Overview of the D-Zero Silicon Detector Purge Air System

Dan Olis

December 28, 2000

D0 Engineering Note
3823.112-EN-539

Approved:____________________Date: 12/28/00

Project Objective
The D-Zero Silicon Detector operates at temperatures well below the maximum ambient dew point maintained by the building's HVAC system. It is critical that moist ambient air be displaced from the detector volume with a dry purge source to prevent the formation of condensate and ice. The purge source is instrument grade compressed air supplied from screw compressors and dried in a desiccant type air dryer. This engineering note documents and describes the design of the fail-safe compressed air system.

System Requirements
The compressed air system must deliver an estimated 50 SCFM of purge air with a dew point below -30°F. The supply must be continuous regardless of power outage, equipment failure, and extreme summer heat and humidity. The purge source is designed to operate in ambient temperatures of 107°F dry bulb and 84°F wet bulb.

The large purge capacity requirement was set to match the expected leak rate of air out of the detector. The air in contact with the detector is dryer (by requirement) and colder (by the cooling effect of the chilled glycol) than D-Zero's ambient air and therefore it is also heavier. Because the detector cannot be perfectly sealed, its dry environment continually leaks out the detector ends.

The leak rate calculation assumes the air inside the detector is perfectly dry and that the D-Zero ambient condition is 107°F dry bulb and 84°F wet bulb. Clearly these are conservative assumptions. Although the collision hall HVAC system will control that environment well, the assembly hall conditions swing largely, particularly because the large overhead door is opened many times a day.

The actual dew point inside the detector depends on the dew point of the purge supply, the dew point of ambient air, and the level of infiltration of ambient air into the detector. The purge air has a nominal dew point temperature of –72F, so the purge supply is practically moisture-less. But infiltration of ambient air is expected and tolerable because the operating temperature of the detector is well above the purge air dew point. As long as the mixture dew point of the purge and infiltration air streams is below the glycol coolant temperature, 14 F, the detector is protected. To allow a large safety factor, the maximum allowable dew point inside the detector has been set to –25 F. Clearly, the purge source will allow the detector to run much colder, as might be required in Run 2b.

System Overview
The system piping and instrumentation schematic (3823.124-ME-386201) is included in the appendix. Two compressors are dedicated as the purge air supply. Each compressor has sufficient capacity for the system so that the second unit stands idle, available for switchover during maintenance or mechanical failure. Hot compressed air discharges from the compressor and passes through a water-cooled aftercooler, condensing out the bulk of water vapor held in the saturated air. The air then passes through a receiver tank, which acts as a buffer volume between the supply and load. The receiver also serves as an air separator, dropping condensate out of the air stream. It is equipped with an automatic drain to discharge the collected water. Downstream of the receiver is the air dryer. It is a dual tower, heated regenerative desiccant type dryer rated to provide a –40F dew point at line pressure. A flow meter after the dryer can be valved in-line to check system demand. The conditioned air then travels to points of use, which currently is the silicon detector purge supply but in the future may include other purge enclosures on the platform.

A closed loop, stand-alone glycol cooling system supplies cooling fluid to the compressors' oil coolers and aftercooler. The cooling system includes circulating pumps, a dry cooling coil which dissipates the heat outdoors, and a trim cooler which uses the house chilled water system as a secondary heat sink for hot days or if the cooling coil is down for any reason.

The compressors, aftercooler, receiver, air dryer, and glycol cooling pumps are located in room 604 on the north side of DAB. The glycol cooling unit is located outside the northwest corner of DAB on the accelerator ring berm. All the equipment and instrumentation are connected to DAB's backup power generator or UPS system (Uninterruptible Power Supply) so that they remain operational during a power failure.

Backup reserve air is stored in a tube trailer on the south side of DAB. The tube trailer serves both the silicon purge system and the cryogenic instrument air system. The trailer will provide a minimum of five hours of reserve. Additionally, if the backup air reserve is depleted, an emergency supply of nitrogen fed from the D-Zero gas shed will provide seven hours of purge to the silicon enclosures (H-disk volumes and the central silicon barrels). The nitrogen source also is triggered in as the purge source in a fire condition.

System Details

Piping System

The main compressed air lines and components are 1" in size. The piping is 1" type K copper while many of the valves and fittings are brass or stainless steel. The compressors supply air at 125 PSI. As the air leaves the piping on the compressor skids, it enters the copper line near 122 PSI. A number of components in room 604 each contribute to pressure losses in the airline:

Aftercooler pressure drop = 4 PSID
Dryer pre-filters pressure drop = 2.5 PSID (clean)
Dryer pressure drop = 3 PSID
Dryer after-filter pressure drop = 0.5 PSID (clean)
Pipe and fittings pressure drop = 4 PSID max. from receiver to room 215.

The system pressure in room 215 is expected to be between 105 and 110 PSIG. There the air is passed through two final filters, regulated down in pressure, and delivered into two parallel 5/8" stainless steel tubing lines, which carry the air down the pipe chase and to the platform. On the platform the air is split into multiple streams and delivered to various positions inside the detector through polyethylene tubing. The polyethylene tubing is bundled inside flame resistant flexible conduit to eliminate flammability concerns. This arrangement is shown on sheet two of the piping schematic included in the appendix.

The final filtration stage in room 215 includes Parker-Balston 2208N-1B1-BX and 2208N-1B1-000 filters. The BX type filter provides 99.99% efficiency of 0.01micron particle removal. It is intended to remove contamination the air may have picked up in piping. The 000 filter cartridge is a charcoal type adsorber, which removes trace oil vapors that may be present in the compressed air. When properly maintained, the compressors discharge about 10 PPM of oil into the compressed air stream. Approximately half of the oil is condensed out of the air in the aftercooler. The dryer and its filters (described below) plus the final filtration described here are estimated at worst to provide 99.999% removal of all oil contamination present in the air stream. So the air delivered into the pipe chase may have as much as 5 PPM x 1/100,000 = 5 parts per 100 billion of oil present.

Compressors

The compressors are mounted on skids originally designed as stand-alone units. Each compressor skid was purchased equipped with an air-cooled oil cooler and aftercooler. Because of the high heat load that the compressors would dump into the room and because the system must survive high ambient temperatures (specified in Silicon TDR), the compressor skids have been converted to allow water/glycol cooling.

At the time of this writing, a water-cooled oil cooler has been installed in series with the existing air-cooled cooler in the oil circuit. The coolers need to be re-piped in parallel to allow 'either/or' use of the coolers. In the current configuration too much heat is entering the room. The piping change needs to be completed by May 2001. With the coolers in parallel, the position of the manual valves upstream of each cooler controls which cooler is in-line. This parallel arrangement is shown in the schematic. Nominally, heat is dumped into the water cooler. When the case oil temperature exceeds some limit, a thermostatic control valve in the case diverts some oil from the compressor into the cooling circuit. The control valve is set to control oil temperature near 180 F.

If the glycol cooling unit is lost for any reason, the compressors can revert back to air cooling. Note though, that the system cannot run continuously on air cooling alone, particularly during warmer months. The high heat load will cause the room temperature to quickly rise above the maximum operating temperature of the compressor (115 F). Also, the air-cooled aftercooler on the compressor skid will not condense out enough water from the air stream to prevent overloading of the air dryer on warmer days. This topic is discussed in more detail later in this note.

The compressors are wired through a selector switch so that only one can run at a time. This provides assurance to electrical personnel that the units draw only their budgeted electric power when on the backup generator and prevents overload of the downstream components that condition the air to instrument grade. A flow switch inserted in the glycol coolant return line of the oil cooler is wired in the starter circuit of each compressor to ensure that the units will not run if coolant is not flowing. (To run compressors on air cooling alone, this flow switch needs to be jumpered out.) The operational status of the compressors is monitored by DAB's DMACS system, which alarms if a compressor shuts down unexpectedly.

A power outage automatic restart feature has been added to the compressors. When power returns after an outage or the backup generator turns on, each compressor will check its status before the power interrupt. If it was running, a warning horn will sound and the compressor will then restart itself.

The table below summarizes some important detail information on the compressors.

Compressors purchased on Fermi PO 508534 from IR Air Center, Elmhurst, IL
Compressors are reconditioned oil cooled, screw type, Ingersoll-Rand model EP25U
25HP, 95 SCFM, 125 PSIG
East Compressor, S/N J3914U92 (upgraded when purchased from 20 to 25HP)
  Running Time as of 10/00: 12950 hrs., 9253 hrs. loaded
West Compressor, S/N J2772U90
  Running Time as of 10/00: 19174 hrs., 10298 hrs. loaded
Maximum operating ambient temperature: 115 F.
Normal operating oil temperature: 170-190 F.
Compressor trips at oil temperature of 228 F.

Aftercooler

An aftercooler is needed on most compressed air systems to remove moisture from the air before it is distributed into the system piping. Compressing ambient air raises its dewpoint to well above typical ambient temperatures. So as hot compressed air cools from compressor discharge temperatures, water vapor will condense out. If water vapor is not forced to condense out in an aftercooler, it will occur downstream in the system piping, resulting in the accumulation of a large amount of water in the system's low spots and the delivery of air/water mixtures to compressed air users. In this system, the aftercooler is critical to properly pre-condition the air for the air dryer so that it is not overloaded with moisture. The aftercooler is an Ingersoll-Rand model WCFB3CA sized for a 5F approach to the coolant temperature: air temp. = glycol temp. + 5 F. It is pitched towards the receiver where the condensate is collected.

Air Receiver Pressure Vessel

The 120-gallon receiver was purchased from Ingersoll-Rand with the compressors. The receiver (vessel number PPD10065) and its relief have been reviewed in D0 Engineering Note 3823.113-EN-537. An automatic drain, Parker model ZLD-10, removes collected condensate from the receiver. The drain operates on 24VDC, consumes no compressed air, and includes failure alarm contacts that are monitored by the DMACS system.

Air Dryer

The air dryer is an Arrow Pneumatics Inc., RE234 externally heated regenerative dryer. The dryer switches between two towers during a cycle; while one tower is drying air, the second tower is regenerating with heated purge air. The RE234 is nominally rated for 150 SCFM at 100 PSIG and 100 F inlet temperature. Since the moisture content of saturated compressed air rises rapidly with temperature, the dryer is 'oversized' to continue to provide dry air on hot summer days.

Two Balston filters (A962-DX and A962-BX) are installed on the inlet of the dryer to provide two-stage filtration to 99.99% of 0.01 micron particles and droplets. The filters coalesce oil and water droplets and include automatic drains to expel the collected fluids. If oil were allowed to enter the air dryer, the adsorption of the desiccant would be greatly reduced. A single Balston A962-DX filter is installed after the air dryer to collect any carry over of desiccant dust from entering the system piping. Both the pre-filters and the after-filter are piped with a bypass to allow changing of the filter cartridges without shutting down the air supply. Pressure differential gages on the filter housings indicate when the cartridges need to be changed.

A spare dryer has been installed in room 215 on the south side of DAB. It serves as a backup dryer to both the silicon detector compressed air system and the cryogenic instrument air system. Nominally the dryer is off-line until required to allow repair of either of the primary dryers serving the above two systems. The RE234 dryer in room 604 is piped so that it can be bypassed but its pre-filters remain on-line to prevent oil contamination of the piping between the primary and spare dryer. The vessels (PPD10063 and PPD10064) on the spare dryer and their relief valves have been reviewed in D0 Engineering Note 3823.113-EN-540.

WARNING

! When the primary dryer is bypassed for repair, it is possible that some water vapor will condense out in the line between the bypassed primary dryer on the north side of the building and the backup dryer on the south side of the building. After the primary dryer is repaired and returned to operation, the backup dryer may need to remain inline for a couple of days to remove any water collected in the piping between dryers.

The dryer consumes 7% of nominal flow capacity for purging the regenerating tower. Since the dryer is 'oversized' for the application, the purge will be set to 7% of the compressor's capacity, or 7 SCFM, not 7% of the 150 SCFM dryer rating. The larger desiccant bed was selected to handle moisture increases in the air stream that may occur on very hot days during power outages (i.e. when the trim cooler on the glycol system is lost). Since the high moisture event is expected to be short lived, the 7 SCFM purge should be adequate to fully regenerate the bed after a cycle or two. More detail of this discussion is included in the failure analyses section.

The exit dew point of the dryer is measured with a hygrometer (HT6227-I) and monitored by the DMACS system. The hygrometer monitors the dew point of the purge air at ambient pressure, or the actual dew point of the delivered air. An alarm will sound if the exit dew point climbs above –60 F. The alarm condition notifies the operator that dryer performance is deteriorating either as a result of moisture overload or the need for maintenance. To protect silicon from a purge with a high dew point, an interlock on this device trips when the dew point climbs above –34 F. This interlock shuts a valve on the air supply from the dryers, causing emergency backup air to flow from tube trailers located in the lot south of DAB. The interlock also begins to warm the silicon detector to minimize the possibility of condensation on the detector.

The dryer also includes a failure to shift alarm, failure to depressurize alarm, and failure to purge alarm that will be tied together and monitored on a single discrete input to the DMACS system.

The table below summarizes some important detail information on the air dryer.

Arrow Pneumatics Inc, heated regenerative air dryer, Model RE234
Purchased on PO 531431
Dryer rated for 150 SCFM, 100 PSIG, 100 F
At 94 SCFM, 125 PSIG, estimated bed overload inlet temperature is 112 F
Dryer requires a nominal purge of 7% of inlet flow, 7 SCFM
Dryer towers have pressure vessel numbers PPD10070 and PPD10071
The vessels and relief valves have been reviewed in D0 Engineering Note 3823.113-EN-538

<u>Glycol Cooling System</u>

Cooling for the air compressors and aftercooler is supplied from a stand-alone glycol cooling system. The system was purchased from Thermotech Corporation. (Thermotech formerly Thermal Precision, manufacturer of the glycol unit on the cryogenic instrument air system, Ref. D0 Engineering Note 3740.510.EN-203). The glycol system includes a pump skid, dry cooling unit, and trim cooler. The pump skid includes dual circulating pumps, a glycol expansion/fill tank, and an electrical and instrumentation panel. The second pump is redundant and automatically turns on with a failure of the lead pump. The expansion tank includes a sight glass and pressure relief valve. The dry cooling unit is located outside DAB's northwest corner on the ring berm. It dissipates heat to the atmosphere with two thermostatically controlled fans mounted above a finned tube heat exchanger.

When dissipating heat through a closed loop cooling system, it is important to 'tune' the system for proper operation. To understand the 'tuning' of the system, it is critical to realize that the glycol loop is not only meant to dissipate a certain amount of heat but that it also is required to keep the oil in the compressor from running too hot. If the glycol temperature rises too high, the oil in the compressors will also become hot. When improperly tuned the cooling loop is still dissipating the full heat load of the compressor, yet the compressor may still trip off on a high temperature limit. Often times an operator will mistakenly assume that since the compressor is running hot, it requires more coolant flow to the oil cooler. In fact though, increasing flow to the cooler worsens the problem. For example, if the glycol cooling unit is dissipating 25 HP of heat outside at some coolant flow rate, the glycol may experience a temperature change of 8 F as it travels through the cooling unit. Now if the flow rate is increased by a factor of two, the cooling unit may still dissipate 25 HP of heat outdoors but the temperature change of the fluid through the cooler is now only 4 F. So as coolant flow rates increase, the temperature of the fluid coming from the glycol cooling unit also increases. Higher coolant temperatures can then result in higher oil temperatures.

To properly tune the glycol cooling system, coolant flow through the oil cooler is throttled to achieve a temperature rise in the glycol of 10 to 20 F across the oil cooler. (Note though, that over-throttling the flow of the glycol will cause a flow switch in the glycol loop to trip off the re-circulating pumps on a low-flow condition.) The tuning valve is on the coolant discharge line from the oil cooler. Once its position is set, the valve handle will be removed so that the adjustment is not lost. The valve on the inlet to the cooler is the on/off control used when switching between compressors. Coolant flow to the aftercooler should also be throttled to accomplish a 10-20 F rise in the glycol.

The trim cooler assists the dry cooling unit when ambient temperatures climb above 85 F. The thermostatic control valve on the chilled water supply to the trim cooler is set to 90 F.

The table below summarizes some important detail information on the glycol system.

Glycol system purchased from Thermotech Corporation (manufacturer), Buffalo, NY
Purchased on PO 531657
Dry cooler sized for 5 F approach to ambient (glycol temp. = ambient temp. + 5 F)
Pumps: (2), 1 HP, second is redundant, 8 GPM nominal, Goulds NPE, 1 x 1 ¼ - 6" impeller
Fans: (2), ½ HP, thermostatically controlled
Fan 1 operates with glycol temperature >/= 72 F
Fan 2 operates with glycol temperature >/= 81 F
Trim Cooler: type 04036 with thermostatic control valve, 1 to 1 flow
Ethylene Glycol, 40% by weight

<u>Reserve Air and Emergency Nitrogen</u>

A tube trailer on the south side of DAB is charged with dry instrument air to serve as a backup air source to both the cryogenic instrument air system and the silicon purge air system. The trailer is connected to both compressed air systems through a regulator which is set to 80 PSIG. If the header pressure in either system falls to 80 PSI, backup air is bled in through the regulator. The trailer has a 334 FT^3 capacity and an MAWP of 2500 PSI. Nominally the trailer is pressurized to 1700 PSI. Assuming the trailer is 'empty' at 180 PSI (i.e. 100 PSID across the regulator), it provides 34,500 FT^3 of reserve air at standard temperature and pressure (STP). The nominal capacity required on each compressed air system is 50 SCFM. If both systems simultaneously require backup air (e.g. failure of emergency generator during a power outage), the tube trailer provides 5.8 hours of reserve. If one system is down, backup air provides more than 11 hours to remedy the failure.

In case of a fire, the purge air system can be shut down so that the purge source does not fan the flames. If the operator believes the detector is on fire, a crash button in the control room will shut off air flow. For this situation, emergency nitrogen gas bottles in the gas shed are tied into the silicon purge lines through a regulator. To eliminate ODH risks and limit the required number of emergency bottles to a reasonable number, nitrogen is fed only to the enclosures immediately surrounding the silicon. It will not flow into the volume inside the fiber tracker that surrounds the silicon enclosures, which normally accounts for 80% of the purge flow.

The P&I schematic shows that the nitrogen source is fed into the system down on the detector platform. (Refer to sheet 2 of the P&I schematic.) A regulator holds the nitrogen supply pressure just below the platform's nominal purge header pressure. If air supply is intentionally shutdown for fire or lost because of system failures, nitrogen gas is automatically fed into the platform header.

Two flow switches on the platform header detect a loss of air flow. Therefore a 'no-flow' condition on both switches indicates that nitrogen has become the purge gas. An interlock on these flow switches begins an emergency warm-up of the silicon detector so that the detector's temperature is above the ambient dew point temperature before the nitrogen supply is depleted. With an estimate of 10 SCFM to the enclosures, sixteen nitrogen bottles will provide almost 7 hours of purge.

Failure Analysis and System Response

A discussion of the failure analyses will flesh out many of the system design decisions. The system must withstand the following possible failure scenarios:

1. Power failure
2. Very hot day + power failure
3. Mechanical failure

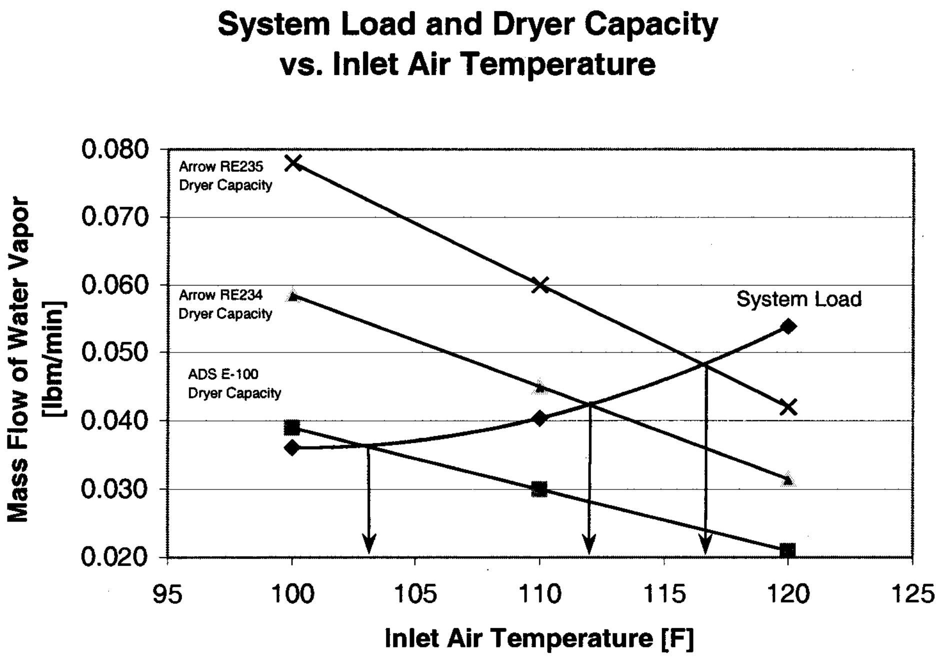
Failure Analysis 1 – Power Failure

Because the system is tied into UPS and the backup power generator, all components and instrumentation will remain operational during a power outage with one exception. The trim cooler on the glycol cooling loop uses DAB's chilled water system to remove excess heat from the glycol that has not been dissipated in the dry cooler. During a power failure, the chilled water system is lost. The trim cooler, though, is not necessary for system operation. It only provides an additional margin of cooling for very hot days and acts as a backup heat sink to the glycol system if the dry cooler were to fail. Both of these scenarios are further discussed below.

Failure Analysis 2 - Hot Day and Power Failure

The typical dew points of air exiting the compressor fall between 120 and 156 F at 125 PSIG. The compressor discharge air temperature is normally near 190 F. So as air cools in the aftercooler and piping from 190 F to near ambient temperatures, water will condense out. The remaining air/water vapor mixture is saturated. The job of the air dryer is to further remove water vapor from the air stream. Aluminum oxide desiccant bed type dryers like the Arrow RE234 are rated to dry air to a dew point of –40 F at line pressure. Dryer manufacturers typically rate their units for 100 PSIG supply pressure, 100 F inlet temperature, and some nominal flow capacity. In our application, the flow capacity is 94 SCFM and the pressure is 125 PSIG. The compressed air temperature entering the dryer is a function of the ambient temperature, glycol cooling unit performance, and size of the aftercooler. Fixing the dryer inlet temperature is important since the variable is a double-edged sword: 1) the moisture content of saturated air increases drastically with temperature; 2) the desiccant adsorption capacity decreases drastically with temperature.

Below is a graph that shows the moisture content of the air stream at 94 SCFM and 125 PSIG as a function of temperature. Also plotted is the maximum flow rate of water vapor as a function of bed temperature that various dryer models can adsorb during a complete cycle before they are overloaded. The intersection of the dryer capacity curve with the compressed air moisture load curve shows the maximum inlet temperature a dryer model can accept before overload. The Arrow RE234 dryer was selected for the silicon compressed air system. The graph shows that the RE234 dryer will overload when inlet temperature exceeds 112 F.



The ADS E-100 is the model of dryer installed on the cryogenic instrument air system. A surplus dryer of the same model was on hand at DAB during the assembly of the silicon detector purge system but it was not used because of its lower moisture capacity. The graph shows an ADS E-100 dryer will overload with air inlet temperatures exceeding 103 F. The surplus ADS E-100 dryer has instead been installed in the system to serve as the backup dryer. While the RE235 dryer will handle inlet temperatures to 117 F, the additional cost and size of the unit over-ruled such excessive conservativeness.

The rated capacity plots were constructed by first calculating the flow rate of water into the dryer at the dryer's advertised rating. For example, the RE234 is rated to handle 150 SCFM at 100 PSIG and 100 F. So the mass flow rate of water into the bed is calculated as:

$$\dot{m}_{water} = \dot{m}_{air}\,\omega \quad \text{where } \omega = humidityratio, \left[\frac{lbm_{water}}{lbm_{air}}\right]$$

$$\omega = 0.622\frac{p_{v,sat}}{p - p_{v,sat}}$$

$p_{v,sat}$ = saturated partial pressure of water vapor and p = absolute pressure.

For T = 100 F, $p_{v,sat}$ = .9503 psia (from steam tables), the humidity ratio is calculated as:

$$\omega = 0.622\frac{.9503}{100+14.7-.9503} = .00520\frac{lbm_{water}}{lbm_{air}}$$

Using the density of air at standard temperature and pressure (STP) as .075 lbm/ft^3, the rated water mass flow into the RE234 dryer bed is:

$$\dot{m}_{water} = 150\frac{ft^3 \text{ @ } STP}{\min}\times .075\frac{lbm_{air}}{ft^3 \text{ @ } STP}\times .00520\frac{lbm_{water}}{lbm_{air}} = .0585\frac{lbm_{water}}{\min}$$

This mass flow rate is plotted for the RE234 at 100 F inlet temperature.

The following discussion describes how the dryer capacities were calculated at higher inlet temperatures. Knowing the weight of desiccant in each tower and the dryer cycle time, it is calculated that the beds are nominally rated to take on 13% moisture by weight at 100 F. In *Gas Purification*, Kohl and Riesenfeld describe that percent moisture adsorption of desiccant decreases with an increase in bed temperature. Arrow Pneumatics was unable to provide any technical information or advice on appropriate de-rating of dryer performance with increasing temperature. A technical expert at Alcoa, the manufacturer of the desiccant, did stress that it is important to consider bed temperature when sizing dryers. He provided the following de-rating rules-of-thumb from his own experience; a bed that will nominally hold 13% by weight of moisture at 100 F, will adsorb 10% moisture at 110 F and 7% moisture at 120 F. His suggested de-rating formula is slightly more conservative than de-rating data provided in Kohl and Riesenfeld for desiccant in equilibrium. But since air drying is a dynamic process, the more conservative scheme was adopted. From this, the dryer capacity versus air inlet temperature curve was constructed. The moisture load curve of the system was generated using the same formulas described above at P=125 PSIG, 94 SCFM (maximum output of compressor), and 100 F, 110 F, and 120 F.

During a power failure, the DAB chilled water system is lost so that the glycol trim cooler provides no assistance to cooling the glycol. Without a functional trim cooler, the ambient temperature, the size of the glycol dry cooler, and the size of the air aftercooler determine the air temperature at the dryer inlet. The dry cooler on the glycol system is sized to provide a maximum 5 F approach to ambient temperature: $T_{glycol} = T_{ambient} + 5$ F. The aftercooler is also sized to cool compressed air to a 5 F approach to the glycol temperature: $T_{air} = T_{glycol} + 5$ F. Therefore the dryer air inlet temperature is expected to be 10 F above ambient temperature during a power failure. The intersection of the system load and dryer performance curves show that the RE234 dryer will overload at 112 F. Therefore the system will remain failsafe with ambient temperatures as high as 102 F occurring during a power failure.

With 112 F inlet temperature (102 F ambient) to the RE234 dryer, the desiccant bed will just be able to adsorb enough moisture throughout the four hour cycle to deliver –40 F dew point in the exiting air stream. If the inlet temperature were to rise above 112 F, the bed will experience 'breakthrough' at some point during the four hour drying cycle. After breakthrough the bed will continue to adsorb moisture, but the delivered dew points will begin to climb. The rate of increase of the exit dew point is difficult to predict. Air dryer manufacturers simply design systems large enough so that breakthrough never occurs. If the ambient temperature climbs to the Silicon Detector TDR's worst case of 107 F, the dryer is calculated to experience breakthrough after 2.9 hours. If the drying cycle shifts towers before 2.9 hours of 107 F ambient temperature has elapsed, the time to breakthrough would reset again to 2.9 hours. For example, if the ambient temperature is 107 F and the power is lost with one hour remaining in the drying time of the left tower, the air dryer would shift the drying bed to the right tower before the left tower experiences breakthrough. Now with air flowing into the right tower at 107 + 10 = 117 F, the right tower will experience breakthrough after 2.9 hours of drying. So breakthrough would not occur until after a total of 3.9 hours of 107 F ambient temperature had elapsed.

The dryer is rated to provide a dewpoint temperature of –40 F at the line pressure. Since the dewpoint of a gas sample will decrease with the sample's pressure, the actual dew point of the purge air as it is delivered into the detector at ambient pressure is much lower. When throttled from 115 PSIG down to ambient pressure, the dewpoint of the purge air will drop from –40 F to –72 F. The purge line hygrometer (HT6227-I) measures the purge dew point at ambient pressure. So the nominal reading on this device when the dryer is operating to specification is –72 F. The requirement of the system is to deliver a constant purge stream to the detector with –30 F maximum dew point. A dew point of –30 F at ambient pressure correlates to a dryer exit dew point of +10 F at 115 PSIG. So there is a large cushion between the nominal dew point of the delivered purge air and the maximum allowable dew point inside the detector.

To summarize, an ambient temperature of 107 F occurring at the same time as a power failure does not result in an immediate threat to the silicon detector. Breakthrough on the dryer is predicted to occur only if the event lasts for 3 hours or more. Additionally, the exit dew point of the dryer may rise as high as +10 F before the dew point of the delivered purge air rises above the acceptable limit of -30 F. Interlock protection is triggered if this condition is reached. The interlock protections are discussed in the next section of this document.

Failure Analysis 3 – Mechanical Failure

Mechanical failure of system components causes a response of system alarms and interlock protections. The step-by-step response of the system and final result to different component failures is summarized below.

Compressor Failure

1. DMACS system alarms on unexpected compressor shutdown
2. Interlock flow switch FS6205-I senses loss of air flow and shuts down refrigeration compressor on silicon chilled glycol system so detector begins to slowly warm.
3. Purge supply header pressure falls to 80 PSIG. Backup tube trailer feeds in reserve air through PRV745-I maintaining header pressure at 80 PSIG.
4. Operator restarts failed compressor or switches over to second compressor.

   Result: Problem resolved before (5) hours of backup air is depleted, or

5. Backup air supply is depleted if compressor down for more than (5) hours.
6. FS6305-I and FS6307-I on platform sense loss of air flow. Interlock on these devices begins 'Emergency Warm-up' of detector.
7. Emergency supply of nitrogen is fed to platform header through PRV6291-GN

   Result: Problem resolved or detector is warm before (7) hours of emergency nitrogen are depleted.

Automatic Drain Failure

1. Water will begin to accumulate in air receiver.
2. Automatic Drain will alarm on failure or automatic drain failure is discovered in daily preventative maintenance checks.
3. Receiver will be manually drained until automatic drain is repaired/replaced.

   Result: Failure of drain will be found before enough condensation accumulates in receiver to spill over into air dryer.

Air Dryer

A. Failure to shift, purge, pressurize/depressurize

1. DMACS system alarms.
2. Operator resolves alarm condition or switches over to backup air dryer.

   Result: Failure is resolved before interlock protection is required.

B. Runaway Purge Heater

1. DMACS system alarms on heater over-temperature condition.

2. Operator resolves alarm condition or switches over to backup air dryer.

   Result: Failure is resolved before interlock protection is required.

C. Insufficient Dew Point Suppression

1. DMACS system alarms on rising dew point at –60 F measured on hygrometer HT6227-I.
2. Operator resolves alarm or switches over to backup air dryer.

   Result: Failure is resolved before interlock protection is required, or

3. If unresolved and dew point continues to rise, interlock on hygrometer HT6227-I trips at –34 F, shuts off flow from air dryer by EV6206-I.
4. Interlock flow switch FS6205-I senses loss of air flow and shuts down refrigeration compressor on silicon chilled glycol system and detector begins to slowly warm.
5. Purge supply header pressure falls to 80 PSIG. Backup tube trailer feeds in reserve air through PRV745-I maintaining header pressure at 80 PSIG.

   Result: Problem resolved before (5) hours of backup air is depleted, or

6. Backup air supply is depleted if compressor down for more than (5) hours.
7. FS6305-I and FS6307-I on platform sense loss of air flow. Interlock on these devices begins 'Emergency Warm-up' of detector.
8. Emergency supply of nitrogen is fed to platform header through PRV6291-GN.

   Result: Problem resolved or detector is warm before (7) hours of emergency nitrogen are depleted.

Glycol Cooling System

A. Glycol Pump Failure

1. Flow switch FS6130-GL on pump skid senses loss of flow, secondary pump automatically starts.
2. Temporary loss of coolant flow to compressor will cause 'no flow' condition on FS6173-GL on east compressor or FS6183-GL on west compressor and trip operating compressor
3. DMACS will alarm on unexpected compressor shutdown
4. Interlock flow switch FS6205-I on purge supply header senses loss of air flow and shuts down refrigeration compressor on silicon chilled glycol system and detector begins to slowly warm.
5. Purge supply header pressure falls to 80 PSIG. Backup tube trailer feeds in reserve air through PRV745-I maintaining header pressure at 80 PSIG.
6. Operator will reset compressor and notify maintenance of need for repair on lead glycol circulation pump.

   Result: Compressor operation disrupted. Problem resolved before (5) hours of backup air is depleted, or

7. Backup air supply is depleted if compressor down for more than (5) hours.
8. FS6305-I and FS6307-I on platform sense loss of air flow. Interlock on these devices begins 'Emergency Warm-up' of detector.
9. Emergency supply of nitrogen is fed to platform header through PRV6291-GN

   Result: Problem resolved or detector is warm before (7) hours of emergency nitrogen are depleted.

B. Glycol Cooling Unit Fan Failure

1. Temperature sensor TT6151-GL senses high temperature of glycol and turns on second fan.
2. If single fan does not dissipate enough heat, trim cooler HX6156-GL cools fluid to 90 F.
3. Weekly preventative maintenance checks will discover single fan failures.

   Result: Glycol system operates uninterrupted.

C. Other Failure - Total loss of cooling
1. Compressor will trip off on high oil temperature or loss of flow to FS6173-GL on east compressor or FS6183-GL on west compressor.
2. DMACS will alarm on unexpected compressor shutdown.
3. Interlock flow switch FS6205-I senses loss of air flow and shuts down refrigeration compressor on silicon chilled glycol system and detector begins to slowly warm.
4. Purge supply header pressure falls to 80 PSIG. Backup tube trailer feeds in reserve air through PRV745-I maintaining header pressure at 80 PSIG.
5. Operator will reset manual valves on compressor skid to utilize air-cooled oil cooler (HX6017-OIL on east unit/HX6037-OIL on west unit) and aftercooler (HX6007-I on east unit/HX6027-I on west unit). Operator will jumper out FS6173-GL on east compressor or FS6183-GL on west compressor to allow compressor operation without glycol flow.

   Result: Compressor operation disrupted. Problem resolved before (5) hours of backup air is depleted, or

10. Backup air supply is depleted if compressor down for more than (5) hours.
11. FS6305-I and FS6307-I on platform sense loss of air flow. Interlock on these devices begins 'Emergency Warm-up' of detector.
12. Emergency supply of nitrogen is fed to platform header through PRV6291-GN

    Result: Problem resolved or detector is warm before (7) hours of emergency nitrogen are depleted.

Possible Future Work Required on System

Since the backup air is stored at high pressure, it experiences a considerable temperature drop when delivered into the supply header due to the Joule-Thompson effect across the regulator. A test of this effect shows that the temperature of the air fed into the header is quite cold but that natural convection of heat into the piping is significant enough to eliminate much of the concern. If it is determined that the air supply is still too cold, additional heat transfer into the backup air stream will be required.

Here is a summary of the test and results:

A combined flow rate of 55 SCFM was set on FI6310-I and FI6320-I on the detector platform.
The inlet pressure into the backup supply regulator (PRV751-I) was 1400 PSIG.
The delivery pressure out of the regulator was 80 PSIG.
After flowing air from the backup supply for 40 minutes, the following pipe temperatures were recorded:

$T_{outdoors} = 33$ F
$T_{intoReg.} = 45$ F
$T_{outReg.} = 25$ F
$T_{platform} = 64$ F

For 1400 PSIG to 80 PSIG expansion, the refrigeration table for air (R729) indicates the air should experience a temperature drop of 36 F for isenthalpic expansion. The data shows that the actual temperature drop across the regulator was 20 F. During the air's travel time through the pipe to the platform, it reheated back to 64 F. This is equivalent to a 700 Watt heat input.

The estimated surface area of the pipe OD between PRV751-I and the header on the platform is 4.7 m^2. The test then indicates a 6.8 W/m^2-K natural convection coefficient. Also, as a heat exchanger the piping network has the following overall $UA = q/\Delta T_{LM} = 700$ W/ 7.3 K = 96 W/K.