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Xenon Gas Recirculating System for E799

J. Krider and R. Tschirhart
Fermilab Physics Section

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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J. Krider and R. Tschirhart, Fermilab Physics Section

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INTRODUCTION

The Fermilab Physics Section has provided an automated gas system for the E799 wire chamber Transition Radiation Detectors (TRDs) [1]. Its design is described, and the results of operation are presented. The system provides for (1) mass-flow gas mixing, (2) mixture recirculation, (3) gas pressure regulation to 0.01 "H_2O in the TRDs, (4) online repurification and (5) recovery of contaminated mixtures that cannot be purified online. Signals from several flow and pressure transducers are used to generate alarms and limits in interlock hardware. The system is self-compensating within specified limits, and it automatically shuts down if these limits are exceeded. A significant part of the conceptual design is derived from the Synchrotron Radiation Detector gas system for the AMY experiment at TRISTAN [2].

TRD CONSTRUCTION

Three TRD chambers are used for electron identification in E799. Each chamber is preceeded by a radiator made from a layer of polypropylene felt. The photons produced in the radiator have an average absorption length of 1 cm in the TRD gas. A cross sectional view of TRD chamber construction is shown in fig. 1. Most of the primary ionization occurs in the 15 mm long gap between aluminized mylar cathode "A1" and wire plane grid "C". This cathode is operated at -5000 V, and the grid is operated at -1800 V. The resulting drift field sweeps electrons through the grid and into the MWPC. The MWPC consists of anode plane "E", which is composed of alternating anode

and field shaping wires, centered in the 10 mm wide gap between the grid and aluminized mylar cathode "D". Cathode "D" operates at -1800 V. The potential of the field shaping wires is nominally -1800 V, but it can be varied to set the desired MWPC gain. Only the signals from the anode wires are read out. The active region of each TRD is 1.8 m square.

The TRDs have double gas window construction to provide buffer volumes which reduce the diffusion of atmospheric gas into the TRD gas system. The active gas volume is contained between a pair of 50 um mylar windows "A1" and "A2" coated with 40 nm of aluminum. To the outside of these windows are the buffer volumes contained by the two outer windows "B1" and "B2". Window "B1" is aluminized mylar, and window "B2" is a composite of aluminized mylar and aclar. Each buffer has a volume of about 30 l, and it is purged at a rate of 30 l/h with an inexpensive gas which is vented to atmosphere. The relatively high purge rate greatly reduces the partial pressure of contaminants within the buffer volumes and the resulting diffusion into the active volume. This technique is sufficient to hold the contamination rate of the TRD gas to a manageable level.

The buffer gas should have low X-ray absorption, since the X-rays must pass through it to reach the TRD. The buffer gas should have a density close to that of the TRD gas, to reduce the variation in differential pressure across the inner windows from bottom to top. For example the difference in pressure head, or hydrostatic pressure, of 1.8 m tall columns of xenon and air is 0.32 "H_2O. Cathode "D" has been made as a separate plane from the "A2" window, and gas flow channels through the frame minimize the pressure difference between the xenon gas volumes on either side. This construction reduces distortion of the cathode from a flat plane, both by changes in the operating differential pressure between the TRD gas and atmosphere and by hydrostatic forces.

GAS MIXING STATION

A two or three component gas mixture is produced from

pure gases by a mass flow mixing station. Xenon is preferred as the primary component of the mixture, because of its short absorption length for X-rays. Other components may be added as quenching agents or to optimize ion drift velocity in the gas mixture.

A flow diagram of the mixing station is shown in fig. 2. Refer to Table 1 for a description of the nomenclature used in the diagrams of the mixing and recirculating systems. The mixing station employs three mass flow controllers with a four channel master control module [3]. The flow controllers have full scale ranges of 1000, 100 and 20 sccm at 15 psid. They have been scaled to read directly in units of sccm for their assigned gases. The flow controller outputs connect to a 5 l mixing tank which has five parallel outputs. Output 1 connects to the makeup gas input of the recirculating system through valves AV9 and NV4. Output 2 supplies the recirculating system initial fill input. Output 3 is connected to TRD input buffer tank TK2 to permit direct initial filling of the chambers. Output 4, which is labeled Sample Port 1, is connected to the oxygen monitor. Output 5 is a spare sample port.

The flow controllers require a minimum of a few psi of differential pressure to deliver their specified flow, and thus to maintain the desired mixing ratio. Pure gases are delivered from the gas supply to the mixing station at a regulated pressure of 10 psig. When AV9 and NV4 are open, most of this pressure drop is across the flow controllers. Digital control inputs on the master flow control module are coupled to the gas system logic to enable the flow controllers only when AV 9 is open. This prevents the mixing tank from filling with an incorrect mixture ratio when AV9 is closed. The primary gas supply pressures are not included in the interlocks, but they are monitored periodically as part of a check list. One cylinder of each type of gas should be sufficient for an entire running period.

The function of NV4 is to provide for coarse adjustment of the makeup gas flow rate during rapid fill or purge procedures when the mass flow controllers are bypassed. NV4 should be fully open during normal operation of the system, in order to maximize the pressure drop across the mass flow controllers.

RECIRCULATION

Xenon gas presently costs about $12 per liter. In order to make the system economically feasible, the mixture must be recirculated in a closed loop. The recirculating and pressure control system consists of a master control module, a circulating pump, pressure and flow control and monitoring, air-actuated automatic valve control, oxygen monitoring and purifiers. The system flow diagram, shown in fig. 3, also appears on the front panel of the master control module. Stainless steel components, plumbing and fittings are used in the gas handling part of the system to minimize contamination. Quarter turn diaphragm valves and bellows-sealed air actuated and needle valves are used throughout. Wherever practical, system joints are welded together. The remaining connections employ either VCO type o-ring seals or VCR metal gasket seals to minimize leaks [4].

The recirculating gas flow can be followed in a clockwise direction around the flow diagram in two partially overlapping loops. The bellows pump output flow of about 500 l/h passes from pump output buffer tank TK5 through a molecular sieve tank (SIEVE 1 or SIEVE 2) to remove water vapor and heavy hydrocarbons. The flow out of the sieve tank splits into two parallel branches, both of which return to pump input buffer tank TK4: (1) a high flow shunt which directly returns about 95% of the total flow and (2) the flow through the oxygen removal hardware, TRDs and pressure control valve. Capacitance manometers P1-8 measure the pressure in the eight buffer tanks in the system. Limits based on these pressures are used to drive alarms and interlocks which apply closed loop corrections to keep the system within acceptable operation limits, or else automatically shut it down. The pressure readbacks also provide important system diagnostic information.

The shunt flow, which provides for rapid recirculation of the gas through the molecular sieve to increase purification, is established by back pressure regulator PREG. PREG, whose input pressure is regulated with respect to atmosphere, is set to produce a

nominal pump output pressure of 200 Torr atmospheric. The pump differential pressure is about 400 Torr when the pump bypass needle valve NV2 is closed. This sets a sufficient differential pressure of about 200 Torr across each the mass flow controller MFC1 and the pressure control valve PCV in the parallel flow branch through the TRDs. Lower system flow may be accomplished either by opening NV2 to provide negative feedback across the pump or by increasing PREG to increase backpressure on the pump output. Opening NV2 lowers the pump differential pressure, as shown in fig. 4 for two settings of PREG. "PREG=max" corresponds to the minimum clockwise opening of the control knob; it provides maximum backpressure and no shunt flow. Increasing PREG raises the pump differential pressure, as shown in fig. 5 with NV2 partially opened. In practice, NV2 and PREG are dependent variables, so a change of one setting may require adjustment of the other to keep the pump differential roughly symmetric about atmospheric pressure. The system is normally operated with NV2 closed. This maximizes total and shunt flows with respect to TRD flow, which minimizes the impact of TRD return flow variations on system equilibrium. Mass flowmeters F2 and F3 measure total system flow into and out of the molecular sieves.

The low flow branch supplies the TRDs. It contains oxygen removal equipment, mass flow controller MFC1 (full scale = 82 l/h of xenon) to set a constant flow rate into the TRDs, and TRD pressure control. These parts of the system are described in detail in the following sections.

PRESSURE CONTROL

Two pressure related conditions affecting TRD signal amplitude should be considered. First, fluctuations in the absolute pressure of the TRD gas will change the amount of ionization produced in a fixed path length. Second, deflection of cathode planes by changes in the differential pressure between atmosphere and the TRD gas will change the ionization path length, resulting in a change in the amount of ionization and drift time. Since absolute

atmospheric pressure varies by only about ±3% (±10 "H_2O), the first condition is easily satisfied, provided that the TRD gas pressure roughly tracks atmospheric pressure. The second condition demands a much higher degree of pressure control, because cathode displacement is extremely sensitive to differential pressure.

Cathode "A1" is referenced through the buffer gas to atmospheric pressure, so a pressure change between the TRD active volume and atmosphere displaces this cathode. A change in cathode position relative to the grid and anode planes changes the ion drift distance and drift field, both of which affect ion drift time. Since drift time is used to improve particle identification, it is important to stabilize this variable. A change in the detector gap also changes the amount of ionization deposited by those X-rays which are not totally absorbed by the TRD gas. For small displacements the cathode behaves like a simple spring with displacement being proportional to applied force or differential pressure. A pressure change of 0.01 "H_2O (19 mTorr) produces a 1 mm displacement of the equilibrium position of the cathode at its center. Differential pressure control at the level of about ±0.01 "H_2O is required in order to maintain adequate stablility in TRD signal timing and amplitude.

The three TRDs operate in a parallel gas flow configuration between common input and output buffer tanks TK1 and TK2, which are located near the TRDs. Mass flow controller MFC1 supplies a constant flow into TK1. Since it was not cost effective to have independent pressure control for each TRD, the control is done only at TK2. Pressure transducer P2 measures the pressure difference between TK2 and local atmosphere with an accuracy of approximately 0.001 "H_2O (2 mTorr). Closed loop control is accomplished with a commercial pressure control module which uses the signal from P2 to modulate the return flow out of TK2 with pressure control valve PCV [3]. Needle valve NV1 can be throttled to reduce the pressure drop across PCV. NV1 is fully open during normal operation, since PCV accuracy improves with increased differential pressure. The pressure at TK2 is controlled to about ±0.001 "H_2O. The control setpoint is +0.01 "H_2O. This holds the TRD gas at a slightly positive pressure

with respect to the buffer gas and atmosphere, in order to prevent contaminants from being drawn into the gas system through small leaks.

Since the pressure is controlled at TK2 instead of in the individual TRDs, a flow dependent pressure drop across the plumbing connecting the TRDs to TK2 introduces a small error in TRD pressure with respect to P2. That pressure drop has been measured to be 0.005 "H_2O at 30 l/h flow of nitrogen. The maximum error in normal operation is estimated to be 0.0067 "H_2O, when PCV is wide open and flowing 120 l/h (40 l/h for each of the three TRDs).

The system initially responds to a step function atmospheric pressure change in the following way. Since TRD output flow rate is limited by the impedance of five relatively small flow channels in parallel (0.00017 "H_2O/l/h), the existing gas in the TRD is first compressed or expanded in proportion to the pressure change. The largest anticipated instantaneous pressure change, about 5% of an atmosphere (20 "H_2O), produces a displacement of about 1 mm at the center of a TRD window. The change in restoring force exerted by the tension in a deflected window is a roughly factor of 2000 smaller than the gas compressive force, since the window deflection constant is only 0.01 "H_2O/mm.

In order to recover to the setpoint differential pressure across the TRD windows, the gas system must move the windows back to their previous equilibrium positions by adding or removing gas to compensate for the density change. The volume change in each TRD is approximately 1.2 l for a 1% instantaneous pressure change. If that amount of gas must be added to each of 3 TRDs because of an atmospheric pressure increase, the control system will reach equilibrium in 6 min by closing PCV to stop output flow, while maintaining the constant input flow of 12 l/h/TRD. Conversely, if that amount of excess gas must be removed from each TRD because of a decrease in atmospheric pressure, the control system will reach equilibrium in 2.6 min by fully opening PCV to exhaust 40 l/h/TRD, while the constant input flow of 12 l/h/TRD is maintained.

The speed of response to a change in the differential

pressure control setpoint is determined by the time required to adjust the TRD gas volume to achieve the new equilibrium window positions. As previously noted, a pressure differential of 0.01 "H_2O will deflect the TRD windows by 1 mm at the center, which represents a change of about 5% in the 120 l TRD gas volume. Accomplishing this volume change under the same control system parameters described above requires about thirty minutes. Since the time response of the system to set point changes is very slow, caution must be exercised to wait long enough for the system to reach the new equilibrium condition before other dependent parameters are adjusted.

The pressure control system causes the TRD gas pressure, and similarly the gas density, to track atmospheric variations in order to maintain a constant anode to cathode gap. A constant volume is maintained in the TRDs. The rest of the system is also a fixed volume; however, the differential pressure between some points in this part of the system is permitted vary by a relatively large amount. In order to avoid having to vent gas from the system each time the atmospheric pressure falls and having to add fresh makeup gas each time the pressure rises, the 48 l reservoir tank TK9 has been included between TK4 and TK5. The nominal pressure in the reservoir is 760 Torr absolute, but it can vary by up to ±200 Torr. This provides a storage capacity of ±13 l-atm, which is sufficient to accomodate 5% density changes in the rest of the system. When the circulating system pressure becomes too low, AV5 automatically opens to transfer gas from the reservoir to TK4. Conversely, when the circulating gas pressure becomes too high, AV3 opens to transfer gas from TK5 to the reservoir. If reservoir limits are exceeded, AV9 will add fresh makeup gas, or AV4 will vent gas to the recovery system as required to return to the operating range of the reservoir.

ONLINE REPURIFICATION - MOLECULAR SIEVE, RIDOX AND OXISORB

The effect of gas permeation through the TRD windows is to raise or lower the partial pressure of each species of gas inside,

depending on that gas's permeability constant and its pressure differential across the windows. This differential diffusion of TRD gas mixture components as well as atmospheric contaminants must be considered. The TRD gas candidates should have low permeabilities to minimize gas loss and to maintain a stable mixture ratio. In addition, two limits on contamination by permeation of external gases into the TRD gas system must be considered. First is the equilibrium concentration inside each TRD of contaminants entering through the windows, assuming some reasonable flow-through rate of pure TRD gas. Second is the level of these contaminants that will build up in a recirculating system with limited purification capacity.

One prototype TRD was operated during a two week beam test period in 1990. At that time a combination of clear and aluminized mylar windows was used. The TRD gas mixture ratio was chosen to be 90% xenon and 10% CO_2, and the buffer volumes were purged with 100% CO_2 at a flow rate of 28 l/h. During that run we found that the permeability of the TRD windows to xenon was negligible; however, the permeability to CO_2 was significant. The net permeation rate of CO_2 from the high concentration in the buffer volume into active volume was calculated to be about 1 l/day. This produced a continuous rise in the recirculating system pressure and an unacceptable dilution of the xenon.

After that test run a facility was assembled to measure the permeability of several window materials to a variety of gases [5]. The materials chosen for the TRD windows described in the TRD CONSTRUCTION section are based on the results of these studies. In future runs a series of TRD gas mixtures will be evaluated, starting with 90% xenon and 10% CO_2. Argon or N_2, both of which have relatively low permeability, will be used as a buffer gas.

One other problem that occurred prior to the test run made it impossible to stabilize the gas mixture or make accurate online permeability measurements. One of the windows between the TRD and buffer volumes had a leak as the result of an earlier chamber wire repair. In order to prevent buffer gas from being drawn into the TRD through the leak, the set point for chamber differential pressure

P2 had to be positive by a large enough amount to ensure outward flow of the TRD mixture during the most severe atmospheric pressure changes. The resulting leak rate was typically considerably larger than the rate of permeation through the windows.

The TRD windows have a relatively high permeability to water vapor, and lower but still significant permeability to several other gases. Water vapor, O_2 and N_2 are the principal gases that degrade chamber performance. The maximum tolerable concentrations of water vapor and N_2 are 1% each, and the maximum for O_2 is 50 ppm. This amount of each contaminant reduces TRD gain by about 10%. Gas returning from the TRDs is passed through a molecular sieve to remove water vapor and heavy hydrocarbons and through a catalytic purifier to remove O_2. The gas is then sent back to the TRDs. The system does not have the capability to remove N_2 online.

Two molecular sieve tanks are built into the system. While one is online, the other can be regenerating. Each tank contains 10 Kg of Linde type 3A sieve pellets. The primary function of the sieves is to remove water vapor. Sieve water capacity at room temperature is approximately 20% by weight, or roughly 2500 l of water vapor at a partial pressure of 1% of an atmosphere. Type 3A sieve adsorbs a relatively small amount of CO_2 and virtually no xenon. The sieves can be regenerated in place by heating to 100°C and pumping with a vacuum pump for a few hours.

O_2 removal is done in two stages. First, 10 Kg of an activated copper catalyst RIDOX R-30 operating at 60°C is used to reduce the O_2 concentration to less than 50 ppm by forming copper oxide [6],[7]. The catalyst has a relatively high capacity of 20 atm-liters of O_2 at a pressure of 38 mTorr (50 ppm), and it can be regenerated in place. The RIDOX is followed by an Oxisorb commercial purifier with activated metal and molecular sieve elements [8]. The Oxisorb can remove O_2 to a level of less than 0.1 ppm, as well as removing other impurities; however, its capacity is only 14 atm-liters of O_2, and each regeneration by the manufacturer costs $500. We found that the RIDOX alone provided adequate gas purity for the recent test run, so the Oxisorb was not used. We anticipate using

the Oxisorb once the system has stabilized during data runs.

The RIDOX regeneration process involves heating the catalyst to 150°C and passing a mixture of 5% H_2 plus 95% inert gas through the tank at a flow rate of 4500 l/hr for 2 hrs. H_2 gas reduces the copper oxide to pure copper plus water vapor. The resulting mixture of gases is vented to the outdoors. The 5% H_2 concentration is below the flammable range.

RECOVERY FOR OFFLINE REPURIFICATION

Two conditions generate levels of impurities that cannot be handled by the online purifiers. First is the initial fill procedure, when the xenon mixture is introduced into the system and must displace a large volume of purge gas from the chambers. The online purifiers do not have enough capacity to effectively remove the system volume of purge gas. Second, during the steady state running condition some contaminants that are difficult to remove diffuse into the system through the chamber windows at a relatively low rate. It is also desirable to have a technique for recovering the xenon from individual chambers that have to be opened for repairs during a running period, and from the entire system volume at the end of a running period. A cryogenic recovery system has been installed by Spectra Gases, Inc. to store the contaminated mixtures, which can be returned to them for repurification at a cost of $1.75/l of recovered xenon [9]. Even though some xenon is lost in the recovery process, the cost of recovery is still considerably lower than the cost of simply replacing the gas.

In this scheme a selectable fraction of from 1% to about 50% of the recirculating gas can be diverted through MFC 2 (17 l/h full scale flow at 1 atm) to one of a pair of recovery tanks cooled to liquid nitrogen temperature. The recovery tank liquifies most gases from the system, so it has a very large capacity in terms of gas volume. The small apertures in the valves in the lines to the recovery system prevent backstreaming, provided that the total vapor pressure of all gases in the recovery system is lower than the pressure in the

recirculating system. This feature permits the accumulation of gases having a liquifaction temperature below that of liquid nitrogen up to about half an atmosphere in the recovery tank. Of particular interest to us, a recovery tank can accomodate several liters of nitrogen gas.

A recovery tank is considered full and is valved off when its pressure has risen to within 5 psi of the pressure at the point in the recirculating system from which gas is being removed. This is accomplished automatically with photohelic pressure gage P9, which measures the differential pressure across MFC2. When the full tank has been isolated from the recirculating system, the other recovery tank can be valved online. The full tank is then warmed to room temperature, and most of its contents are transferred to a larger room temperature storage tank by letting the two tanks reach the same pressure. The contaminated recovery tank can then be isolated and cooled down for another recovery cycle. After several cycles the storage tank pressure becomes large enough to limit the effective transfer of gas from the recovery tanks. At that point the storage tank is removed from the system and sent to Spectra Gases, Inc. for repurification of its contents.

The initial fill procedure consists of the following steps: (1) Isolate the TRDs from the recirculating system. (2) Flow an inert purge gas such as CO_2 through the TRDs at a high rate for long enough to flush out most of the contaminants. This purge gas must have a lower density than xenon to prevent gravitational mixing, and a low diffusion coefficient to minimize mixing by diffusion when xenon is introduced into the bottom of the TRDs. (3) Evacuate the rest of the gas system, regenerate purifiers and fill them with the TRD gas mixture. (4) Valve off the purge gas supply to the TRDs and open only the bottom inlet port and the top exhaust port of each TRD. (5) Introduce the TRD gas mixture into the bottom of each TRD to push the purge gas out the top exhaust port to atmosphere. (6) After approx. 90% of filling time, connect the output to the gas recovery system and continue to fill. (7) After about 1.1 fill times, valve the recirculating system online into the normal running configuration.

Some contaminants, such as N_2, which slowly permeate

into the recirculating system, cannot be removed with the existing online equipment. To hold such contaminants to acceptable concentrations, a small constant fraction of the circulating gas is diverted to the cryogenic recovery system through MFC2.

Gas must occasionally be removed from the recirculating system to stay within preset operating limits. The excess gas can be diverted to the recovery system automatically via AV4 or manually via AV7. To "empty" a chamber or the entire recirculating system, purge gas is added while flowing two chamber or system volumes to the recovery system via MFC2 at the maximum rate of 17 l/h. Assuming that the purge gas and the xenon fully mix by diffusion, two volume changes should recover 90% of the xenon.

All lines to the recovery system must be protected against backstreaming of contaminants. This is accomplished with interlocks which permit AV4, AV6 and AV7 to be opened only if the forward pressure drop P9 across MFC2 is greater than +5 psi.

FILTERS, FLOW RESTRICTORS AND CHECK VALVES

Mechanical hardware has been installed to provide filtering and to limit flow and pressure at critical locations in the system. Filters reduce particulate damage to mechanical components. Flow restrictors limit the rate of change of selected system pressures and limit the rate at which expensive gases can be vented from the system. The buffer tanks in the mixing and recirculating system have been designed to operate at a maximum of 30 psig. Excluding the TRD chambers, this is the lowest limit in the system, and it establishes the limit at which most of the system must have pressure relief protection.

The performance and lifetime of a number of components in the system, such as valve seats and guides and the bellows pump, can be adversely affected by particulate contamination. Two micron pleated mesh filters FIL1-3 are located in each primary gas supply line. Similar filters FIL5-6 on the output of the molecular sieve tanks and FIL7 on the output of the RIDOX catalyst tank trap dust from

these purifier devices in normal gas flow. A single filter FIL4 on the output of the circulating pump is designed to catch dust from the purifiers in case of backstreaming.

Sintered metal flow restrictors are used to coarsely limit flow at selected points in the recirculating system. Different density elements are used, depending on the desired flow at the nominal pressure of each point. R1 (10000 sccm at 2 atm) limits the rate at which gas can be automatically withdrawn from the recirculating system to the recovery system. R2 (10000 sccm at 2 atm) limits the rate at which gas can be manually withdrawn from the recirculating system to the recovery system. R3 (5000 sccm at 2 atm) and R4 (1000 sccm at 2 atm) limit the flow rate of gas shunted through the oxygen analyzer. The analyzer requires a minimum flow rate of about 200 sccm for reliable operation, but the shunted flow must be limited to a modest percentage of the flow to the TRDs in order to maintain stability in the control system.

Two lift check valves CV1,2 are included in the recirculating system. CV1 prevents possible backstreaming and loss of purified gases to the recovery system when the circulating system is operating in a non-standard mode. CV2 prevents backstreaming of gas and particulates from the purifiers when the circulating pump is turned off. Lift check valves were chosen because they have a very low forward pressure drop. They operate by gravity, so orientation is important.

PRESSURE RELIEFS

The gas system has four sections with different pressure ratings. The first section, which consists of the primary gas cylinders and the input stage of the pressure regulators in the gas storage shed, is rated at 2500 psig. The second section, the output stage of the pressure regulators, the lines to the gas mixing station in the north PortaKamp, and the mass flow controllers in the mixing station, is rated at 150 pisg. The third section, the rest of the system excluding the TRDs, is rated at 30 psig. The fourth section is

the TRDs, which are rated at 0.1 inch of water. The system is protected against overpressure by three types of mechanical devices: spring loaded relief valves, rupture disks and oil-filled bubblers.

The output stage of each pressure regulator in the gas shed contains an integral 150 psig relief. This protects section two.

Section three is protected by two types of relief. When all three purifiers (molecular sieves and RIDOX) are valved off, the circulating loop and the mixing tank are protected with 30 psi reliefs exhausting to the recovery system. The recovery system normally operates at a partial vacuum, but it has its own 1 psi emergency relief to the atmosphere. In the worst case, with all purifiers valved off and the recovery system "full", section three could reach 31 psi.

If a contaminated purifier were accidentally heated for regeneration while isolated from both the recirculating system and the vacuum pump, a high pressure could result from the gas desorption process. Therefore, a 1 psi spring loaded relief valve in series with a 14 psi rupture disk is included on each purifier tank. The reliefs from the three tanks empty into a common line which vents to atmosphere outdoors. Rupture disks were chosen because low pressure spring loaded reliefs may not completely reseal after being actuated. Spring loaded reliefs are included to prevent most of the backstreaming of atmospheric contamination through a ruptured disk. When any one of the purifiers is online, it also provides section three of the circulating system with this 15 psi relief to atmosphere.

Since the rupture disks vent directly to atmosphere, gas leaking at this point cannot be recovered. A flow monitor has been installed in the common vent line to prevent excessive gas loss. The monitor consists of a 0.05 "H_2O pressure switch connected in parallel with the 30 m length of 3 mm ID tubing which forms the vent line. The switch trips at a flow of less than 2 sccm, and it automatically shuts down the recirculating system. In case of a large leak through a rupture disk, the long small diameter vent line restricts flow to about 4 slpm at 15 psid.

The TRDs are protected by bubblers which vent to the local atmosphere. The bubblers have an intermediate buffer volume to

trap bubbling fluid that might otherwise be drawn into the gas system by negative pressure. Since the bubblers vent directly to atmosphere, they are a potential loss point for the gas mixture. They are located in a radiation area and are not directly accessible, but their status is periodically monitored with a video camera.

OXYGEN MONITOR AND ASSOCIATED AUTOMATIC VALVE CONTROL MODULE

The TRDs are highly sensitive to O_2 contamination. A monitor has been installed to permit measuring the O_2 concentration at any one of four points in the recirculating system. The monitoring point is selected with quarter-turn manual valves on the recirculating system master control panel. Inline porous metal flow restrictors establish acceptable flow rates through the monitor.

The monitor requires periodic calibration. A zero gas, which has less than 5 ppm O_2, is used to set the zero response of the monitor. A reference gas mixture with 500 ppm O_2 is used to set the scale factor. These two monitor variables are dependent, so several iterations may be required to reach the desired setpoints.

The monitor flow control logic, shown in fig. 6, employs four push button switches to control three input pneumatic valves and two output pneumatic valves. All valves are closed on power up, or by pushing the VALVES CLOSED button. Selecting TRD GAS opens the input valve supplying gas from the recirculating system and the output valve returning gas to the recirculating system, and it closes the other three valves. Selecting either ZERO GAS or REFERENCE GAS closes the two TRD gas valves, and opens both the appropriate input source valve and an output valve vented to atmosphere. The logic is designed to operate in a "failsafe" mode to the extent that it minimizes the venting of TRD gas to the atmosphere or the contamination of TRD gas with O_2.

During normal operation the monitor is set up to measure the O_2 concentration at the input to the Oxisorb commercial purifier. A relay output from the monitor enables the recirculating system only

when the O_2 concentration is less than 50 ppm at this point. This feature protects the Oxisorb, which has a relatively low capacity, from being quickly saturated if the RIDOX should malfunction.

A manually valved sample port at the O_2 monitor input permits withdrawing gas from any one of the four locations in the recirculating system for offline analysis by gas chromatography. Gas samples can also be withdrawn from the mixing tank of the gas mixing station. Fig. 7 is the chromatograph output for a reference gas mixture of approximately 40% argon, 10% CO_2 and 50% xenon. Fig. 8 is the chromatograph of a gas sample drawn from the output of the TRD gas mixing station. Fig. 9 is the chromatograph of a sample taken from the TRD output during beam tests on 8/23/90. Fig. 10 is a chromatograph of a sample taken from the TRD output on 8/27/90. The split peak in fig. 9 demonstrates that the analyzer can resolve argon and N_2. N_2 is the earlier peak. A comparison of Figs. 9 and 10 suggests that the N_2 concentration was increasing during this running period. This is consistent with the fact that the TRD had significant leaks, which allowed atmospheric N_2 to diffuse into the system at a greater rate than it was being removed in the fraction of gas being diverted to the recovery system. Meanwhile, the concentration of argon, which had been introduced in the initial TRD purge, decreased since it was being removed to the recovery system without being replaced.

SYSTEM AUTOMATIC VALVE CONTROL

The mass density of gas in the constant-volume recirculating loops must track atmospheric pressure changes reasonably closely to maintain the loop pressures within the range required by the analog pressure and flow controllers. This is accomplished automatically by transferring gas to or from storage reservoir TK9 with a system of pneumatic control valves. The valves are operated with relay logic based on preset pressure limits. The quantity of gas transferred in each operation is proportional to the amount of hystersis, or deadband, set in the pressure limit hardware.

The circulating system includes nine pneumatically actuated valves AV 1-9, nine pressure transducers P1-9, two pressure switches PS1,2 and the oxygen monitor. The valves can be operated either automatically or manually from a master control module which contains relay logic based on various system pressure and O_2 concentration limits. The relay logic is shown in fig. 11. All valves are the normally closed type, to ensure that the system shuts down in the proper state in case of loss of actuating gas pressure or electrical power. An audible alarm sounds locally to indicate system shutdown, loss of pneumatic valve actuating gas pressure, or insufficient vacuum in the recovery system.

Gage pressures P1-8 are measured with Baratron capacitance manometers. These pressures are monitored with two five channel power supply and display modules (MKS PDR-5B). Each module also contains five independent limit relays which can be assigned to any combination of inputs. Each module displays one manually selected pressure or limit at a time. Pressure switch PS1 monitors the status of the pneumatic valve gas supply pressure, and PS2 monitors leaks through the rupture disks. Two other limits, one from photohelic differential pressure gage P9, and the other from the O_2 monitor, are also used in the automatic valve control logic.

The standard limit/alarm circuitry in the PDR-5B accomodates only positive limit settings of 0-10 V, a fixed deadband of 13 mV, and ascending type alarms. The circuitry for each limit has been modified to meet the requirements of this application. Since some system pressures and limits are negative, the range of limit adjustment has been made symmetric about zero. All of the limits in this system are less than ±3 V, so the adjustment range has been decreased to ±3 V to improve the stability in the adjustment potentiometer setting. The deadband, or differential between on/off for increasing versus decreasing input levels, has been made adjustable over the range 13-40 mV, since some valves would cycle too frequently at the minimum deadband setting.

Failsafe interlocks require the use of normally open relays. The relays must be energized to permit system operation. This

protects the system in case of power failure or an open circuit in any of the wiring. A failsafe "ascending" type alarm, one in which the relay is energized to permit system operation only at pressures below (more negative than) the limit, is required to establish maximum pressure limits. A failsafe "descending" type alarm, one in which the relay is energized only at pressures above (more positive than) the limit, is required to establish minimum pressure limits. Both types of alarms are required in this system, so a switch and appropriate circuitry has been added to each alarm channel to permit selection of either ascending or descending type.

The system limits used in automatic valve control are tabulated in Table 2, and the control logic for each valve is shown in Table 3. Gas is added to or removed from the circulating loops based on various limits on P4, the pressure in TK4. Most gas density changes can be accomodated by buffer tank TK9, either by transferring gas from the circulating loops into the tank via AV3, or by transferring gas back to the recirculating loops via AV5. When the required change exceeds the capacity of the buffer tank, fresh makeup gas is added via AV9, or excess gas is dumped to the recovery system via AV4. When the system is unable to correct itself, and a second tier of limits is reached, the system will automatically shut down, with AV1 and AV2 isolating the TRD chambers and AV8 isolating the Oxisorb purifier. The opening of pressure switch PS2, which indicates gas loss through a rupture disk, will also automatically shut down the system. In addition, the constant bleed to the recovery system through MFC2 can be isolated with AV6. AV7 permits manual venting of gas to the recovery system. Both the manual and automatic opening of AV4, AV6 and AV7 are inhibited by a low limit set on P9. This prevents backstreaming of gases from the recovery system when it has insufficient vacuum to remove gas from the recirculating system.

ACKNOWLEDGEMENTS

The project was funded by the Fermilab Physics Section. Eugene Beck coordinated all mechanical assembly and installation of the mixing and recirculating systems and the TRD manifolds. Ivan Staursboll did most of the system welding. Don Carpenter's shop assembled the purifier and reservoir tanks. Willie Cyko's group provided the artwork for the front panels. Two summer students, M. Daum and D. Segel, assisted in the installation of the TRD chambers and the gas recirculating system. Pat Gorak assembled the electrical components. Jeff Gordon operated the Lab 6 chromatograph used for offline gas sample analysis.

The cryogenic recovery system and a commitment to repurify xenon were provided by Spectra Gases, Inc. Tom Galagher, the district sales representative, coordinated the arrangements. Joel Teufel spent several days at Fermilab installing and commissioning the recovery system.

REFERENCES

[1] Fermilab E799 proposal.

[2] H. Harada et al., Nucl. Inst. and Meth. A265(1988)141.

Unpublished gas system documentation including system drawings and specifications.

[3] Pressure and flow monitoring and control hardware supplied by MKS Instruments, Inc., Andover, MA 01810.

[4] Nupro and Cajon valves and fittings supplied by Dearborn Valve & Fitting Co., Wauconda, IL 60084-0847.

[5] Gas Permeability Measurement Facility, to appear as a Fermilab TM.

[6] Ridox R-30 supplied by Fisher Scientific Company Chemical Division.

[7] P. J. Doe et al., Nucl. Inst. and Meth. A258(1987)170.

[8] MG Industries Gas Division, North Branch, NJ 08876.

[9] Spectra Gases, Inc., Irvington, NJ 07111.

LIST OF TABLES

TABLE 1 NOMENCLATURE USED IN FLOW DIAGRAMS

AV1-9	Pneumatically Actuated Automatic Valve
CV1-2	Check Valve
F1-4	Mass Flowmeter
FIL1-7	Particulate Filter
MFC1-2	Mass Flow Controller
NV1-4	Manual Needle Valve
P1-9	Pressure Transducer
PCV	Pressure Control Valve
PREG	Backpressure Regulator
R1-5	Flow Restrictor
PS1-2	Pressure Switch
TK1-9	Tank
V	Manual Valve

Table 2 TRD GAS SYSTEM PRESSURE AND LIMIT ASSIGNMENTS

PDR CH	PDR INPUT	LIMIT (TYPE)	THRESHOLD TORR	THRESHOLD mV	DEAD-BAND mV	LIMIT RELAY	RELAY ON IF:	BURNDY PIN
A1	P1	nP2H(D)	0.200	2000	min	K2	<P2HH	J1-A
A2	P2	nP2L(A)	-0.200	-2000	min	K3	>P2LL	J1-C
A3	P3	P4HH(A)	-100	-100	40	K8	>P4HH	J1-E
A4	P4	P4H(A)	-150	-150	40	K	>P4H	J1-G
A5		P4L(D)	-250	-250	40	K	<P4L	J1-J
B1	P5	P4LL(D)	-300	-300	40	K10	<P4LL	J2-A
B2	P6	nP5H(D)	250	250	min	K4	<P5H	J2-C
B3	P7	nP5L(A)	100	100	min	K5	>P5L	J2-E
B4	P8	P8H(A)	0.100	100	min	K12	>P8H	J2-G
B5								J2-J
Photohelic		nP9L(A)	1 psi			K7	>P9L	J3-A
Oxy. mon.		nxppm(D)	100 ppm			K1	<xppm	J4-A/B
AV gas		nPS1L	75 psi			K13	>PS1L	
Rupture		nPS2H	0.05 "H_2O			K12	<PS2H	J7

Table 3 PNEUMATIC VALVE LOGIC EQUATIONS

LOGIC REQUIREMENT TO OPEN VALVE	RELAY NUMBERS
Z = nxppmO2 * nP2H * nP2L * nP5H * nP5L * nPS2H	K1*K2*K3*K4*K5*K12
AV1 = Z	Z
AV2 = Z	Z
AV3 = Z * P4H	Z*K6
AV4 = Z * P4H * P4HH * nP9L	Z*K6*K7*K11
AV4 (manual) = nP9L	K11
AV5 = Z * P4L	Z*K8
AV6 = Z * nP9L	Z*K11
AV6 (manual) = nP9L	K11
AV7 (manual only) = nP9L	K11
AV8 = Z	Z
AV9 = Z * P4L * P4LL	Z*K8*K9
AV10, AV11, AV12, K15, K16 unused	
AUDIBLE ALARM REQUIRES: Z + K11 + K13	

LIST OF FIGURES

Fig. 1 TRD cross section

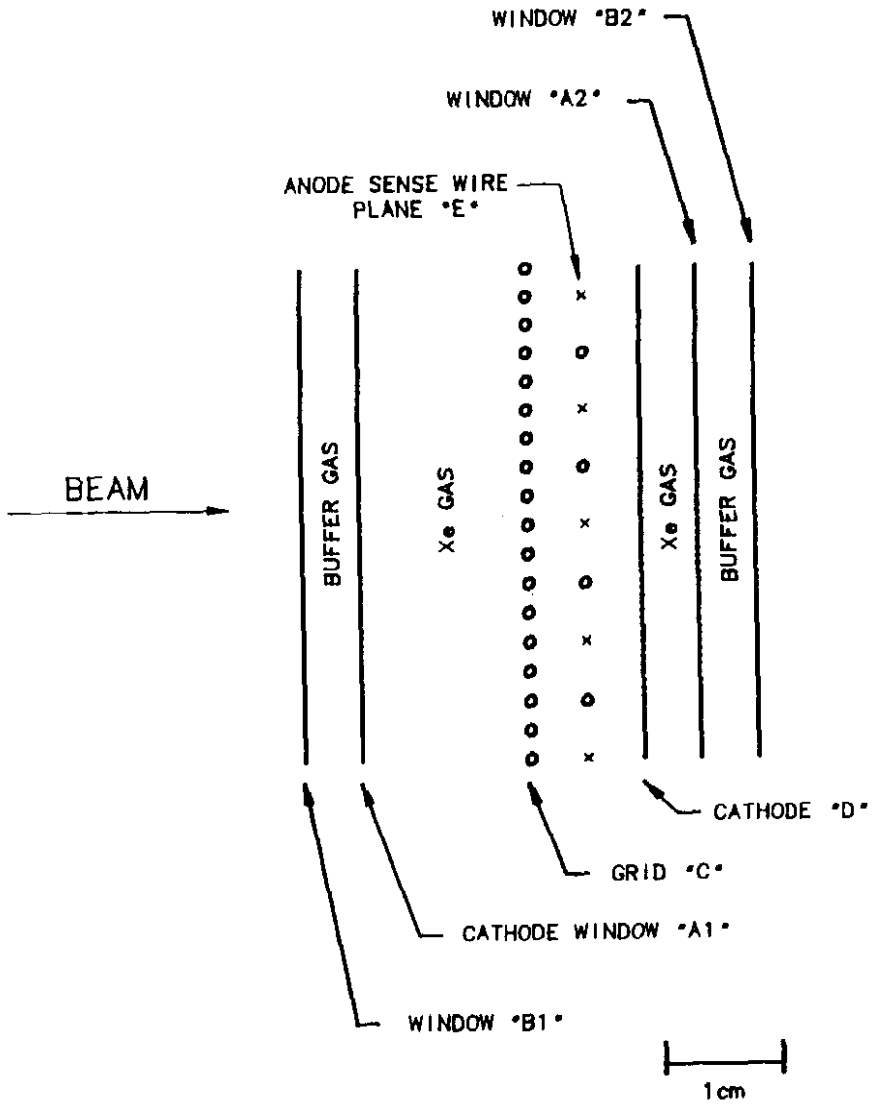


Fig. 2 Mixing module flow diagram

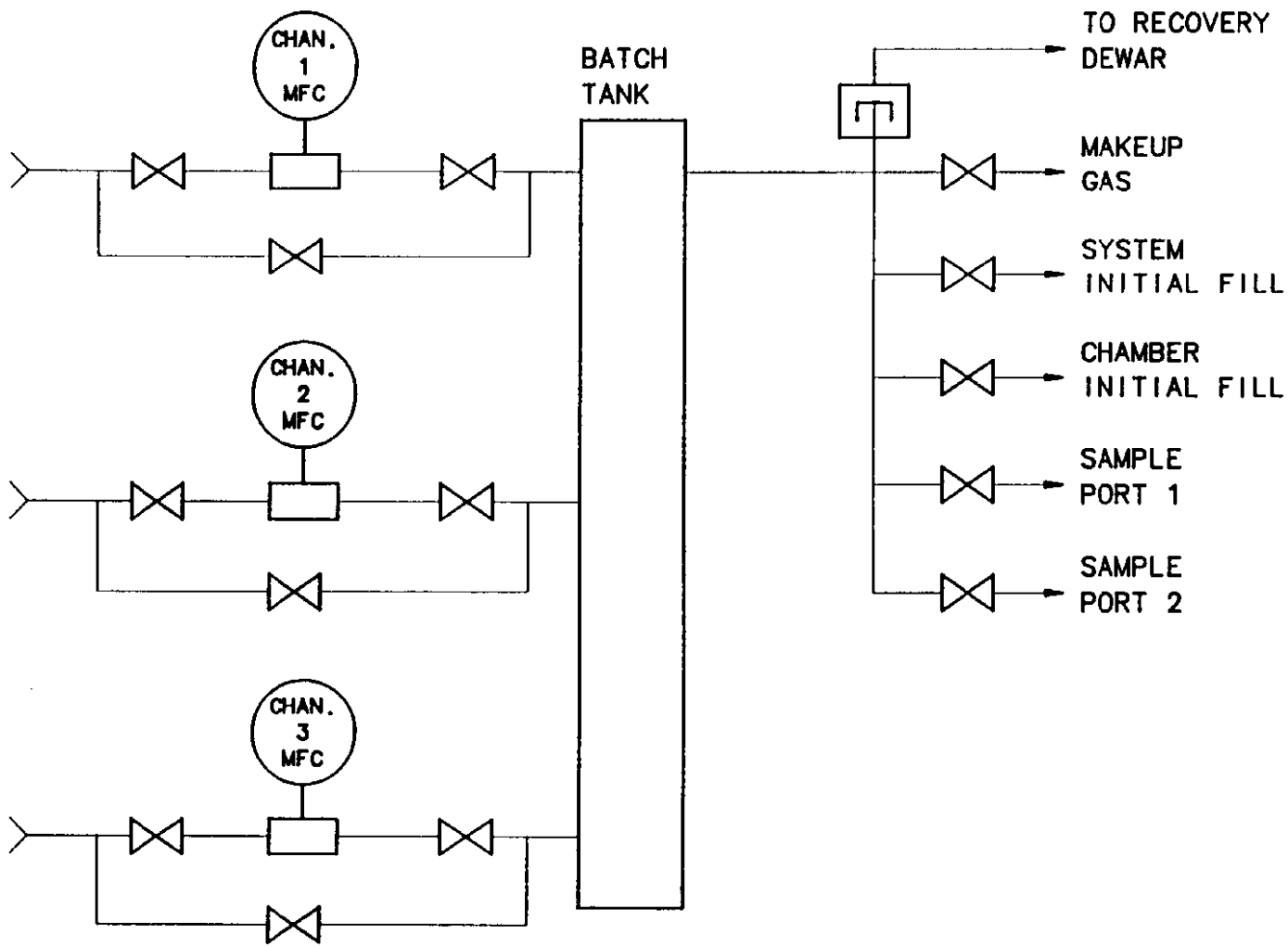


Fig. 3 Master module flow diagram

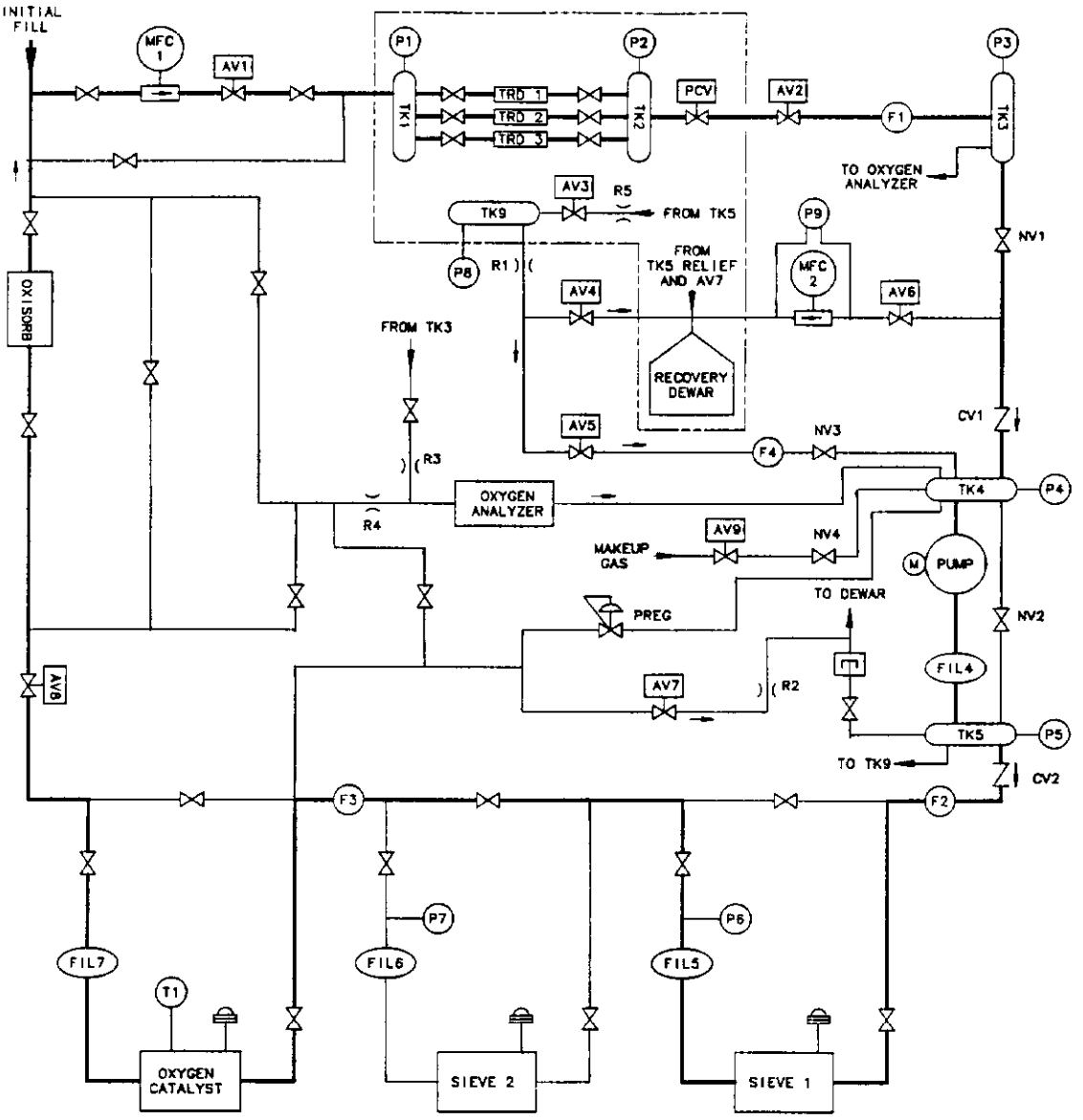


Fig. 4 PUMP DIFFERENTIAL PRESSURE vs. NV2 OPENING for two PREG settings

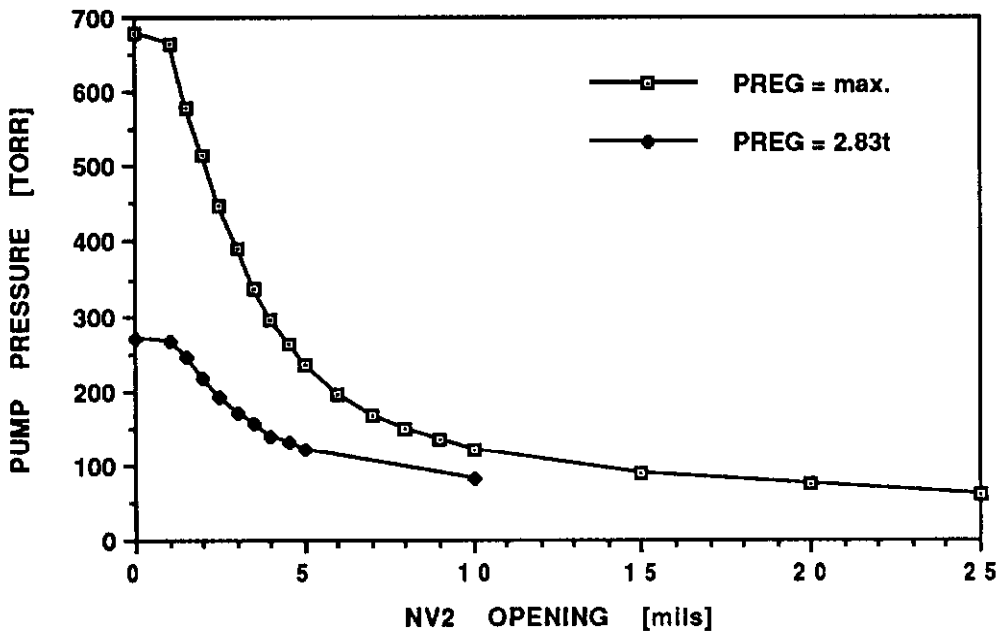


Fig. 5 PUMP DIFFERENTIAL PRESSURE vs. PREG OPENING with NV2 open 2.0 mils

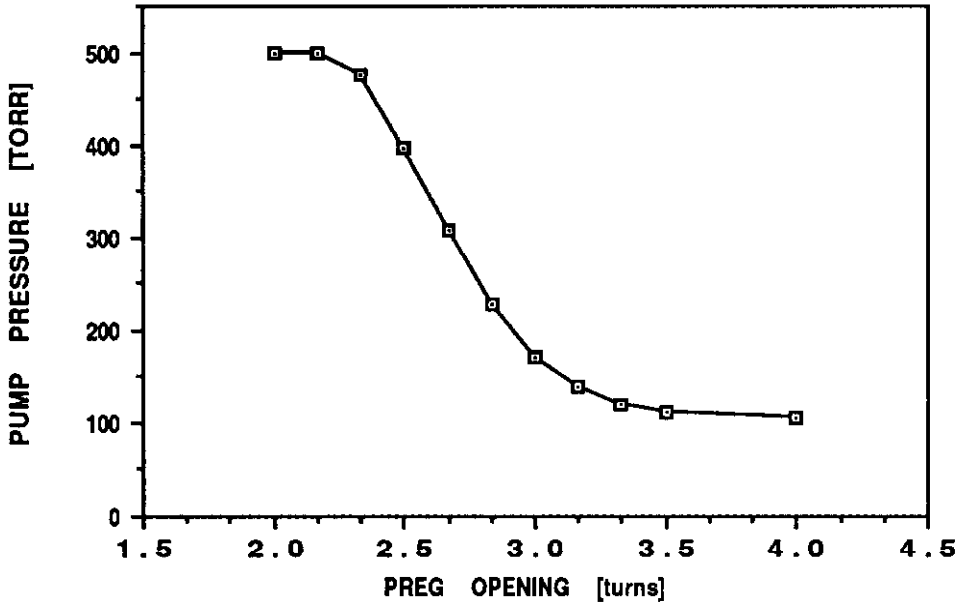


Fig. 6 Oxygen monitor flow diagram

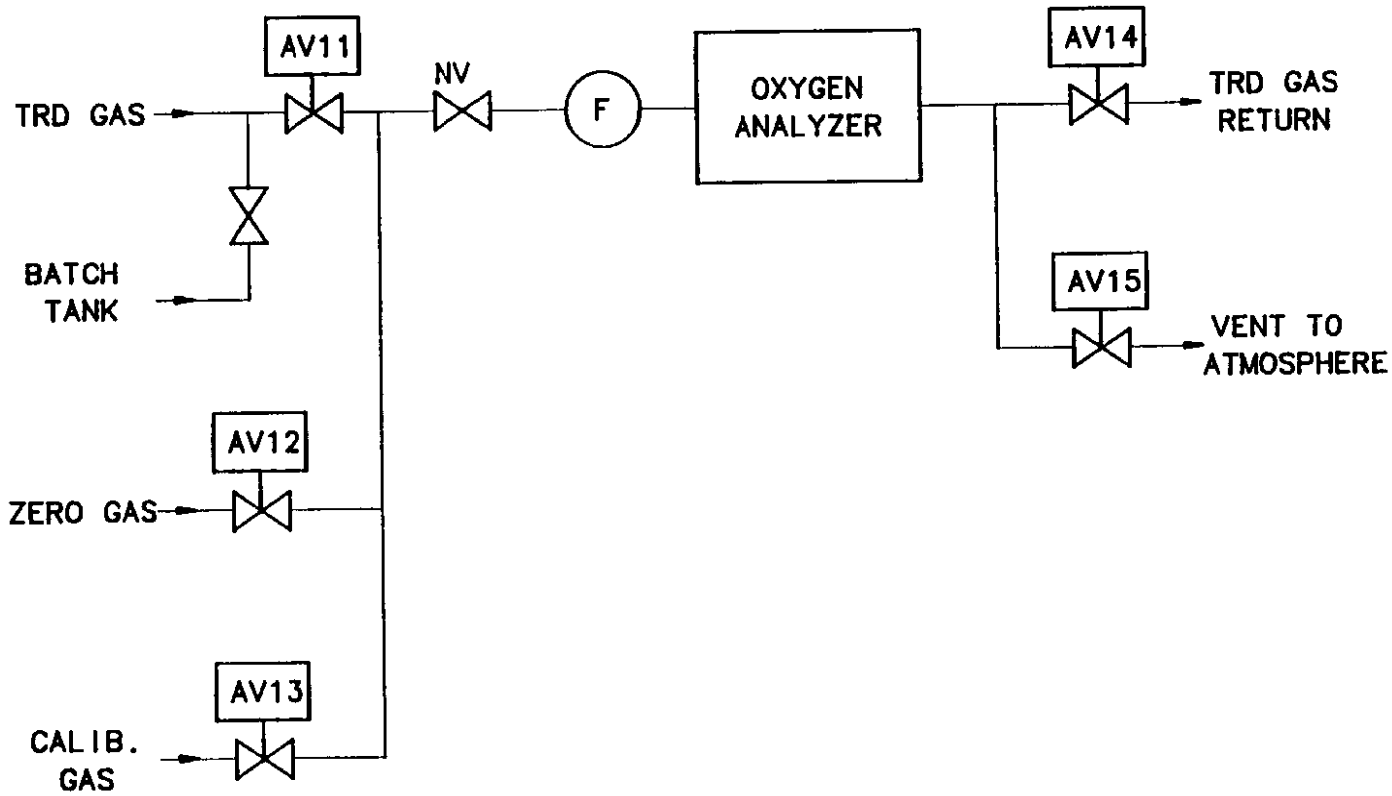
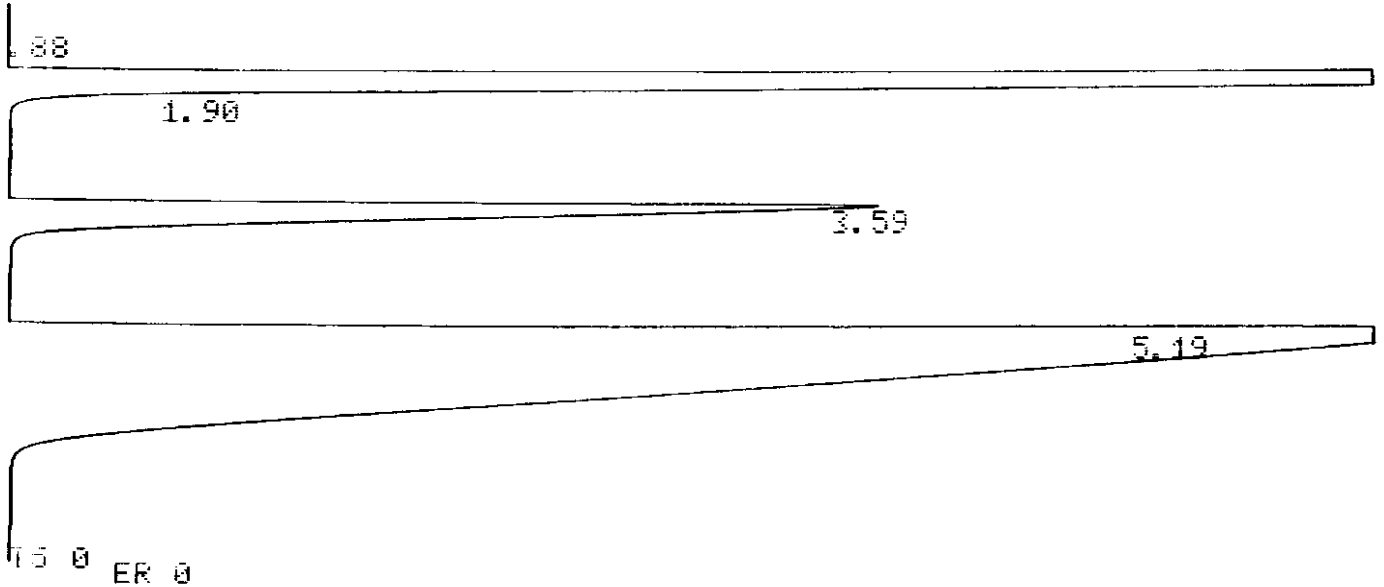


Fig. 7 Reference gas mixture 8/21/90



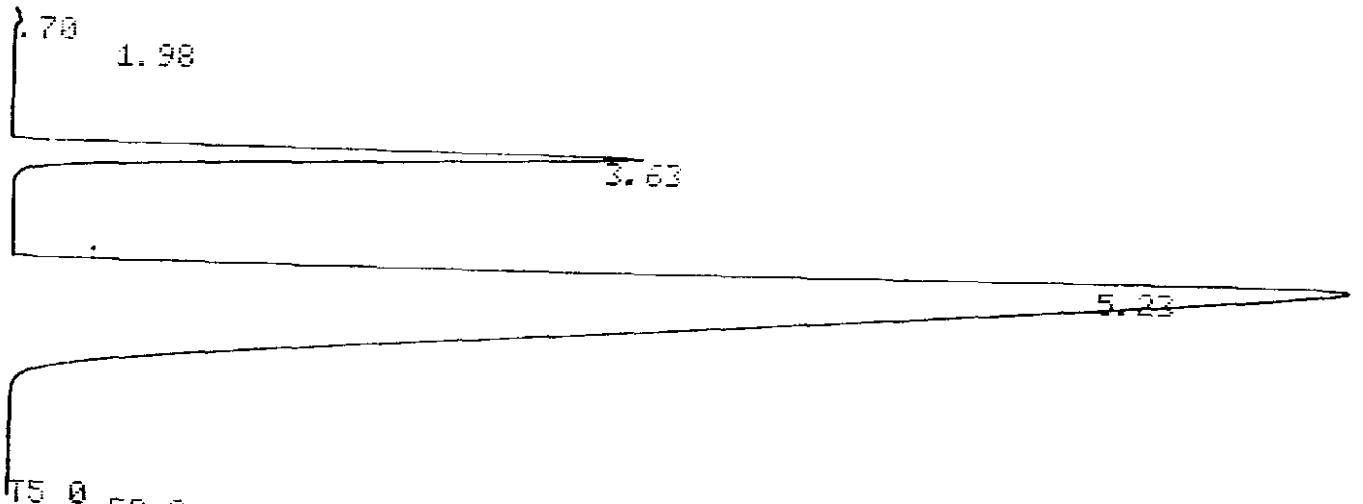
TS 0 ER 0
DATA SAVED TO BIN # 24

XE, AR, CO2 CALIB 08/23/90 09:50:40 CH= "A" PS= 1.

FILE 3. METHOD 1. RUN 11 INDEX 1 CALIB BIN 24

NAME	AREA %	RT	AREA BC	RF	RRT
1	0.	0.88	614 02		0.17
ARGON	40.6	1.9	1986371 03	1.305	0.366
CO2	9.9	3.59	492541 01	1.283	0.692
XENON	49.5	5.19	3159270 01	1.	1.

Fig. 8 TRD gas mixing station output 8/23/90



DATA SAVED TO BIN # 25

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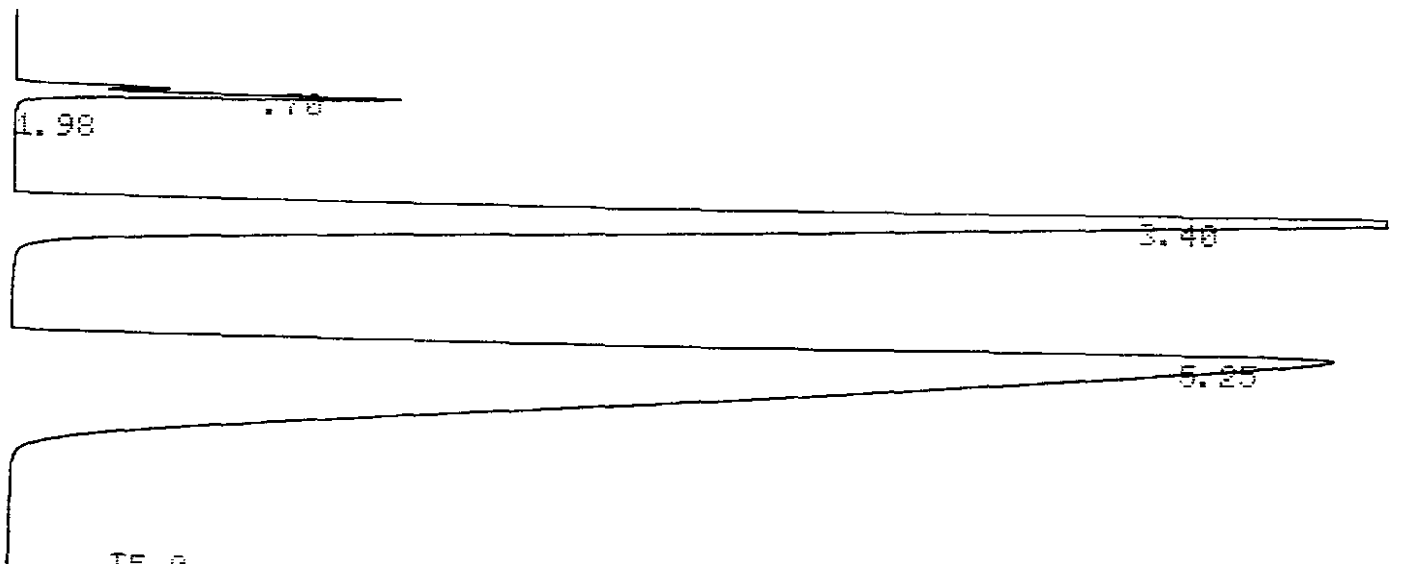
FILE 3. METHOD 1. RUN 12 INDEX 1 BIN 25

NAME	AREA %	RT	AREA BC	RF	RRT
	0.	0.7	758 02		0.134
NITROGEN / ARGON	0.094	1.98	2216 03	1.305	0.379
CO2	12.523	3.63	301813 01	1.283	0.694
XENON	87.383	5.23	2701505 01	1.	1.

Fig. 9 Gas returning from TRD 8/23/90



ER 0 T5 0
DATA SAVED TO BIN # 26

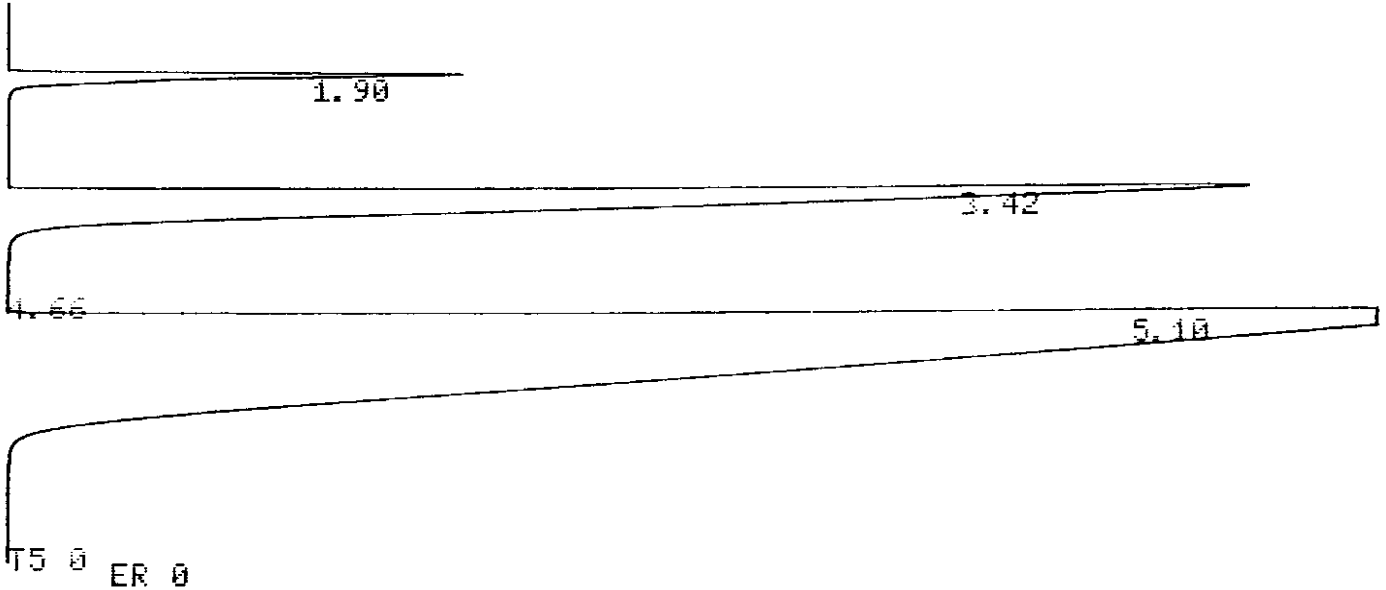
XE, CO2 08/23/90 11:09:29 CH= "A" PS= 1.

FILE 4. METHOD 1. RUN 1 INDEX 1 BIN 26

ANALYST: JG

NAME	AREA %	RT	AREA BC	RF	RRT
	0.	0.7	714 02		0.133
NITROGEN / ARGON	2.937	1.98	98087 03	1.305	0.377
CO2	37.034	3.4	1257831 01	1.283	0.648
XENON	60.029	5.25	2615897 01	1.	1.

Fig. 10 Gas returning from TRD 8/27/90



T5 0 ER 0
DATA SAVED TO BIN # 32

XE, AR, CO2 CALIB 08/27/90 09:30:05 CH= "A" PS= 1.

FILE 3. METHOD 1. RUN 16 INDEX 1 BIN 32

NAME	AREA %	RT	AREA BC	RF	RRT
NITROGEN	3.081	1.9	104271 01	1.306	0.373
CO2	25.206	3.42	870397 01	1.28	0.671
	0.	4.66	155 01		0.914
XENON	71.713	5.1	3170348 01	1.	1.

Fig. 11 Automatic valve logic circuit schematic