remote console via the telephone lines. This allows any of the computer functions to be controlled from LBL when the system is in the field.

The dual floppy disk drive has a capacity of 512,000 bytes. Most of this is used to store the data collected from the various experiments. However, about 10,000 bytes of this disk space are used to store system operating parameters which may be changed through the console typewriter. This disk organization is the key element in providing power failure restart and in field reprogramming of the system.

Sampling, Calibration, and Monitoring Systems

The sampling system allows air to be sampled from four sampling sites in a sequential manner through teflon 3-way solenoid valves. Sample and calibration air contacts only teflon and glass, except for a small amount of stainless steel in some fittings, a throttling valve, and the two mass flow controllers. This is to prevent components of the air from coming into contact with reactive surfaces in the sampling and monitoring systems. Each sampling line (up to 150' in length) is 3/8" O.D., 1/16" wall TFE teflon tube with a teflon filter holder and 5 micron fibrous filter on the teflon input side to prevent particulate matter from entering the system. These filters are changed daily to prevent surface deposits from reacting with the sample. Sample air from any one of the four sites is pumped by a teflon pump into the glass manifold for measurement, while the other three sampling lines are drawing air continuously. The glass manifold is vented through a rotameter at atmospheric pressure. This design allows the gas analyzers

to sample air from a manifold which is at atmospheric pressure. This is desirable since some of the monitors are pressure sensitive. By controlling the teflon 3-way solenoid valves in the sampling system, the four sites can be monitored sequentially for intervals of approximately five minutes each, after which the process is repeated.

Zero, span, and multipoint calibration of the gas monitors is routinely performed by using cylinder calibration gases, mass flow controllers, and a zero gas generator to inject known concentrations into the manifold. An ozone generator and mixing chamber are used to convert NO into NO₂ in testing the NO_x → NO converter in the NO_x instrument. Zero and span calibrations are done daily, while multipoint calibrations are done approximately once every two weeks. Calibrations are routinely performed by the microprocessor but also can be done manually.

Instrumentation Exterior to the Mobile Laboratory

In addition to the parameters discussed above, there are several others for which continuous monitoring is not feasible. Some samples must be collected at the sampling sites using gas bubblers and other sampling techniques. These include radon, ammonia, aldehydes, and other selected organic compounds. Laboratory techniques such as UV/visible spectrophotometry, gas chromatography, liquid chromatography, mass spectroscopy, etc., are required for the analyses of these chemical species.

The size distribution of the particulate matter in the air will be measured using both an optical scattering instrument and automatic dichotomous air samplers. The latter are also used to collect particulate matter for chemical analysis. The dichotomous air samplers, developed at LBL, separate the aerosols into respirable and non-respirable fractions (below and above 2.5 micron size) using a flow-controlled virtual impaction system for deposition of the particulate matter on teflon filters. The collected particulate matter on the filters is analyzed at LBL using a beta ray attenuation method to measure mass concentration, and x-ray fluorescence to determine chemical composition for 27 elements. The bacterial content of the air is measured with automated samplers that deposit particles from specific size intervals on petri dishes. These inertial impaction devices provide the capability of semi-automatically obtaining measured samples of air

in rooms and removing the airborne particulates onto 6 size-selecting plates of growth medium. Living microbes on or in such particles will, within two days, grow to the extent that a visible spot (colony) appears on the surface of the medium, and the colonies can be counted. A comparison will be made between the optical size distribution of the particulates and bacterial count as a function of particulate size.

Conclusion

Many design considerations have gone into the LBL mobile laboratory for research and development studies of ventilation requirements and energy utilization. Functionality, flexibility, and versatility have been stressed without sacrificing appearance and operator convenience. It is believed that modifications of and additions to the mobile laboratory (such as adding the capability to monitor building energy flow) can be made with a minimum of inconvenience. The studies being performed will provide data needed for the establishment of energy efficient ventilation standards. Pages 41 through 48 are photographs of the laboratory.

Acknowledgement

The work described in this report is funded by the Department of Energy, Office of Assistant Secretary for Conservation and Solar Applications, Division of Buildings and Community Systems.

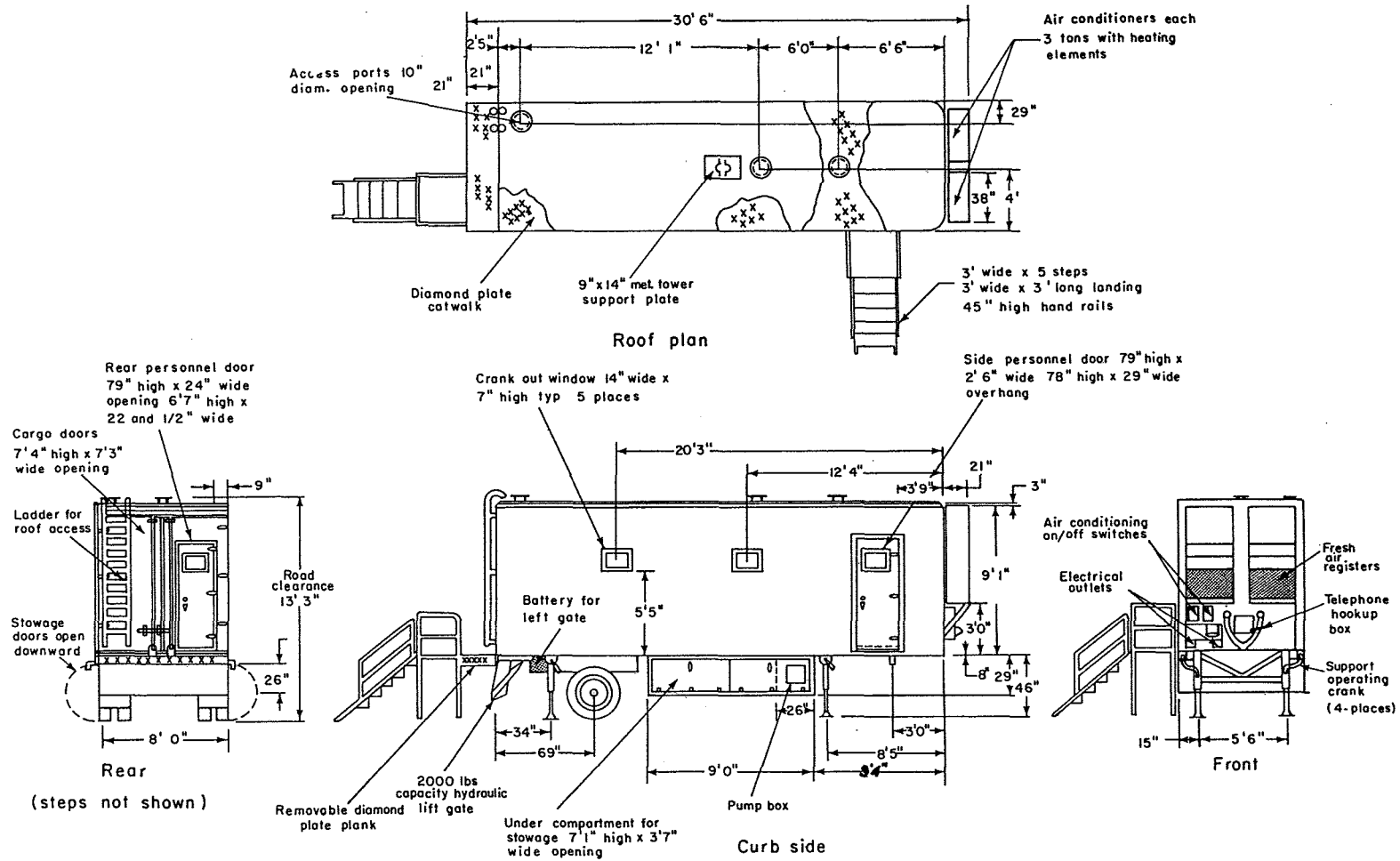


Figure 1: Exterior - Curbside, rear, front and roof views

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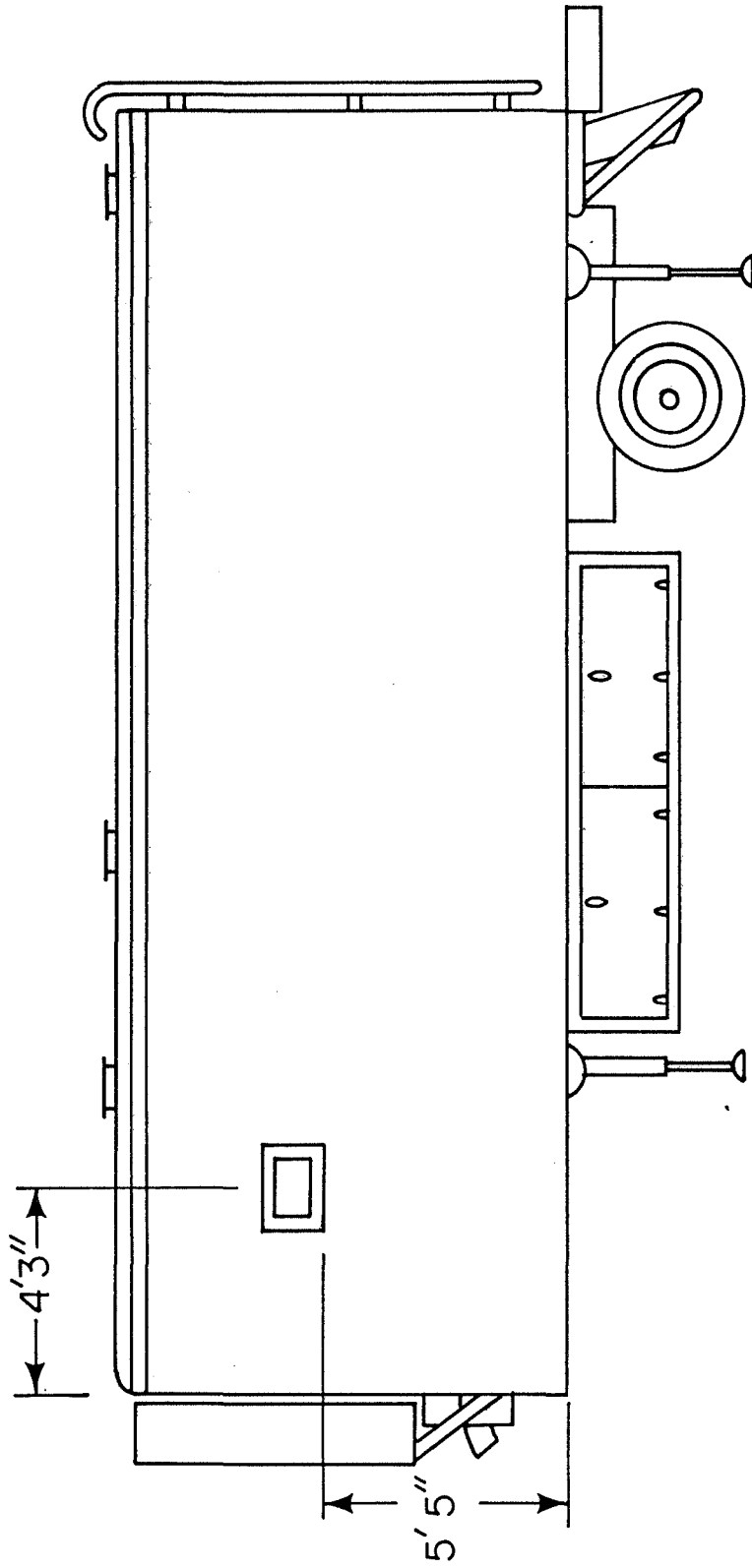
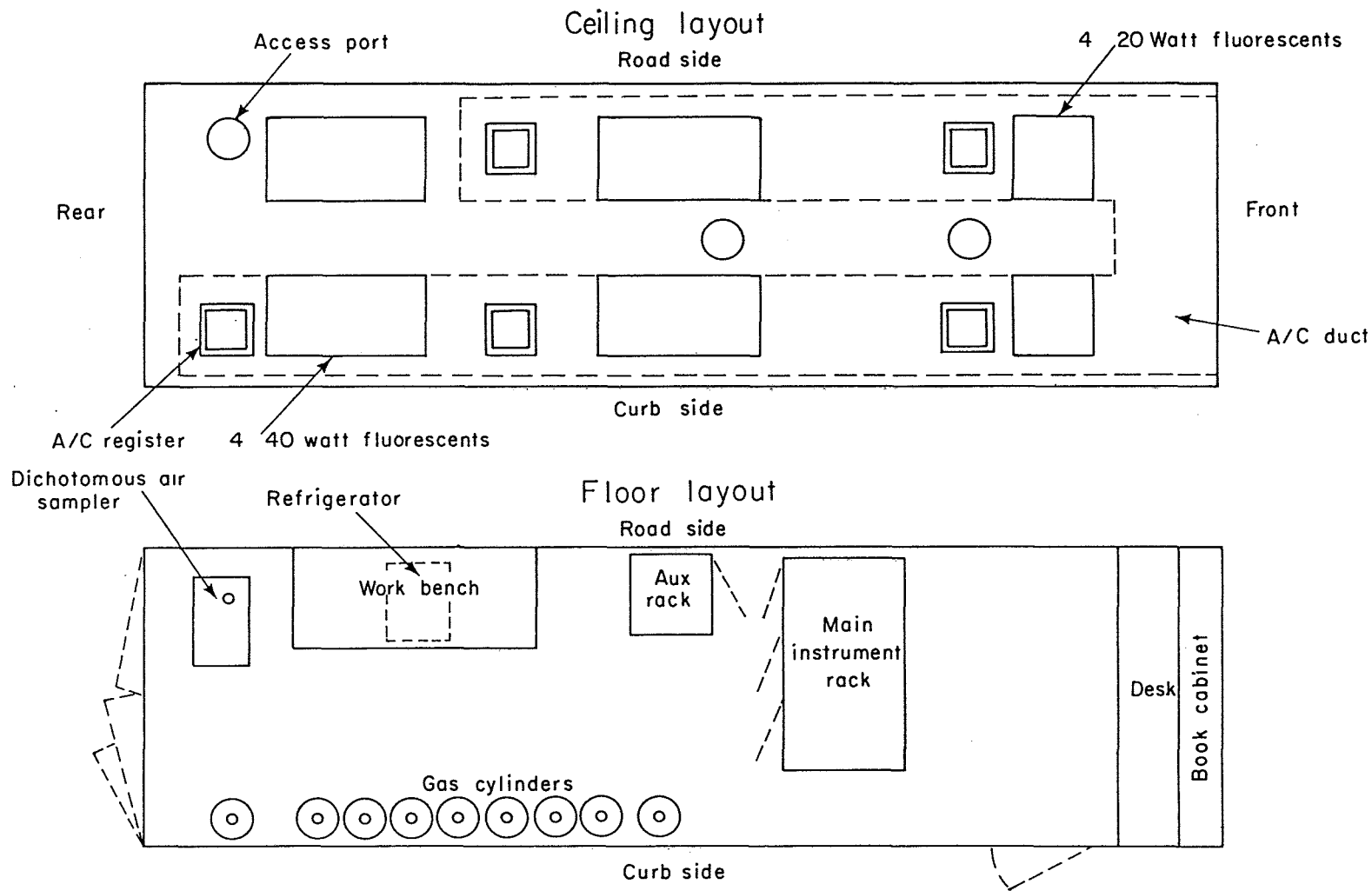


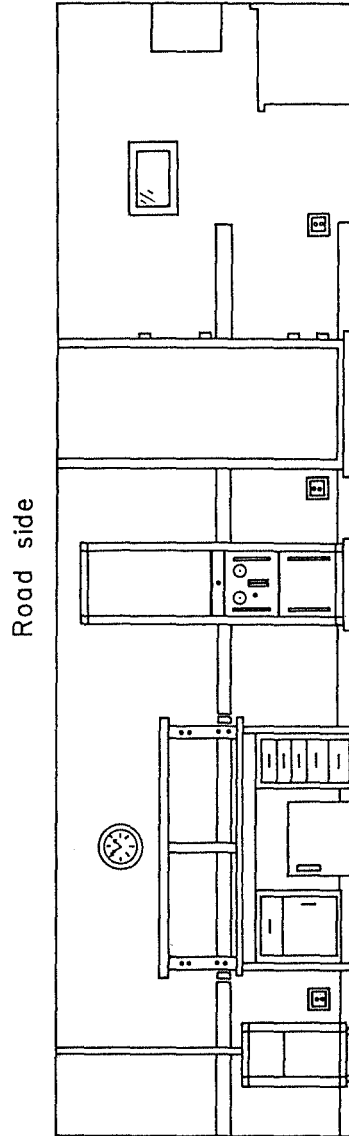
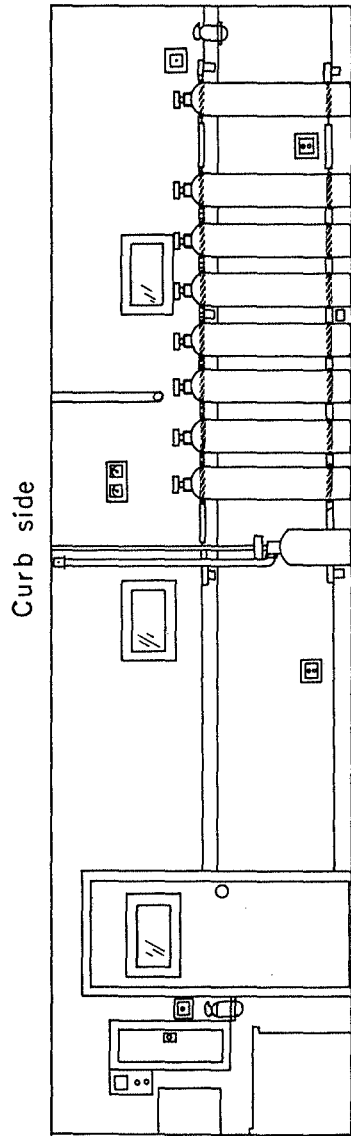
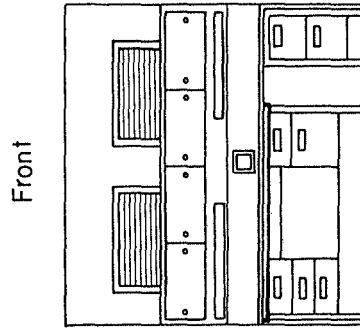
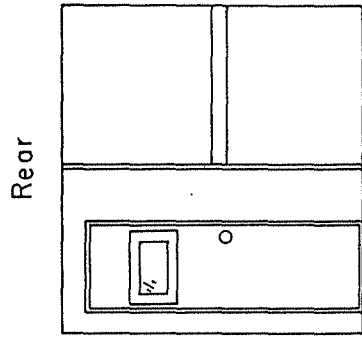
Figure 2: Roadside view

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Figure 3: Ceiling and floor layout



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Figure 4: Interior wall layout

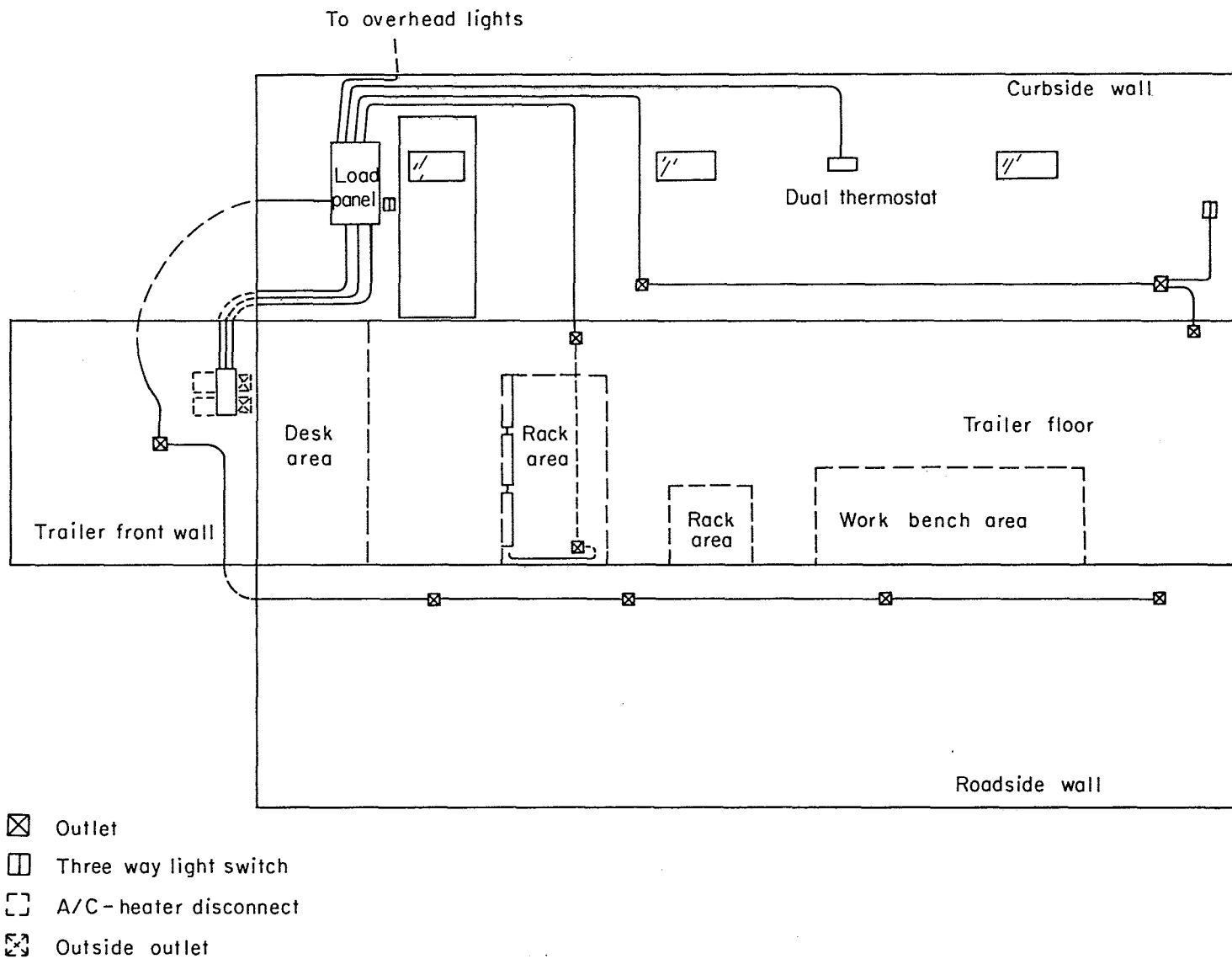
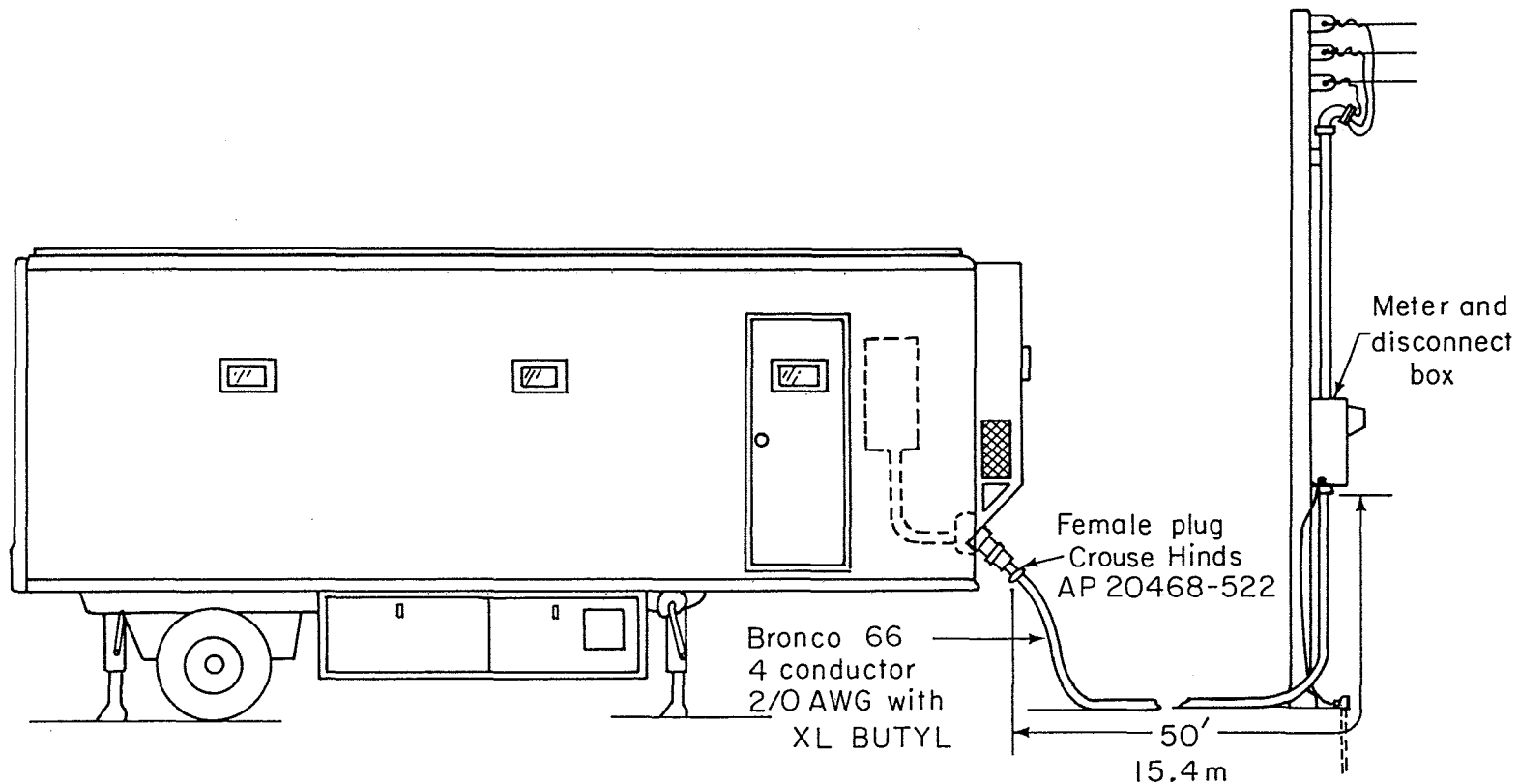
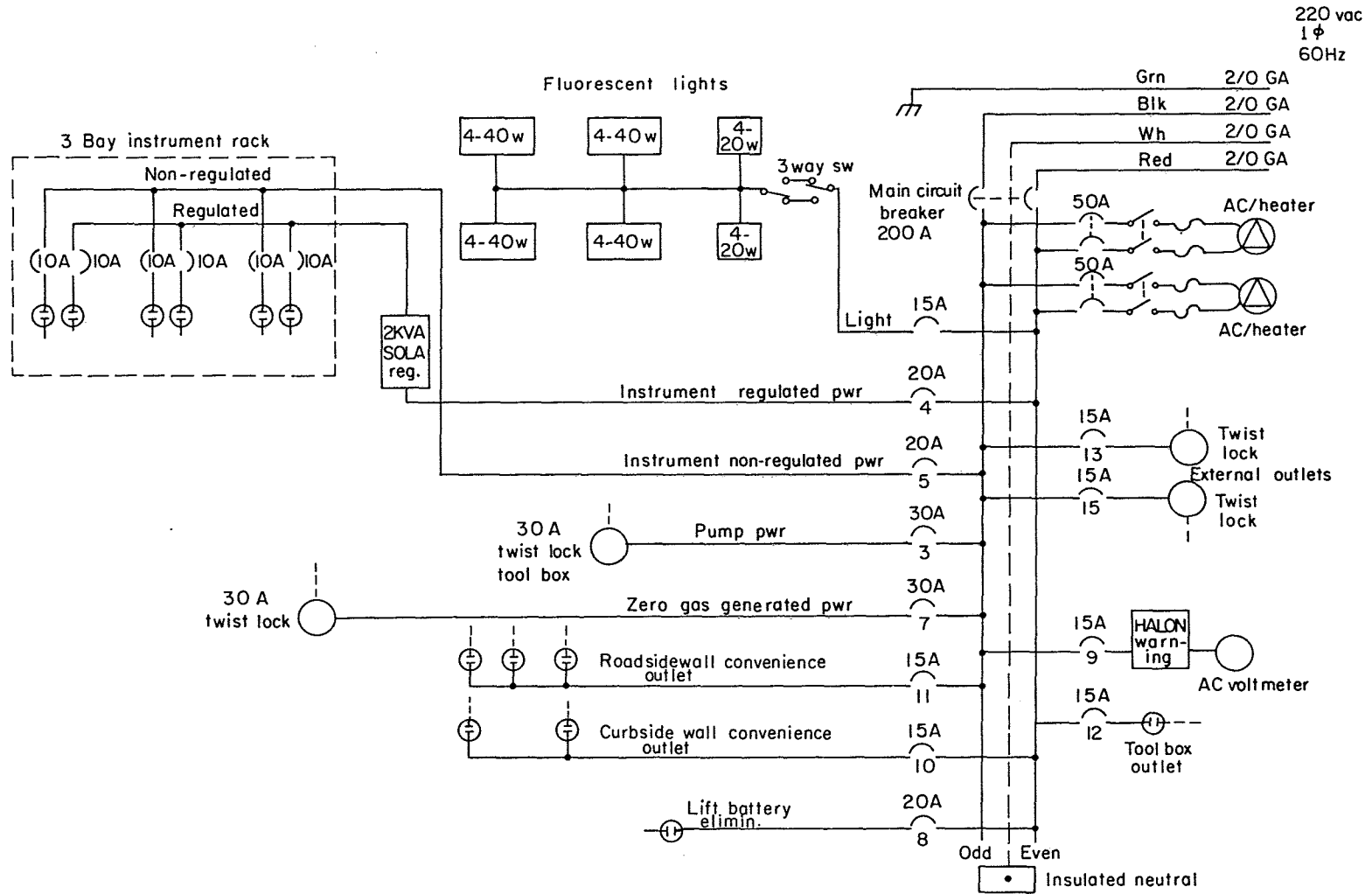


Figure 5: Conduit layout



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Figure 6: A.C. power connection



XBL 784-744

Figure 7: Electrical power system circuit layout

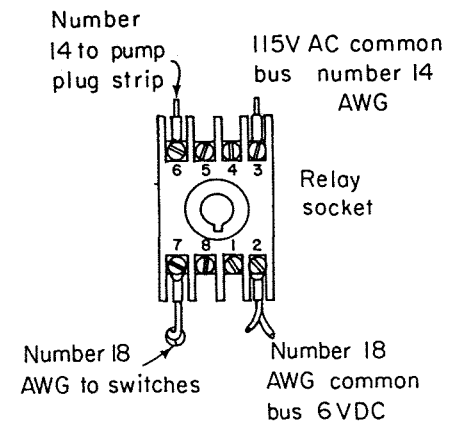
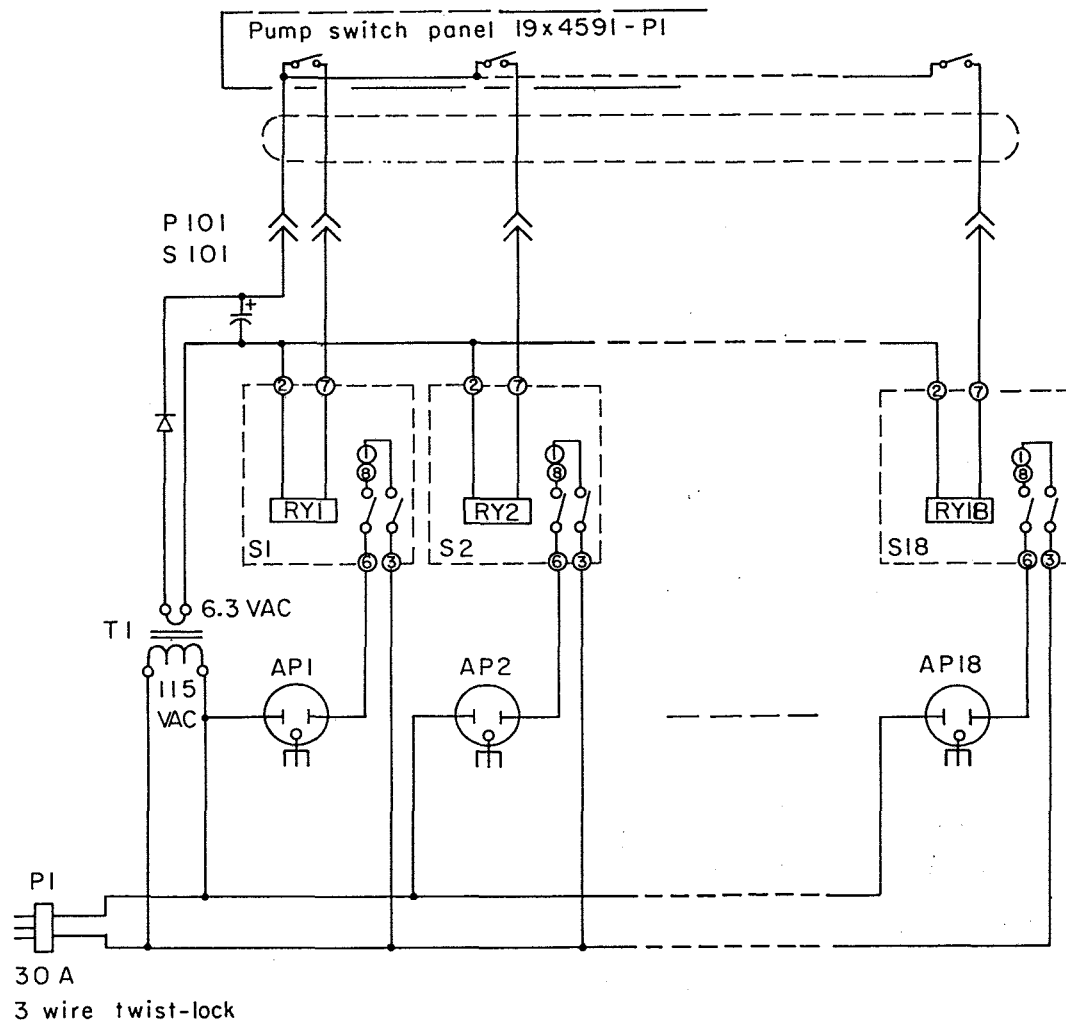
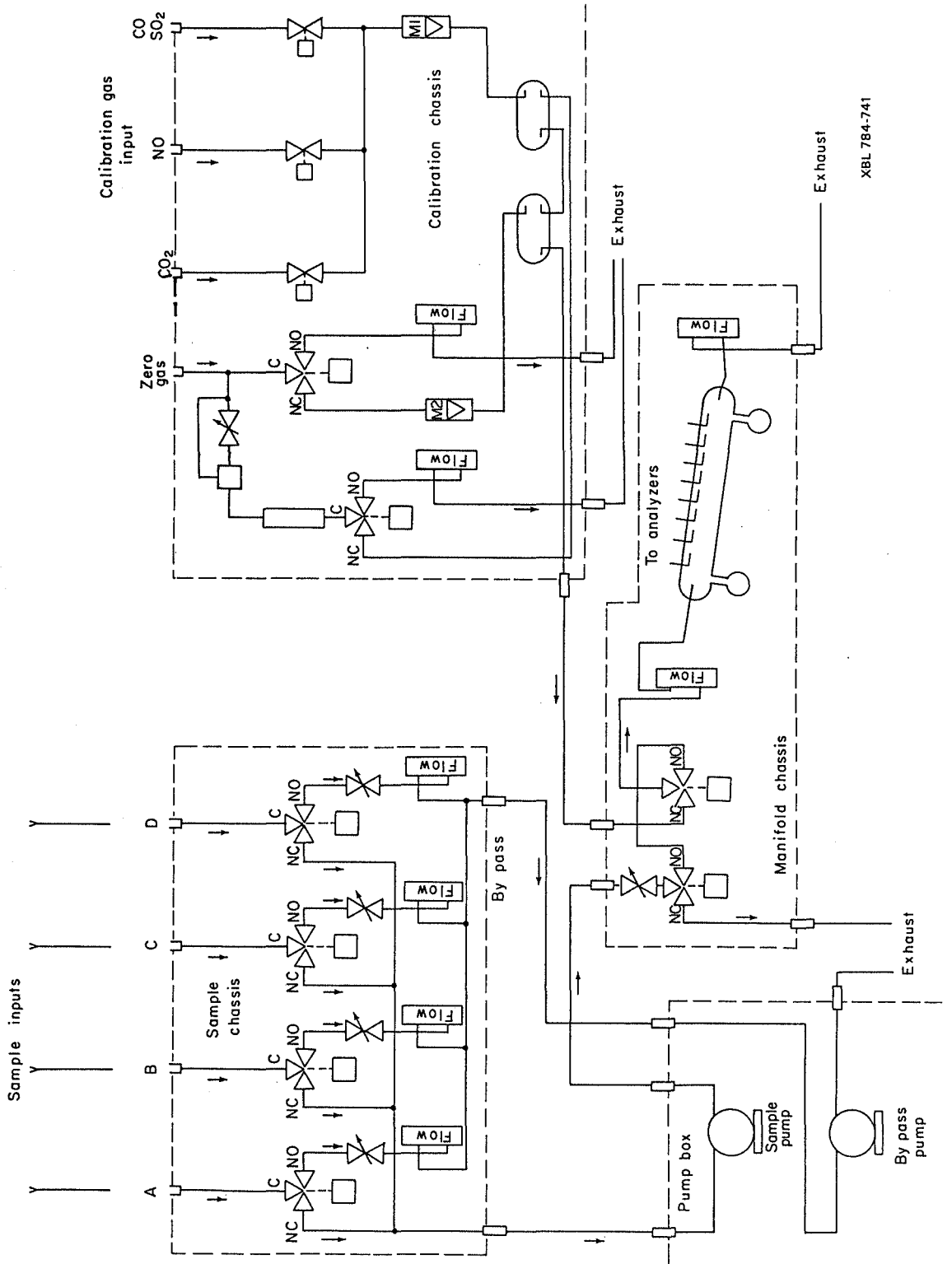


Figure 8: Pump rack wiring schematic

False ceiling level		
Power panel	Power panel	Power panel
MRI weather station chassis	ROYCO air sampler	LBL infiltration cable interface
ROYCO line printer	LBL four input air sample chassis	Intel 80/20
LBL infiltration chassis	LBL calibration chassis	ICOM floppy disc
MSA lira 303 CO ₂ analyzer	LBL monitor chassis	SOLTEC six channel chart recorder
TECO series 43 SO ₂ analyzer	MSA lira 202 CO analyzer	SOLTEC input atten.
LBL pump control panel		LBL real time clock
DASIBI 1003 - AH ozone monitor		Intel 80/20
Wilks IOI N ₂ O analyzer		Spare
TECO series 14 NO, NO ₂ and NO _x analyzer		Burr Brown MUX RCVR
		LBL cable interface
		LBL temp-hum.-ampl chassis
		B.B. MUX remote 16 ch.
		B.B. MUX remote 16 ch.

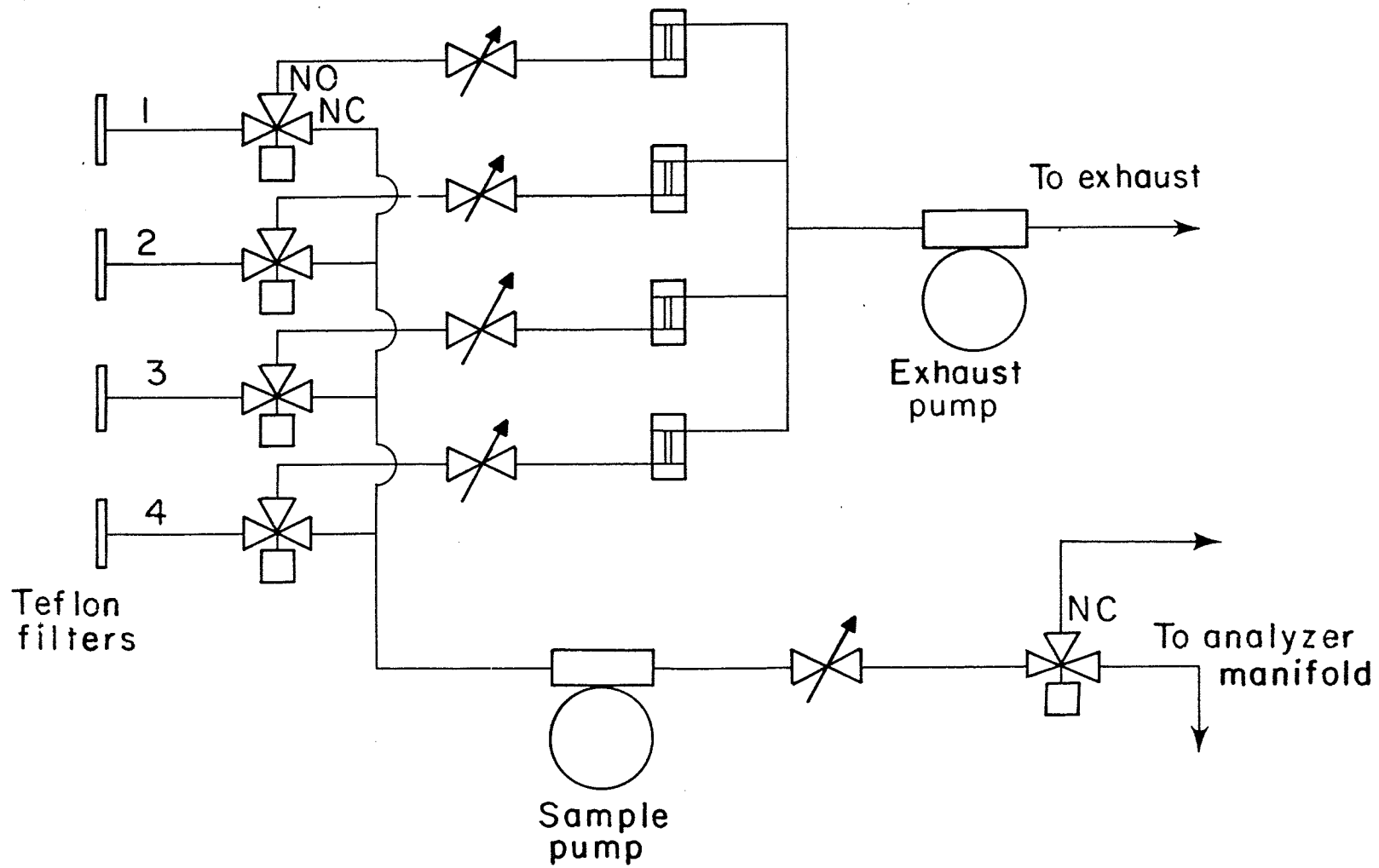
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Figure 9: Main instrumentation rack panel layout



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Figure 10: System flow diagram



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Figure 11: Sampling system

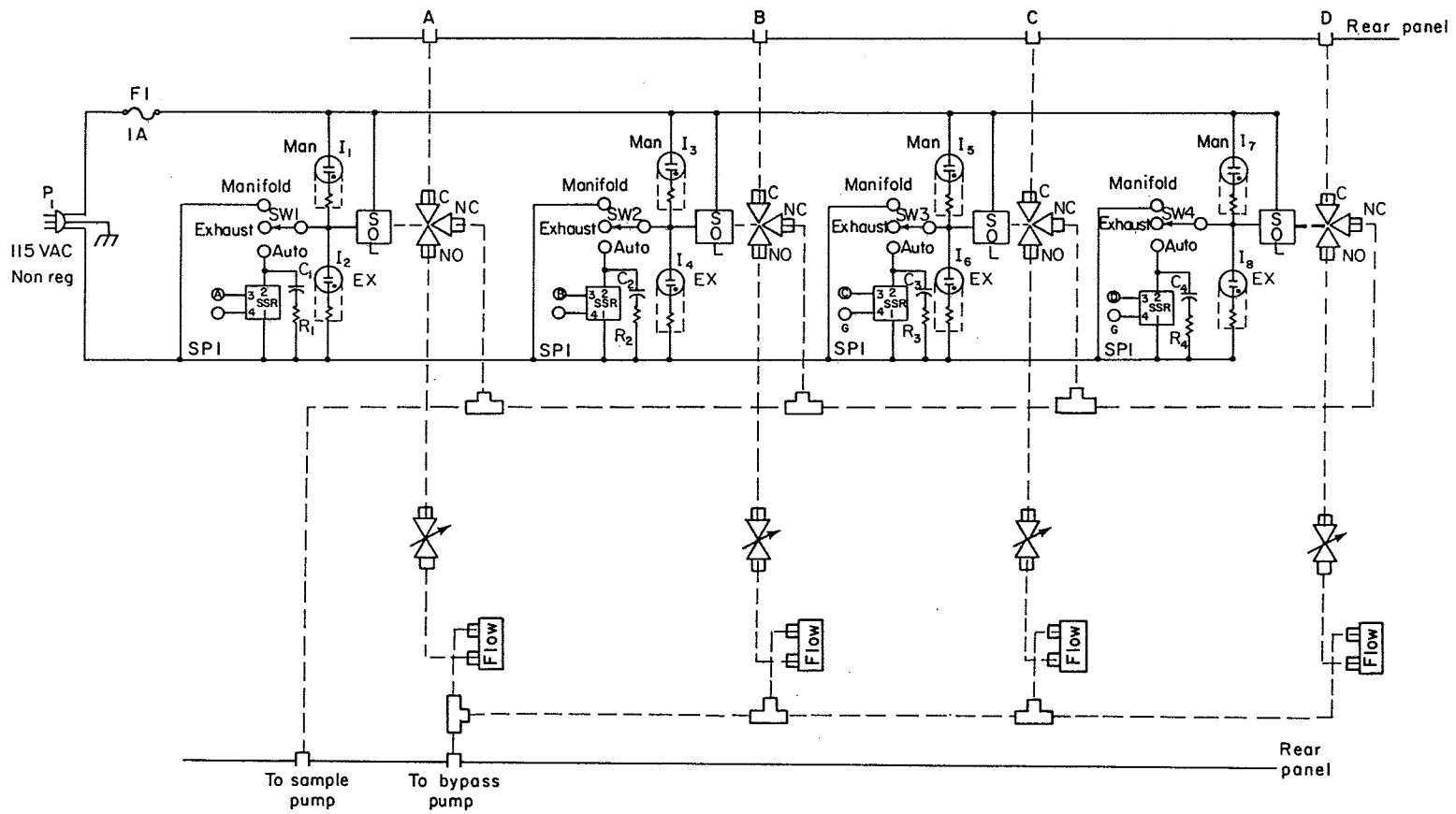


Figure 12: Sample system air and electrical schematic

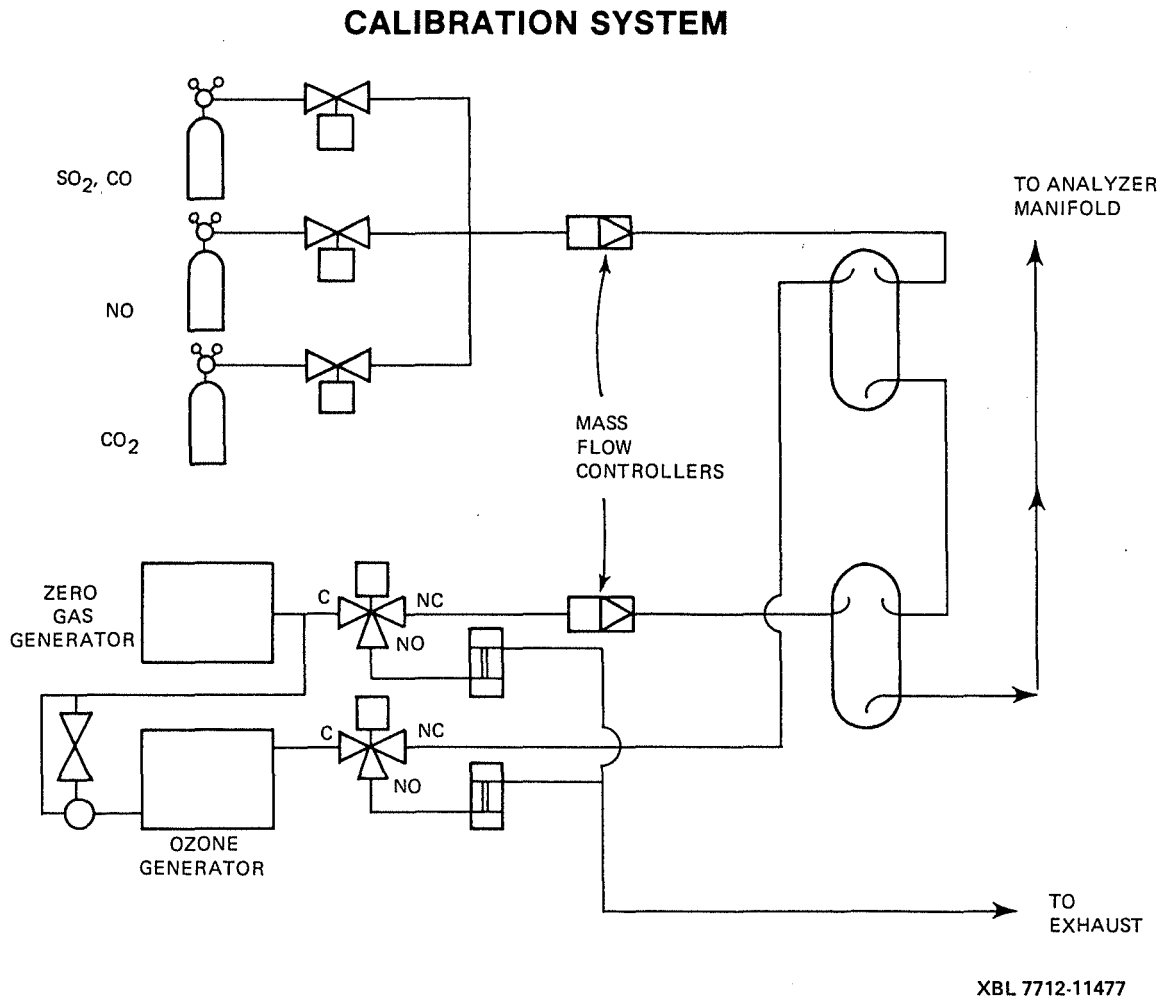


Figure 13: Calibration system

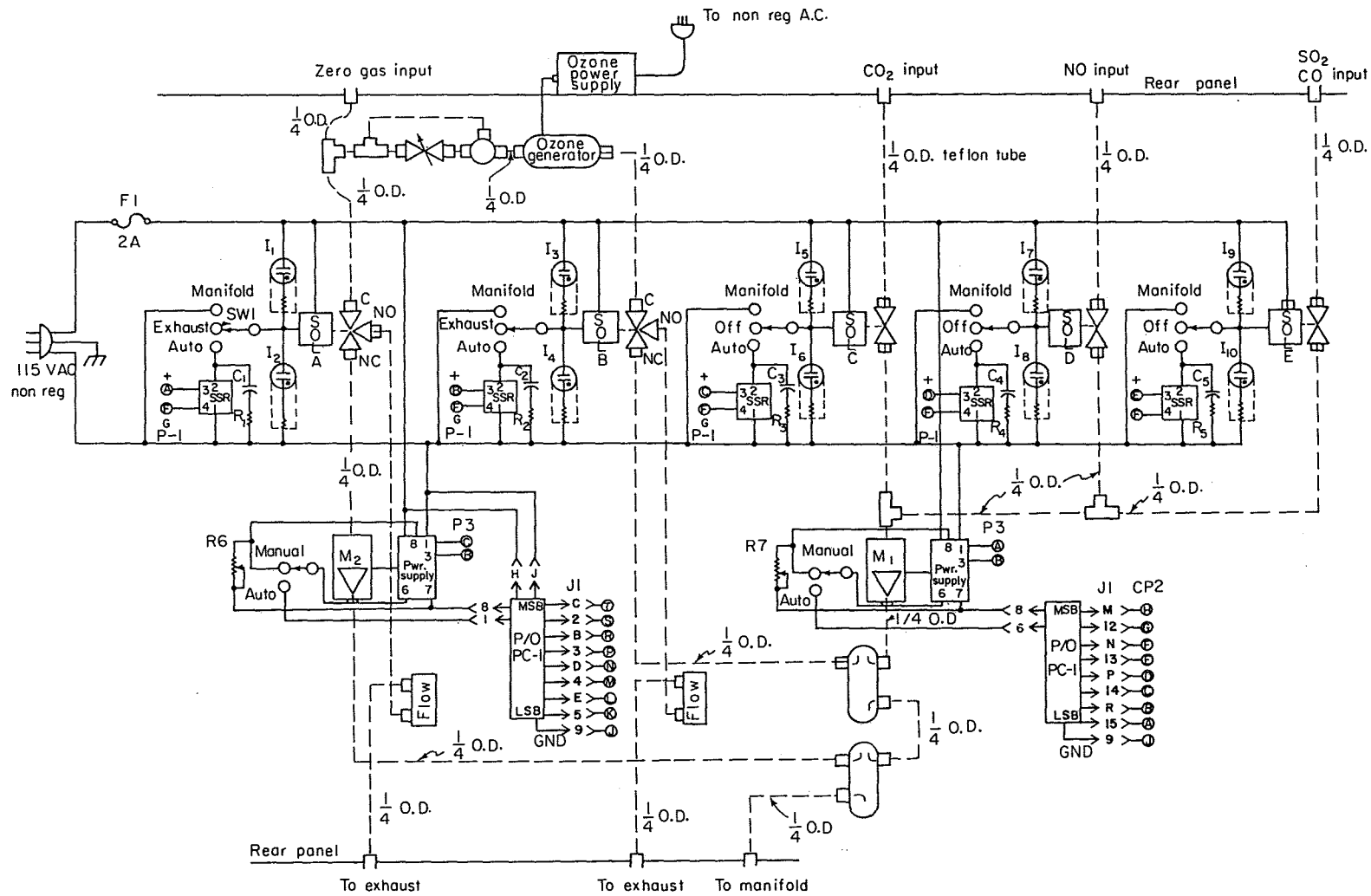
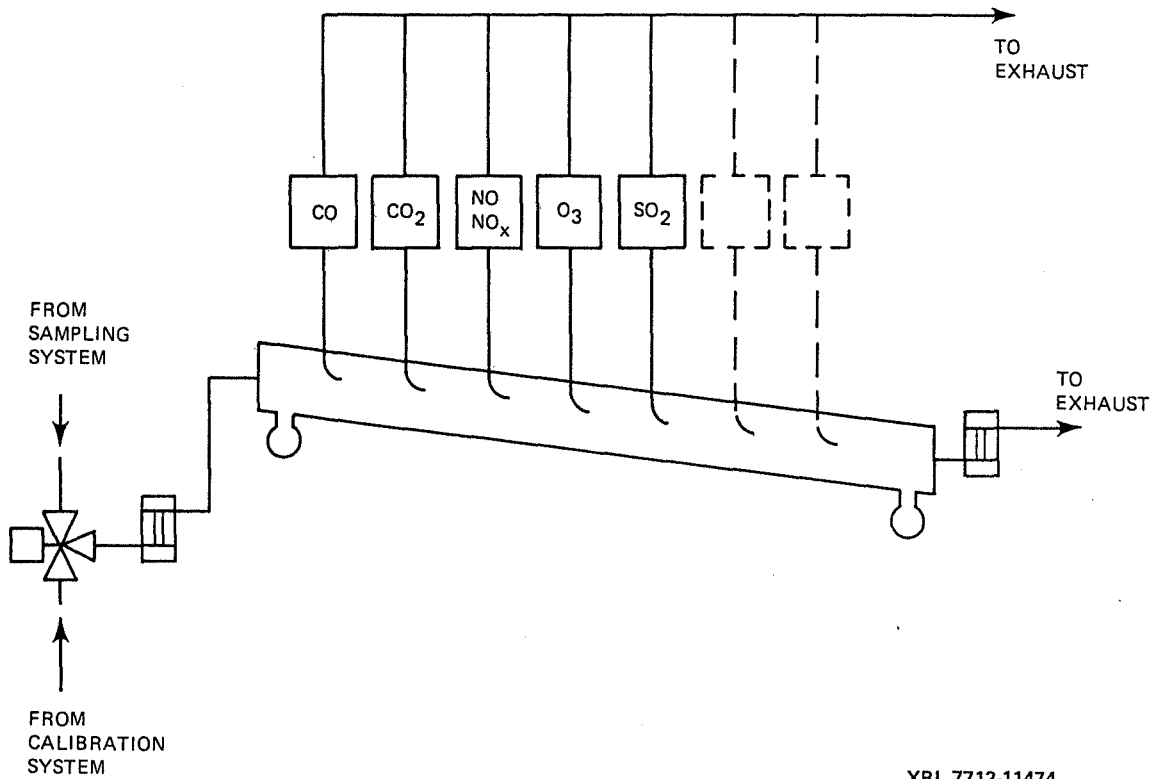


Figure 14: Calibration system air and electrical schematic

MONITORING SYSTEM



XBL 7712-11474

Figure 15: Monitoring system

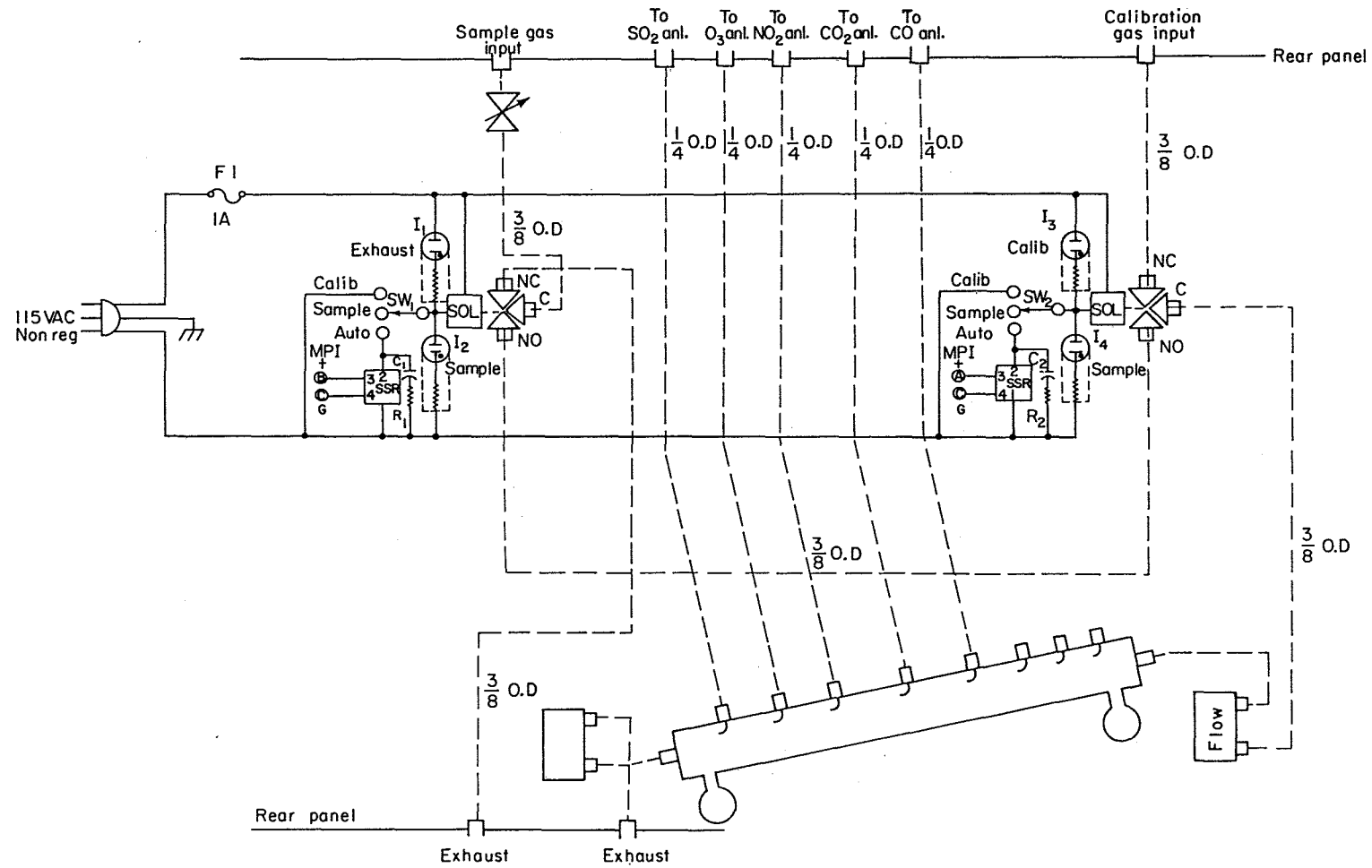
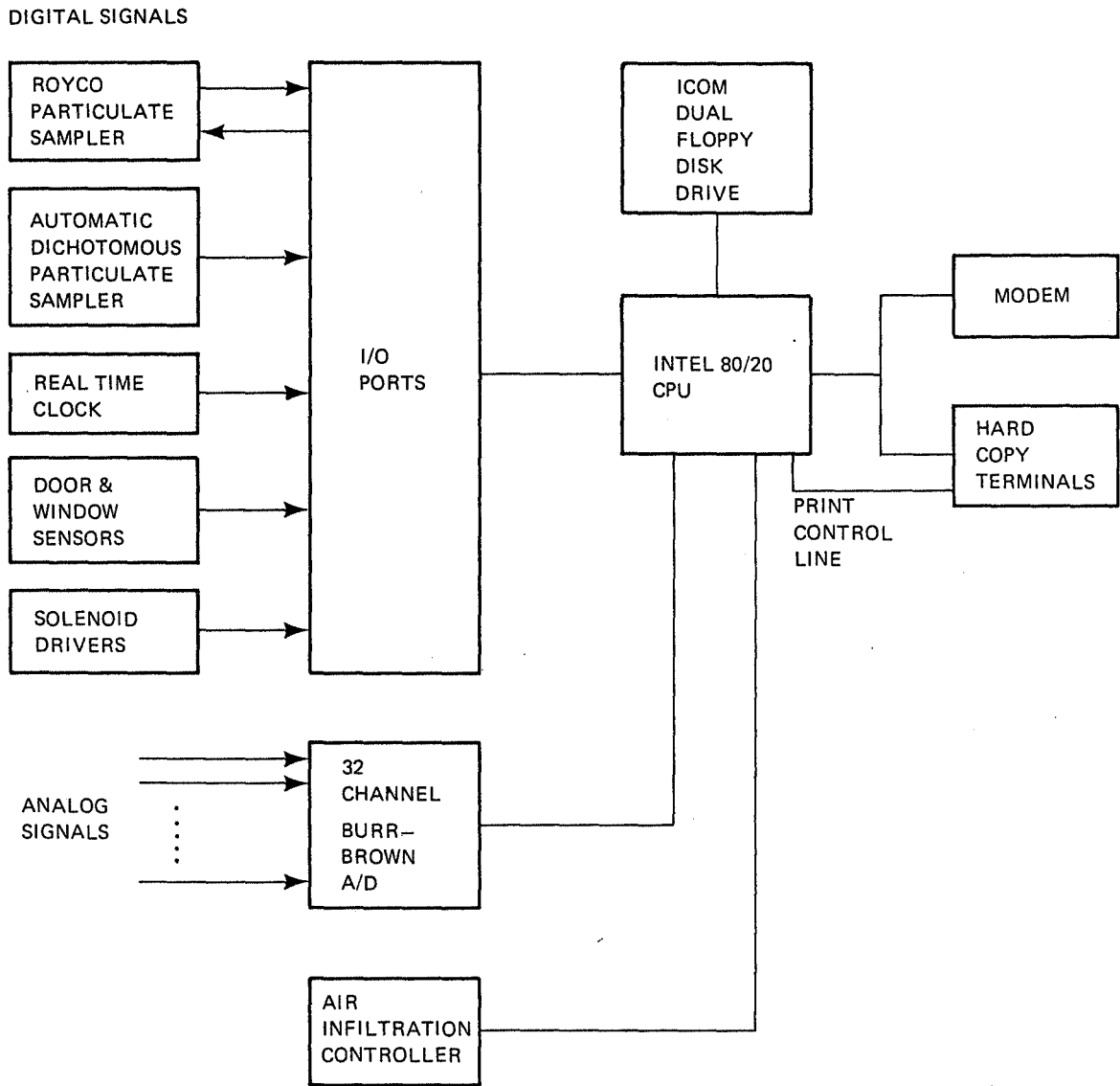


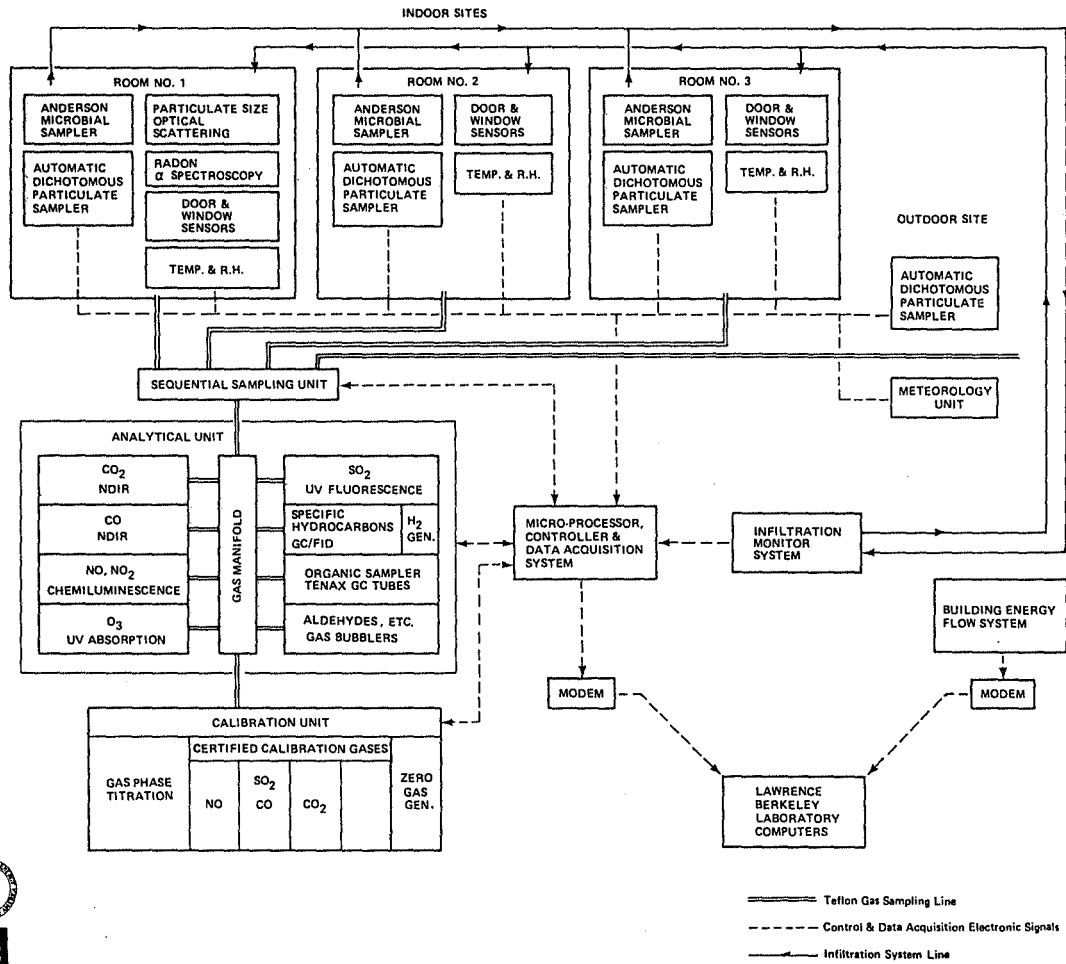
Figure 16: Monitor system air and electrical schematic

DATA LOGGER HARDWARE



XBL 7712-11475

Figure 17: Data Logger hardware



XBL 7712-11471

Figure 18: Ventilation requirements system

INSTRUMENTATION FOR LAWRENCE BERKELEY LABORATORY
VENTILATION REQUIREMENTS SYSTEM

<u>Parameter</u>	<u>Principle of Operation</u>	<u>Manufacturer/Model</u>
Field		
Continuous Monitoring Instruments:		
Infiltration		
N ₂ O or C ₂ H ₆ (Tracer gas)	IR	LBL
Indoor Temperature and Moisture		
Dry-Bulb Temperature	Thermistor	Yellow Springs 701
Relative Humidity	Lithium Chloride Hygrometer	Yellow Springs 91 HC
Outdoor Meteorology		
Dry-Bulb Temperature	Thermistor	Meteorology Research 915-2
Relative Humidity	Lithium Chloride Hygrometer	MRI 915-2
Wind Speed	Generator	MRI 1074-2
Wind Direction	Potentiometer	MRI 1074-2
Solar Radiation	Spectral Pyranometer	Eppley PSP
Metric Rain Gauge	Tipping Bucket	MRI 382
Gases		
SO ₂	UV Fluorescence	Thermo Electron 43
NO, NO _x	Chemiluminescence	Thermo Electron 14D
O ₃	UV Absorption	Dasibi 1003-AH
CO	NDIR	Mine Safety Appliances- Lira 202S
CO ₂	NDIR	M.S.A. Lira 303
Radon	Under Development	LBL (under development)
Particulate Matter		
Size Distribution	Optical Scattering	Royco Particle Counter 225
Radon Progeny	Under Development	LBL
Sample Collectors		
Gases		
Aldehydes, NH ₃	Chemical Reaction/Absorption (Gas Bubbler)	LBL
Selected Organic Compounds	Absorption (Tenax GC Absorption Tubes)	LBL
Particulate Matter		
Aerosols (Respirable/ Non-respirable)	Virtual Impaction/Filtration	LBL
Bacterial Content	Inertial Impaction	Modified Anderson Sampler
Data Acquisition System		
Microprocessor		Intel System 80/20-4
Multiplexer A/D Converter		Burr Brown Micromux Receiver MM6016 AA Remote MM6401
Floppy Disk Drive		ICOM FD3712-56/20-19
Modem		Vadic VA-317S

Table 1

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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