S-AA-M-12

OMEGA
System Operations Manual
Volume I–System Description

Chapter 12: Target Chamber–Tritium Removal System Description

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Chapter 12
Target Chamber–Tritium Removal System

12.1 INTRODUCTION

The OMEGA laser at the University of Rochester's Laboratory for Laser Energetics (UR/LLE) has been upgraded to conduct direct-drive laser implosion campaigns using ICF targets containing cryogenic solid deuterium–tritium (DT) ice layers. These campaigns are an important step in the U.S. effort to achieve ignition of DT and energy gain on the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory using targets containing cryogenic solid DT fuel.

Cryogenic targets are positioned at the center of the OMEGA target chamber by the Cryogenic Target Handling System (CTHS). The CTHS is described in detail in *Volume IV—Cryogenic Target Handling System (S-AA-M-3 1)*. The target chamber (TC) is a 530-ft^3 spherical chamber that provides the vacuum environment for laser shots and associated diagnostics. The ambient target positioner and approximately ten of the target diagnostics have vacuum volumes that can be isolated from the TC and vented and pumped separately. The six ten-inch manipulators (TIM's) are typical of these volumes.

Shots involving room-temperature DT targets release approximately 20 mCi and cryogenic targets will release approximately 400 mCi. The Target Chamber-Tritium Removal System (TC-TRS) provides the tritium handling capability needed to deal with this significant increase and allows cryogenic DT operations to be conducted on a routine basis. Figure 12.1-1 shows the target chamber and the major elements of the CTHS. The TC-TRS appears on the right.

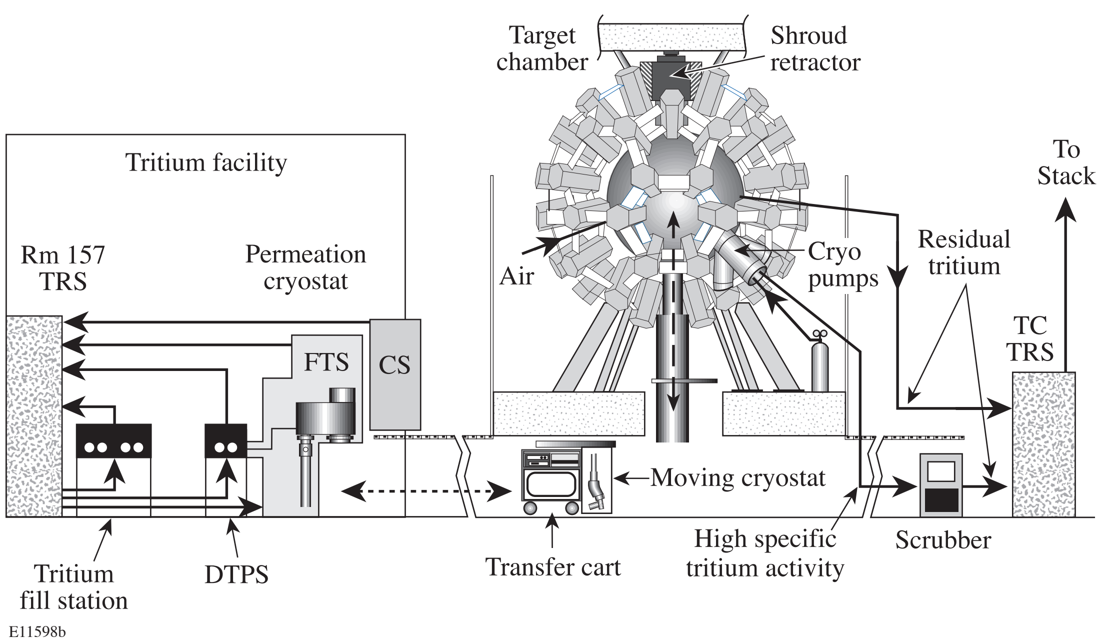

Figure 12.1-1
The Cryogenic Target Handling System (CTHS) includes target preparation subsystems located in the Room 157 Tritium Facility, the Moving Cryostat Transfer Cart, and equipment installed on the target chamber. The Target Chamber Tritium Recover System (TC-TRS) is on the right.

The TC-TRS is a gas-processing system that removes tritium by catalytically oxidizing DT and hydrocarbons to produce HTO or DTO and CO_2. The DTO is then adsorbed by molecular sieve drier beds and is periodically recovered by regenerating the driers and condensing the water vapor in a holding tank. This tritium removal technology has been successfully used in industry for many years.

12.1.1 Process Overview

As is shown in Fig. 12.1-1, gas streams can enter the TC-TRS from the discharge side of the tritium scrubber and from the OMEGA mechanical vacuum pump discharge manifold. The gas streams processed by the TC-TRS are generated in three ways:

(1) Cryopump Regeneration—The target chamber cryopumps capture most of the DT that is released into the TC. This DT is transferred to the scrubber system when the cryopumps are regenerated into the tritium scrubber. The effluent that leaves the scrubber enters the TC-TRS for finial cleanup.

(2) Pump-down of Contaminated Volumes—Tritium that is not captured by the cryopumps is adsorbed onto the interior surfaces of the target chamber and auxiliary volumes such as the TIM's. When these volumes are pumped out after having been vented to atmospheric pressure, some of this tritium becomes part of the exhaust stream from the mechanical roughing and backing pumps that is routed to the TC-TRS.

(3) Purge/Decontamination of Contaminated Volumes—The TC-TRS is also used to implement atmospheric pressure purges the of the vacuum volumes to reduce the tritium contamination levels to acceptable levels. The mechanical vaccum pumps are bypassed for these operations. This process is described in more detail in Sec. 12.1.3.

The cryopump regeneration and target area roughing and backing circuits are shown in more detail in Fig. 12.1-2 along with a simplified schematic of the TC-TRS. In normal operation, the effluents from the OMEGA sources are pumped into the TC-TRS by the TC-TRS blower. (The TC-TRS bypass is only used for special situations.) The blower discharge flows into the regenerative heat exchanger and is heated by the catalytic reactor outlet gas. The incoming gas then flows to the preheater, where it is heated to 515°C. The gas then flows into the catalytic reactor, where the tritium is converted to HTO and DTO. The gas leaves the reactor and enters the heat exchanger, where it is cooled by the incoming OMEGA effluent. It then enters the after-cooler, where it is cooled to ambient temperature. Finally, the gas flows through the mole sieve bed, where the tritiated water is removed or diverted to the Low Pressure Receiver tank to provide a source of gas for the recirculation loop. Effluent from the mole sieve is discharged to the stack.

The TC-TRS recirculation loop provides a constant flow through the heat exchanger and reactor. Recirculation eliminates the large process temperature transients that can result from sudden changes in the OMEGA discharge rates. These transients reduce the effectiveness in methane oxidation in the catalytic reactor and increases the discharge of tritiated organic species. The recycle valve opens when the OMEGA effluent flow is low (i.e., turbo pump effluent only) and closes when the OMEGA flow rate is high (i.e., target chamger purge cycles).

Eventually, the molecular sieve bed will become saturated with water and must be regenerated. The TC-TRS is designed to regenerate the beds *in situ*. This reduces the radiological hazard by avoiding the need to break into process lines to replace the beds. The regeneration subsystem drives the tritiated

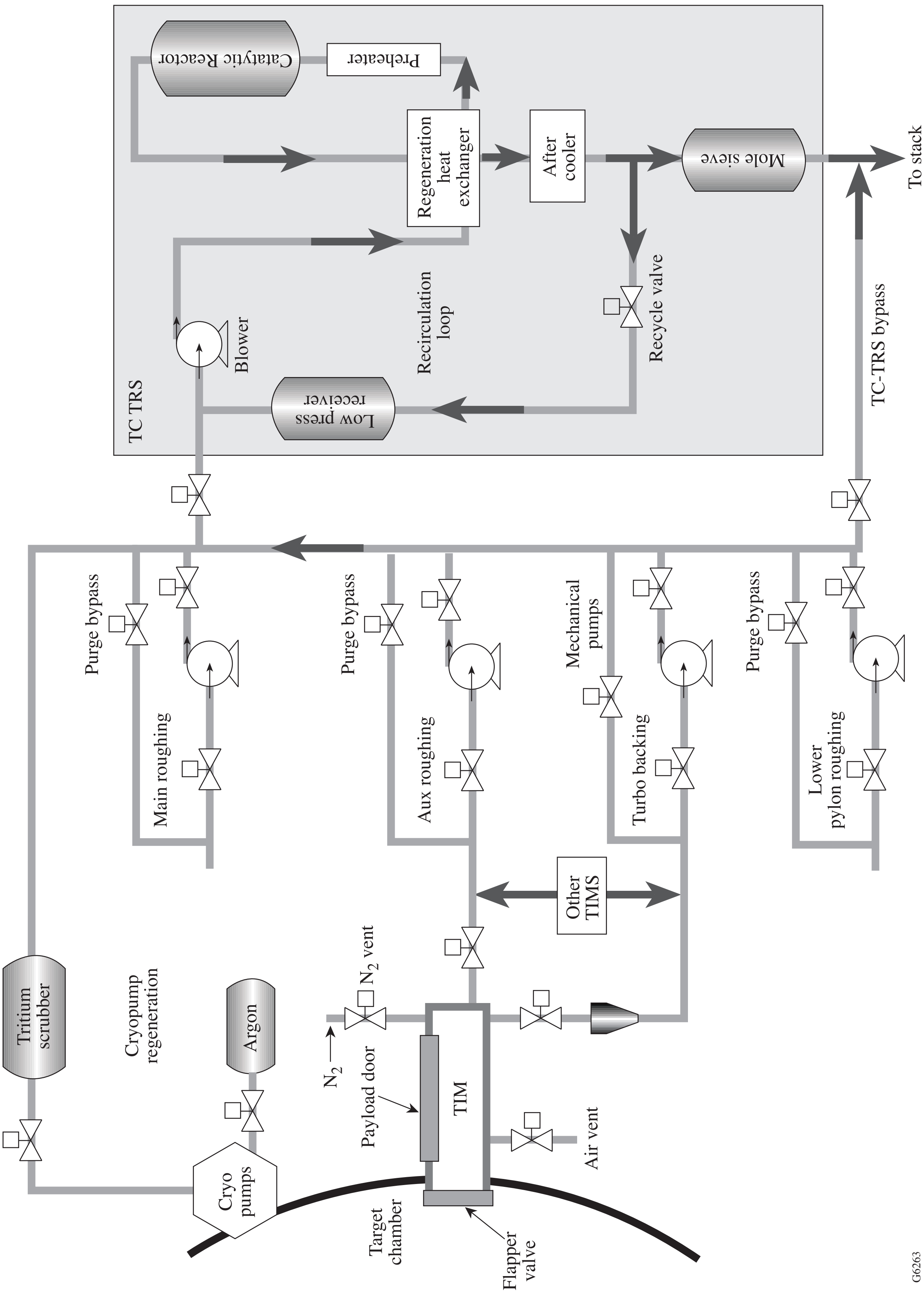

Figure 12.1-2
The OMEGA vacuum and TC-TRS overview. The ten-inch manipulator (TIM) is typical of the auxiliary volumes serviced by the vacuum and tritium recovery systems.

water off of the molecular sieve desiccant and collects it a receiving tank. High-specific-activity water (concentrations exceeding 500 μCi/L) is shipped off-site for enrichment and reuse. Low-specific-activity tritium is periodically shipped off-site for disposal. The total activity per drum shipped will not exceed 60 mCi. Water with a specific activity below 100 μCi/L is discharged to the sewer.

12.1.2 OMEGA Target Vacuum System

The OMEGA Target Vacuum System includes three cryogenic pumps that maintain the TC at high vacuum and four mechanical pumps that are used for roughing and backing. The tritium scrubber is used to trap tritium when the cryogenic pumps are regenerated. This system is described in more detail in Section 7.2 of Volume I. The mechanical pumps and the tritium scrubber are connected to the TC-TRS for tritium removal.

The four mechanical pumps and their inlet headers are arranged so that any combination of pumps and can be connected to the “Main Roughing,” the “Auxiliary Roughing,” or the “Turbo Backing” manifolds that service the OMEGA vacuum volumes. These include the 530-cu-ft target chamber and many smaller (5-cu-ft) diagnostic chambers typified by the TIM’s. Each mechanical pump can produce a maximum flow of 55 cfm at a suction head of 1 atm. Maximum allowable inlet pressure is 13.5 psig. The discharge pressure is constrained to the range of –2 to 1.5 psig (0.85 to 1.1 atm).

12.1.3 Purge Cycles for Tritium Operations

During shot operations, the TIM’s and the other auxiliary volumes are vented to atmospheric pressure and opened to the Target Bay for manual servicing on an hourly basis. Because cryogenic DT operations have the potential to expose operations personnel to hazardous levels of tritium, the volumes can be purged into the TC-TRS prior to being opened. Purging is the fastest way to reduce post-shot DT contamination to a level that allows payload servicing.

As is shown in Fig. 12.1-2, this is achieved by connecting the TC-TRS blower directly to the auxiliary volume (bypassing the OMEGA pump) and venting the volume with air. The use of room air introduces moisture that aids in the removal of tritium. Bypassing the mechanical vacuum pump allows the TC-TRS blower to pump the contaminated air into the TC-TRS via the auxiliary roughing lines and avoids the mechanical pump outlet pressure limitation.

The Target Chamber is vented and opened to the atmosphere approximately once per month to allow it to be opened for maintenance operations. The tritium hazard for these operations is reduced by bypassing the main roughing manifold to the TC-TRS so that the TC-TRS blower can draw room air through the TC (top center in Fig. 12.1-2).

12.2 TC-TRS Process Equipment

The TC-TRS, located in the Pumphouse, Room 150B, is comprised of the following equipment:

1. Reactor skid: contains the gas delivery equipment and the reactor equipment.
2. Molecular sieve skid: contains the gas drying and regeneration equipment.
3. Water chiller (CH-8200): dedicated water chiller.
4. Heater electrical panel: houses the electrical heating controls.
5. Pump electrical panel: houses the pump controls.
6. PLC controls cabinet: contains the PLC control system.
7. Personal computer cabinet: houses the operator display and PC system.

Figure 12.2-1 illustrates the layout of process equipment in the TC-TRS. The reactor skid and the molecular sieve skid are butted up against each other, end to end, and interconnecting piping joins them together.

The reactor skid contains the equipment for the gas delivery and catalytic oxidation processes. The molecular sieve skid contains equipment for the adsorption and regeneration processes. The molecular sieve skid contains the PLC cabinet and the personal computer (PC) cabinet which is the operator interface for the TC-TRS.

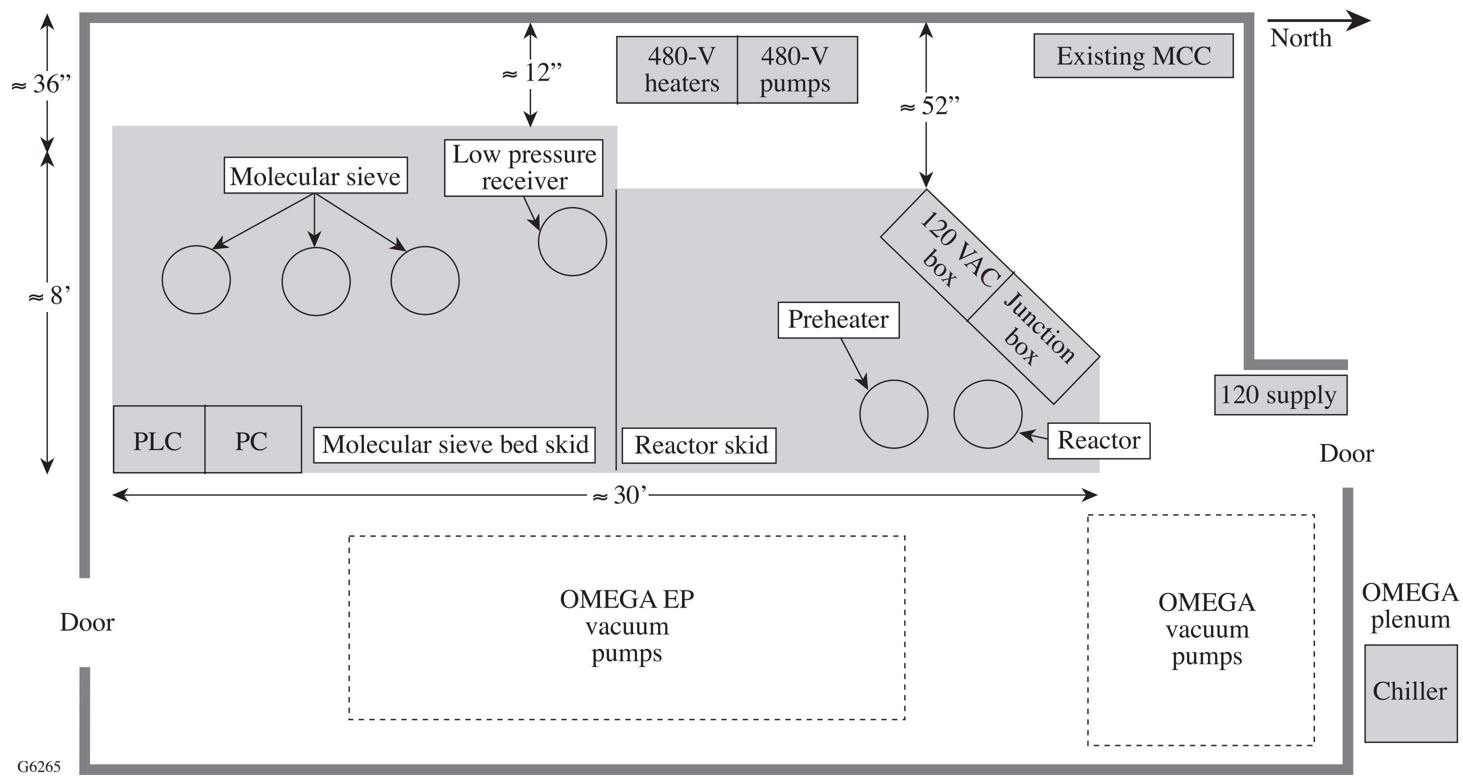

Figure 12.2-1
Arrangement of TC-TRS skids in Room 150B.

12.2.1 TC-TRS EQUIPMENT OVERVIEW

The TC-TRS equipment described in this section is shown in the process schematic (Fig. 12.3-1). It can be grouped into five process operations:

1. Gas delivery process: services OMEGA and cryopump regeneration.
2. Reactor process: converts elemental tritium and organically bound tritium to tritiated water.
3. Molecular sieve drying: absorbs tritiated water from the process effluent.
4. Molecular sieve regeneration: regenerates saturated molecular sieve beds.
5. Chilled water: dedicated chilled water system for the TC-TRS to prevent contamination of the building chilled water system.

The major components required for these process operations are summarized as follows:

1. Blower: receives high-volume flow from the two OMEGA effluents.
2. Low-pressure receiver: provides surge capacity for the OMEGA process effluent.
3. Reactor regenerative heat exchanger: heats incoming effluent and cools the outgoing effluent.
4. Reactor preheater: boosts the incoming effluent's temperature before it enters the reactor.
5. Reactor: oxidizes tritium to tritiated water.
6. After-cooler: cools the reactor's outgoing effluent.
7. After-cooler chilled water preheater: controls the after-cooler chilled water temperature.
8. Mole sieve bed: removes tritiated water from the effluent.
9. N_2 preheater: heats the nitrogen used in regeneration.
10. Condenser: removes the tritiated water from the regeneration nitrogen stream.
11. Jacketed condensate receiver: stores the tritiated water from the condenser.

This equipment can be seen in Figs. 12.2.2–12.2-4.

12.2.2 BLOWER (P-8401)

A Seimens model 2BH7620OAK52Z side-channel regenerative blower pumps a nominal 60 scfm of gas from OMEGA into the TC-TRS (see Fig. 12.2-5). The blower is a rotary device similar to a conventional rotary blower but can discharge gas at a high volumetric flow rate.

The regenerative side-channel design utilizes a turbine rotating within a fixed housing without mechanical contact. The flow channel is ring shaped with gas entering on one end and discharging on the other end. Since there is no mechanical contact and there are no internal fluids, the blower delivers oil-free gas.

The blower discharge head is limited to about 12 psig, and the flow range is from 10 to 120 scfm. The design maximum flow through the TC-TRS of 80 scfm is restricted by the pressure drop across the valves and through the beds. The higher the effluent discharge head, the higher the temperature of the effluent. For every 1 psig in the discharge head, the gas will heat up by ≈15°F. The blower can also achieve a maximum vacuum of about 350 Torr.

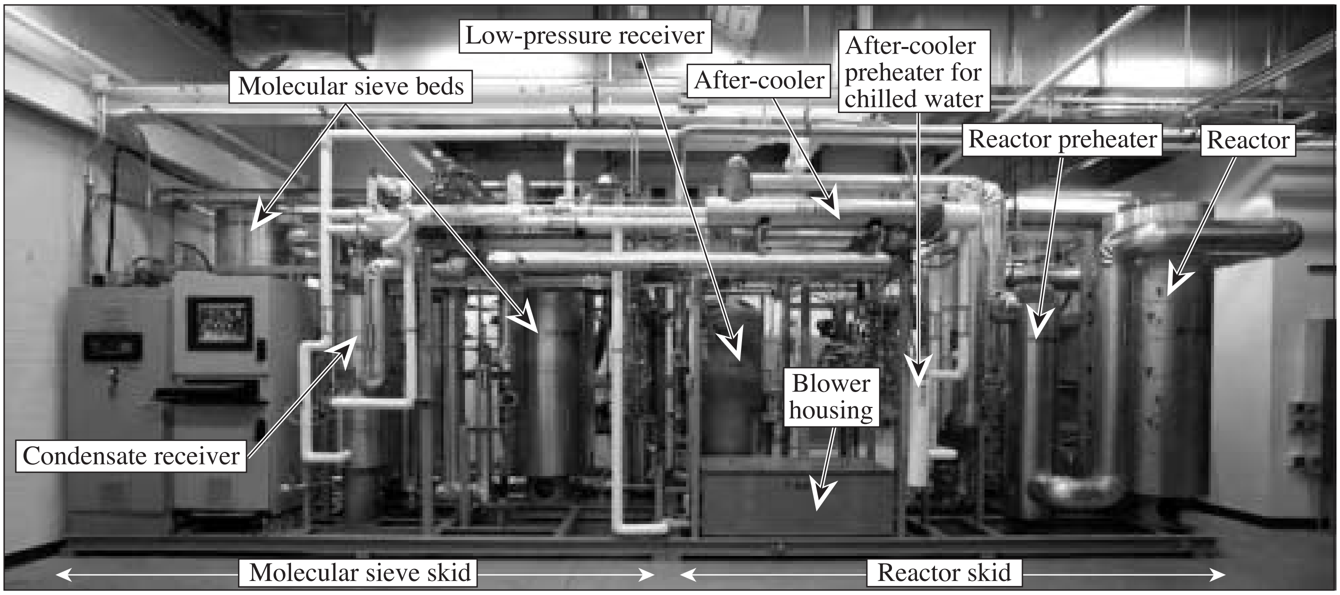

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Figure 12.2-2
TC-TRS system showing the reactor skid and molecular sieve skid.

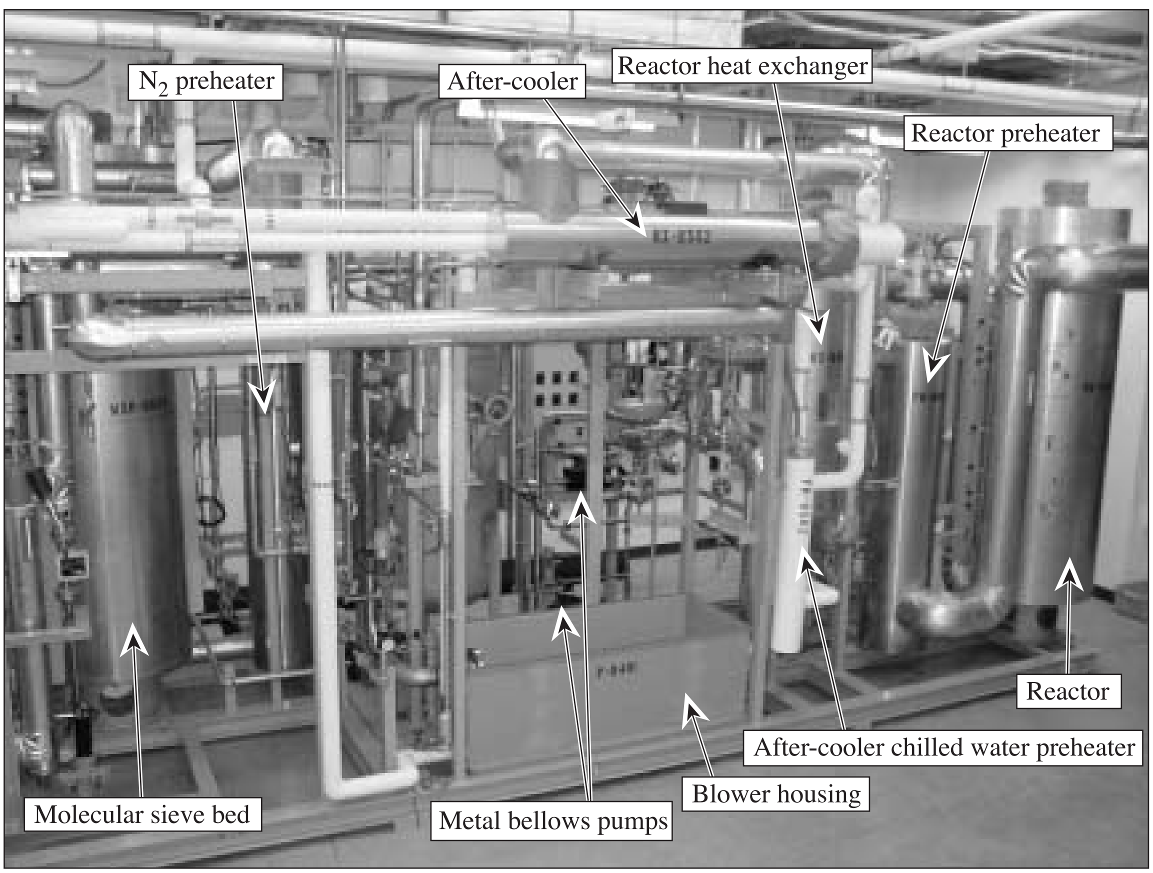

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Figure 12.2.3
The reactor skid.

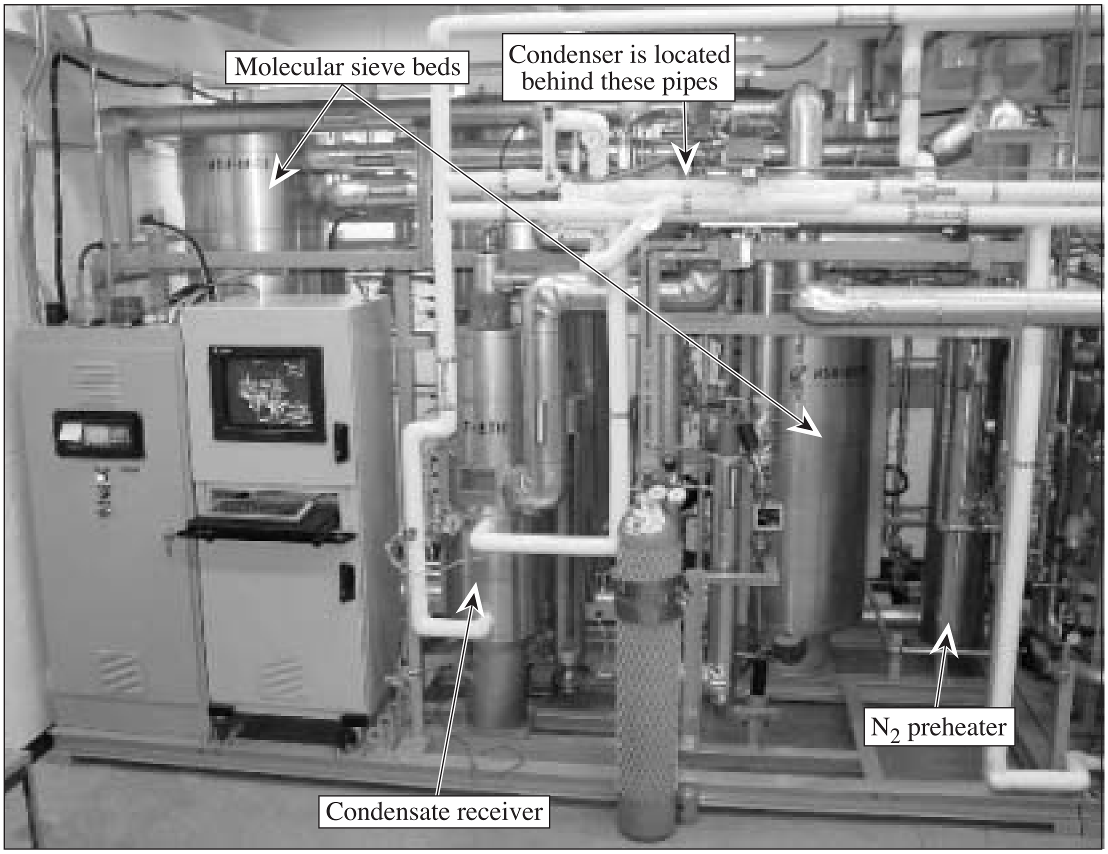

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Figure 12.2-4
The molecular sieve skid and operator workstation.

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Figure 12.2-5
Blower containment housing.

The blower is outfitted with a 480-V, 7.5-hp induction motor coupled with a variable speed drive inverter. The variable speed drive is capable of varying the frequency of the 480-V power to the blower motor from 15 to 73 Hz. At 73 Hz the blower can discharge 80 scfm of room air.

Because the blower is not leak tight, it is contained in an enclosure under negative pressure to eliminate tritium leakage into the room. The containment housing, shown in Fig. 12.2-5, is a welded steel box with neoprene seals. The negative pressure is provided from the suction side of the blower and controlled via an automatic valve (PV-8403) with a rotameter for setting flow. The containment housing is cooled using chilled water in coiled 1/4-in. copper hose lines located within the housing. The blower motor cooling fan provides necessary air flow within the box to circulate air across the chilled water cooling coils to keep the blower cool.

12.2.3 Reactor Equipment

The reactor removes tritium and tritiated organic species from the process air stream. The reactor and associated equipment (Fig. 12.2-3) are located on the reactor skid and comprise the following:

1. Reactor regenerative heat exchanger: This unit utilizes the reactor outlet gas, which is at 932°F to preheat the incoming effluent. In addition, the reactor outlet gas is precooled in this process.
2. Preheater: An electrically energized preheater boosts the inlet gas temperature.
3. Reactor: The catalytic reactor oxidizes tritium and organic species in the presence of air.
4. After-cooler: This heat exchanger uses chilled water to cool the reactor outlet gas temperature.

This equipment is described in more detail as follows:

12.2.3.1 Reactor Regenerative Heat Exchanger (HX-8501)

The reactor regenerative heat exchanger utilizes hot returning gas from the reactor to preheat incoming cool gas from the blower. The heat exchanger is rated to 87 psig at 1000°F. An image of the heat exchanger is shown in Fig. 12.2-6. The reactor regenerative heat exchanger is a single-pass BEM design shell and tube construction. Cool gas from the blower flows through the tubes, while hot gas from the reactor flows through the shell in a counter-current fashion.

The shell and bundle assembly consists of a bank of 85 tubes inside a 316-L, 6.6-in. ID schedule 10S shell. The heat exchanger is 89 in. in total length; its orientation in the system is vertical. The total external surface area of the tubes is 41 sq ft. The shell and tube side were designed and leak tested to 1×10^{-9} atm-cc/s. All butt-welds were 100% radiographed and inspected for flaws with a dye-penetrant testing.

12.2.3.2 Reactor Preheater (PH-8501)

The reactor preheater is an electrical preheater that increases the temperature of the inlet gas to the catalytic reactor up to 932°F. An image of the preheater is shown in Fig. 12.2-7.

The preheater is rated to 87 psig at 1000°F and consists of a 4-in., schedule-40 seamless shell with a welded bottom cap. A bank of Incoloy heaters is immersed inside the shell. The shell was leak tested to 1×10^{-9} atm-cc/s. All butt-welds were 100% radiographed and inspected for flaws with a dye-penetrant testing.

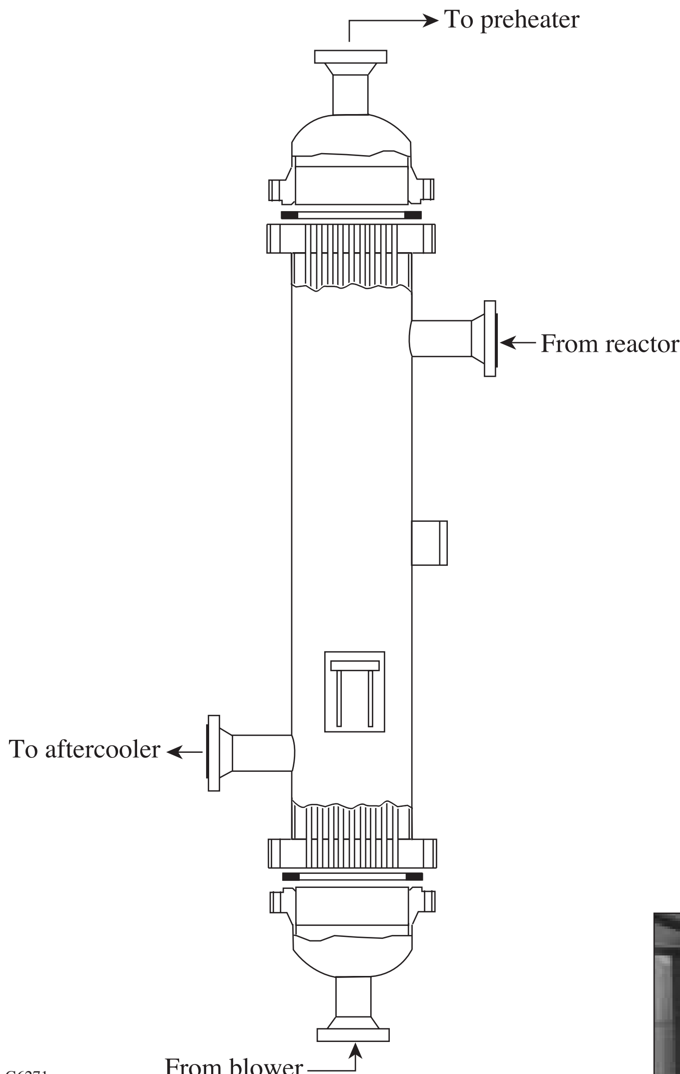

Figure 12.2-6
Reactor heat-exchanger.

Figure 12.2-7
Reactor preheater.

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Six Incoloy heaters with a 6-in. cold length and a 50-in. heated length are arranged in a tight bundle. The preheater is mounted vertically with the heating elements pointing up. The power density of the heaters is 15 W/in^2 and operates using three phase 480 VAC. The preheater utilizes two type-K thermocouples in thermowells mounted alongside the Incology elements for over-temperature protection.

12.2.3.3 Catalytic Reactor (RE-8501)

The catalytic reactor is a vertically oriented 6-ft. long, 14-in.-o.d., cylindrical, stainless steel, heated pressure vessel containing 300 lb of reactor catalyst. Gas flows in the top and out the bottom of the reactor. An image of this vessel is shown in Fig. 12.2-8.

The tank is rated for full vacuum and pressures to 87 psig at 1000°F. The process gas inlet nozzle utilizes a cylindrical mesh screen on its terminus to prevent media from backstreaming during regeneration. A media support, located just above the bottom seam, consists of a #4 mesh screen sitting atop a #24 mesh screen that sits atop a 316SS perforated plate. The screens and plate are sandwiched between two support rings. The tank was designed and leak tested to 1×10^{-9} atm-cc/s.

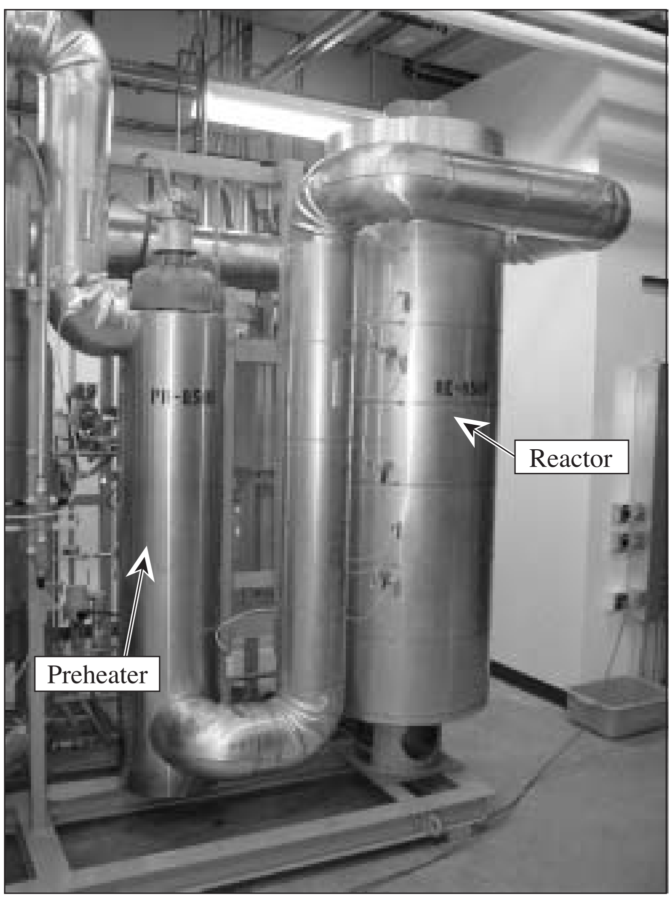

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Figure 12.2-8
Reactor and preheater.

The catalyst in this reactor is Type RO-20/47 provided by BASF of Mount Olive, NJ. It consists of alumina (Al_2O_3) beads 2 to 4 mm in diameter coated with palladium (Pd).

Electrical heating bands in the reactor maintain the catalyst temperature at a nominal 932°F. There are a total of six band heaters per bed. These are two-piece, Watlow-style, MI band heaters, 6-in. wide × 14-in. i.d. and are constructed with a 4 W/in^2 operating power density limit. The six band heaters cover 50% of the shell and are rated for 1000°F. There are two heating zones for the catalytic reactor, each of which uses three heaters.

The reactor is outfitted with seven type-K thermocouples. Three of these are inserted into the thermowells to measure catalyst temperature; the other four monitor the band heaters. Each grouping of three band heaters is provided with a control and an over-temperature safety shutoff thermocouple. The safety thermocouple interrupts power to the heater if an over-temperature condition occurs.

12.2.3.4 After-Cooler (HX-8502)

The after-cooler heat exchanger is rated to 87 psig at 600°F on the shell side and 330°F on the tube side. The after-cooler is a water-cooled, single-pass heat exchanger used to remove heat from gas exiting the regenerative heat exchanger. An image of the heat exchanger is shown in Fig. 12.2-9.

The after-cooler is a single-pass BEU design of shell and tube construction. Hot gas from the regen heat exchanger flows through the shell while chilled, 35°F water flows through the tubes. The exchanger is comprised of three parts: a cylindrical shell, U-bundle, and a bonnet. The U-bundle and shell are sealed together using a Helicoflex-style HN208 gasket. The bonnet connects to the opposite side of the tube sheet using a spiral-wound gasket. The bundle comprises 15 U-tubes seal welded to the tube sheet.

The total length of the heat exchanger is 70 in. It is positioned horizontally in the system. The external total surface area of the tubes is 12 sq ft. The shell-side was designed and leak tested to 1×10^{-9} atm-cc/s.

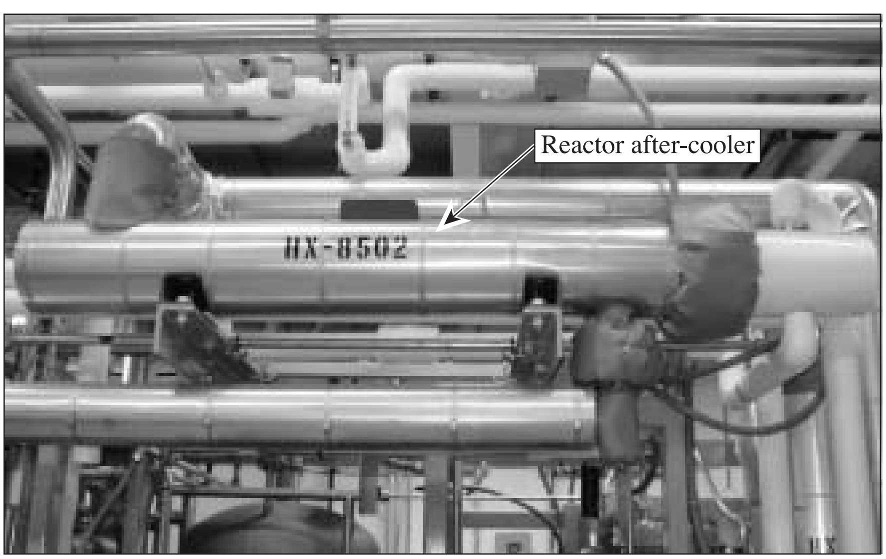

Figure 12.2-9
Reactor after-cooler.

12.2.3.5 System Chilled Water Heater (PH-8502)

The chilled-water from the TC-TRS chiller is too cold to be effective for use in the after-cooler because the efficiency becomes erratic if the water flow rate becomes too low. By slightly heating the water, the flow rate through the after-cooler can be increased for a given heat duty. An electric-fired preheater PH-8502 is provided for this purpose. The preheater is a 480 VAC, 7.5-kW flow-through heater. The heater is oriented in a vertical fashion.

12.2.4 Molecular Sieve Drying Equipment

Tritium converted to tritiated water is removed in a molecular sieve drier. The adsorption beds (MSB-8600, MSB-8610, MSB-8620) that perform this task are described in more detail below.

The molecular sieve adsorption beds are vertically oriented, 6-ft × 6-ft-long, 16-in.-o.d., stainless steel, cylindrical, heated, pressure vessels containing 300 lb of desiccant. Process gas flows in the top and out of the bottom of the vessels. A diagram of one the vessels is shown in Fig. 12.2-10.

The tank is rated for full vacuum and pressures to 87 psig at 750°F and is constructed from 16-in.-diam, schedule-10 pipe with 16-in.-diam, schedule-10 pipe end caps. Three thermowells are welded into the shell at three evenly spaced positions along the shell's vertical axis. The process gas inlet nozzle utilizes a cylindrical mesh screen on its terminus to prevent media from backstreaming during regeneration. A media support, located just above the bottom seam, consists of a #4 mesh screen sitting on a #24 mesh screen that sits on a perforated plate. The screens and plate are sandwiched by two support rings. The media is type-4A (5 Å, type-4A DG molecular sieve, 1/15-in. pellets).

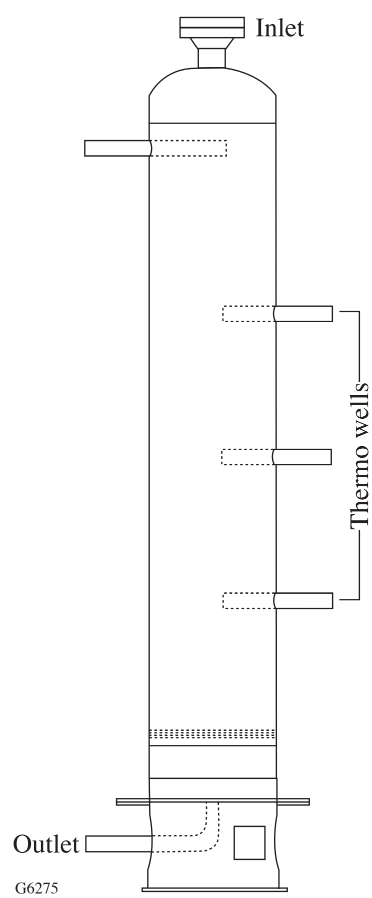

Figure 12.2-10
Molecular sieve bed.

Safety concerns include dust and heat upon contact with water. Molecular sieve dust contains small amounts of quartz, which causes irritation upon inhalation. When the molecular sieve media contacts water, it releases enough heat to boil water. Precautions must be taken to avoid getting the molecular sieve media in the eyes, mouth, or respiratory system. Each vessel is protected with a pressure relief valve that is set for 87 psig and connected to the exhaust stack.

The reactor utilizes electrical heating bands to maintain a regeneration temperature of 932°F. There are a total of six band heaters per bed. These are two-piece, Watlow-style, MI band heaters, 6-in. wide × 16-in. i.d., that produce 4 W/in^2 of heating or 1200 W. Six band heaters provide 50% area coverage on the shell. There are two heating zones for the vessels; each heating zone is comprised of three heaters.

12.2.5 Recirculation Loop

The recirculation loop is illustrated in Fig. 12.1-2 and detailed in the top part of Fig. 12.3.-1. It funtions to control the pressure in the low-pressure receiver to 13.5±0.5 psig. A low-pressure receiver, flow control valve, redundant pressure transmitters, and PID control loop have been installed for this purpose.

The low-pressure receiver is a 20 ft^3 stainless steel cylindrical tank (see Fig. 12.2-11). This vessel provides surge capacity for the blower and metal bellows pumps.

The tank is rated for full vacuum and pressures to 14 psig at 150°F. The tank is constructed from a 30-in.-diam cylindrical shell and two ASME 2:1 elliptical heads. The tank was designed and leak tested to 1×10^{-9} atm-cc/s. The tank is protected with a pressure relief valve that is set at 14 psig and connected to the exhaust stack.

G6276

Figure 12.2-11
Low-pressure receiver.

12.2.6 MOLECULAR SIEVE REGENERATION EQUIPMENT

When the drier beds become saturated with water, they must be regenerated. This regeneration is accomplished by passing heated dry-nitrogen gas through the bed in the opposite direction to the normal processor flow. The equipment required for this process is as follows:

1. Regeneration Preheater: This is an electrical heater that heats the nitrogen gas.
2. Regeneration Mole Sieve Bed: This is the saturated molecular sieve bed that is being regenerated.
3. Water Condenser: The water in the heated nitrogen is condensed.
4. Dryer Mole Sieve Bed: The nitrogen gas flows from the water condenser into the designated molecular sieve bed that removes residual water from the nitrogen.
5. Condensate Receiver: This vessel receives the tritiated water from the condenser.

The regeneration preheater, water condenser, and condensate receiver are described in more detail below.

12.2.6.1 Nitrogen Preheater (PH-8630)

The preheater is rated to 87 psig at 700°F. It is an electrically energized preheater that increases the temperature of the nitrogen regeneration gas delivered to the molecular sieves to up to 570°F. An image of the preheater is shown in Fig. 12.2-12.

Figure 12.2-12
Nitrogen preheater.

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The preheater consists of a 4-in., schedule-40, seamless shell with welded bottom cap and a 4-in. raised-face flange welded on top. A bank of incoloy heaters is immersed inside the shell with their cold lengths penetrating through a 4-in. raised-face flange. The two flange faces are sealed using a Helicoflex HN208A gasket. The shell was leak tested to 1×10^{-9} atm-cc/s.

Six incoloy heaters are arranged in a tight bundle. They have a 6-in. cold length and a 52-in. heated length. The shell has a polished internal surface of 35 Ra (180 grit finish). The preheater is mounted vertically with the heating elements pointing up. The heater power density is limited to 12 W/in^2 and it operates using three-phase 480 VAC. The preheater uses two type-K thermocouples for overtemperature protection that are mounted in thermowells alongside the incology elements.

12.2.6.2 Condenser (HX-8701)

The condenser is a water-cooled, single-pass heat exchanger used to condense water from the warm, wet gas exiting from a molecular sieve bed that is undergoing regeneration. Water condenses on tubes cooled by 35°F water. The condensate water collects at the bottom of the shell and flows out the outlet along with the cool gas in two-phase flow. The two-phase stream travels to the condensation tank where the liquid water is separated from the gas. The condenser is identical to the after-cooler (HX-8502). The gas outlet nozzle of the condenser is vertically down so that liquid can drain from the shell.

12.2.6.3 Condensate Receiver (T-8701)

An image of the condensate receiver is shown in Fig. 12.2-13. The condensate tank is constructed from 10-in.-diam, schedule-10 stainless steel pipe and two stainless steel pipe caps butt-welded together. The shell is 3.5 ft seam to seam. Two-phase gas/condensate flow enters on the sidewall, and demisted

G6278

Figure 12.2-13
Codensate receiver.

gas exits out the top after passing through a mist eliminator fabricated from 304 mesh and 316 rods. There is a jacket around the bottom of the tank consisting of 12-in. schedule-10 pipe welded to the 10-in. shell. Chilled water flows through the jacket to maintain condensate temperature less than 40°F.

The condensate receiver has a jacket that decreases the vapor pressure over the condensate, which in turn, reduces the water load to the drier. Chilled water in the jacket maintains the condensate at ≈40°F. A manual shutoff valve controls the flow of water into the jacket.

The tank is rated for vacuum at 100°F and 87 psig at 572°F. The jacket is rated for 50 psig at 572°F. The tank was designed and leak tested to 1×10^{-9} atm-cc/s. The tank is protected with a pressure relief valve set for 87 psig that relieves to the exhaust stack.

The water capacity of the tank is limited by the location of the gas inlet nozzle on the sidewall. The length of the shell between the bottom of this nozzle and the bottom seam is 2 ft. The volume of the shell between these points plus the bottom cap is 1.2 cu ft or approximately 9 gal (34 kg of water).

12.2.7 Dedicated Chilled Water System

The TC-TRS has a dedicated chilled water system (Fig. 12.2-14) that isolates the TC-TRS system from the building chilled water supply. The chiller (CH-8200) is a Cornelius model CH7503-W-2CS-HG-LL water chiller with a recirculation pump. The device is capable of providing 35°F chilled water at a flow rate of 5 gpm at 60 psig. The cooling power is 85,000 BTU/h achieved by a 7.5-hp refrigeration compressor (R22–Chlorodifluoromethane). It has a 40-gal chilled water reservoir and 2-hp centrifugal pump rated for 12 gpm at 40 psig head to circulate water to and from the TC-TRS. The unit operates using a three-phase 480 VAC drawing 22 amps. 10 gpm of building chilled water is used in the refrigeration condenser with a 40°F inlet and 50°F return temperature.

12.2.8 Miscellaneous Equipment

This section introduces seven auxiliary and instrumentation components that complement the major equipment items discussed above.

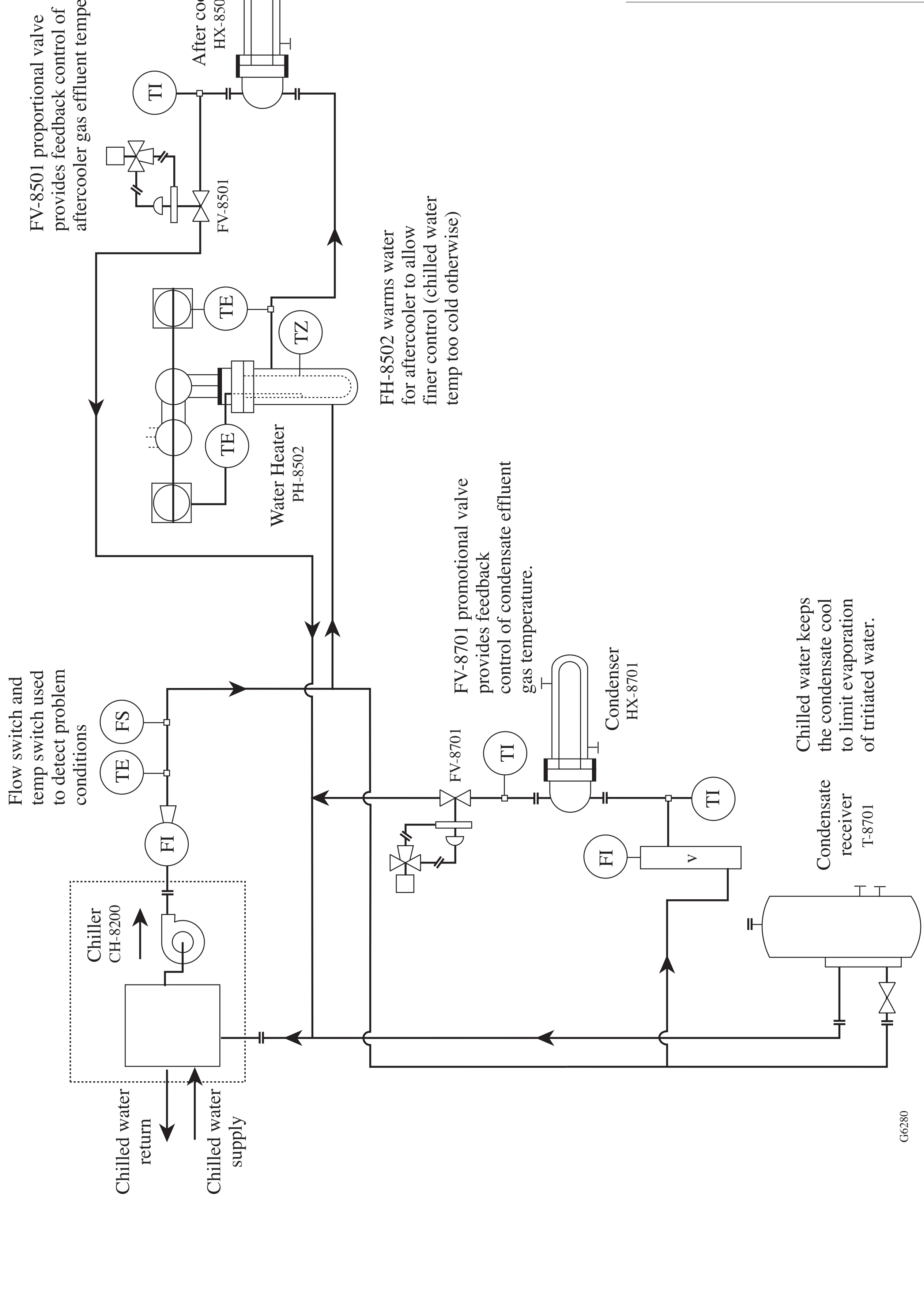
12.2.8.1 Scrubber Effluent Booster Pump (P-8420)

This pump is used to boost the effluent pressure from the OMEGA Cryopump Regen Scrubber into the TC-TRS. The effluent must overcome the head pressure of the system since it enters just after the blower before the regenerative heat exchanger. The booster pump is a Senior Flexonics MB-158 pump modified for tritium service. This pump is similar to the MB-601 pump except that it has one chamber. The pump delivers a maximum of 1.4 scfm of air with atmospheric suction.

12.2.8.2 Thomas Air Compressor (P-8430)

A pump is provided to mix air with the scrubber effluent (argon) flow in order to ensure sufficient oxygen for catalytic oxidation. The pump is a Thomas model 917CA22 diaphragm compressor with an aluminum head, Buna-N diaphragm, and stainless steel valves. The pump is driven by a single-phase, 1/8-hp, 110 VAC close-coupled motor. The pump delivers steady 1.25 scfm flow at 10-psig discharge pressure.

Figure 12.2-14
Chilled water keeps the condensate cool to limit evaporation of tritiated water.



12.2.8.3 Effluent Tritium Sample Pump (P-8640)

A pump is required to provide constant 1-cfm flow to the effluent tritium monitor, TMT-8601. A Senior Flexonics MB-158 standard pump model #25950 (NOT modified for tritium service) is provided to constantly pump a sample stream to and from the effluent line. The pump is identical to P-8420 except that it possesses viton gaskets around the valve assembly and has PT fittings. The pump was not designed for tritium service since the effluent from the system will be exposed to only background concentrations of tritium.

12.2.8.4 Tritium Monitors

Three ITS-type, 1-liter tritium monitors from Tyne Engineering (listed in Table 12.2-1) are used to measure gaseous concentrations of tritium. As is shown in Fig. 12.2-15, these monitors are in-line devices: the process gas flows through them. These devices ionize the process gas and measure the current that is generated by emitted β particles. This current (in femto-amps) is measured by the controller and reported back to the PLC using a 0- to 10-V signal. The tritium monitors report tritium concentrations in curies per cubic meter. The ITS units are stand-alone and provide a direct voltage output. The monitors use gas flow up to 1 cfm. As a result, pump and/or diversion flow controls are provided.

Table 12.2-1: Tritium Monitors in the TC-TRS.

Identifier	Description	Range of Tritium Concentration Exp (per cubic meter)
TMT-8401	Blower tritium inlet concentration	100 μCi–1.5 Ci
TMT-8701	Regen condenser effluent tritium outlet	100 μCi–1.5 Ci
TMT-8601	Stack outlet tritium concentration	10 μCi–150 mCi

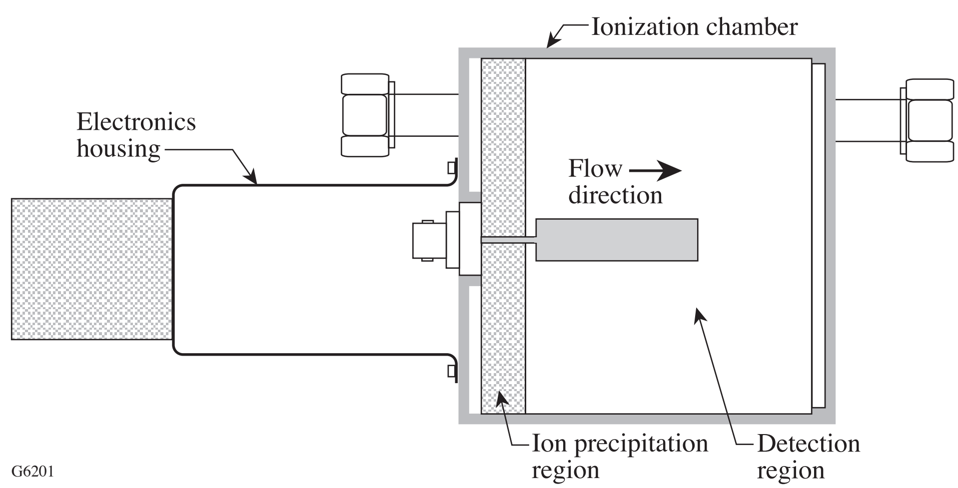


Figure 12.2-15
1-liter in-line tritium monitor from Tyne Engineering.

12.2.8.5 Flow Meters

Four mass flow meters are used in the system to measure the flow of gas. These are summarized in Table 12.2-2.

The Micromotion coriolis-type mass flow meter and the Kurz thermal mass flow meter were chosen for their simplicity (no moving parts), low-pressure drop, high leak tightness (only leak source is at flange), and materials compatibilty (100% 316 stainless steel construction). The nitrogen gas flow meter was chosen by the vendor and did not need to be tritium compatible since it is exposed only to clean nitrogen. Good agreement has been observed between all three mass flow meters.

Table 12.2-2: Summary of TC-TRS Flowmeters.

Description	Tag #	Type	Range
Gas inlet flow to system	FE-8401	Coriolis	0 to 100 SCFM
Metal bellows pump flow	FE-8410	Coriolis	0 to 10 SCFM
N2 inlet flow for regen	FE-8630	Orifice Plate with differential press element	0 to 133 #/hr nitrogen
Effluent flow to stack	FE-8601	Thermal mass	0 to 100 SCFM

12.2.8.6 Dew Point Instruments

The system contains three dewpoint sensors. All are Panametrics M1SP-type with a range of –166 to 68°F dewpoint. They are listed in Table 12.2-3.

The sensors provide an electrical signal to the Panametrics 6-channel Moisture Image Series 1 Hygrometer analyzer. The analyzer provides a 4- to 20-mA signal to the PLC as well as a local readout and has many capabilities for analysis and sensor setup. The analyzer is mounted into the PLC control cabinet.

Table 12.2-3: Summary of TC-TRS Dewpoint Sensors.

Description	Tag #	Purpose
Post-Reactor	DPT-8501	Measures water load to mole sieve beds
Effluent	DPT-8601	Determines when mole sieve bed is exhausted

12.2.8.7 Liquid Level Instrument (LI/LT-8701)

The condensate receiver utilizes a float-type level gauge (LI/LT-8701) to measure the amount of condensate in the receiver. It operates by measuring the vertical position of a float located within a stainless steel cylinder attached to the receiver. A magnetic vertical encoder is used to determine the float location. A drain is provided on the bottom of the float cylinder to ensure that no trapped condensate remains once the tank is emptied.

12.3 PROCESS DESCRIPTION

This section discusses the four major TC-TRS process areas: the Gas Delivery subsystem, the Catalytic Oxidation section, the Dryer Beds, and the Dryer Bed Regeneration subsystem. Most of the elements of these subsystems are mounted on the reactor skid and the molecular sieve skid shown in Fig. 12.3-1.

12.3.1 GAS DELIVERY/BLOWER (P-8401)

Gas with residual amounts of water contaminated by tritium and air enters at room temperature at the reactor skid and is compressed into the system by the blower, which has a flow capacity in the range of $10 > Q > 80$ scfm and can generate the moderate head pressures (max 12 psig) needed to overcome the pressure drop through the TC-TRS at elevated flow rates. The speed of the blower is manually controlled via the TC-TRS operator interface. The reason for high flow rates from OMEGA is twofold:

1. To purge OMEGA vacuum spaces with room air to decontaminate tritiated surfaces. A maximum of 80 cfm can be pulled through the system. The suction is taken either from the TIM volumes or through the Target Chamber, opened to atmosphere.

2. To support the evacuation of the target chamber during pump-down. The maximum output from the OMEGA vacuum pumps is 60 cfm per pump.

There are several ways to protect the blower against overpressure:

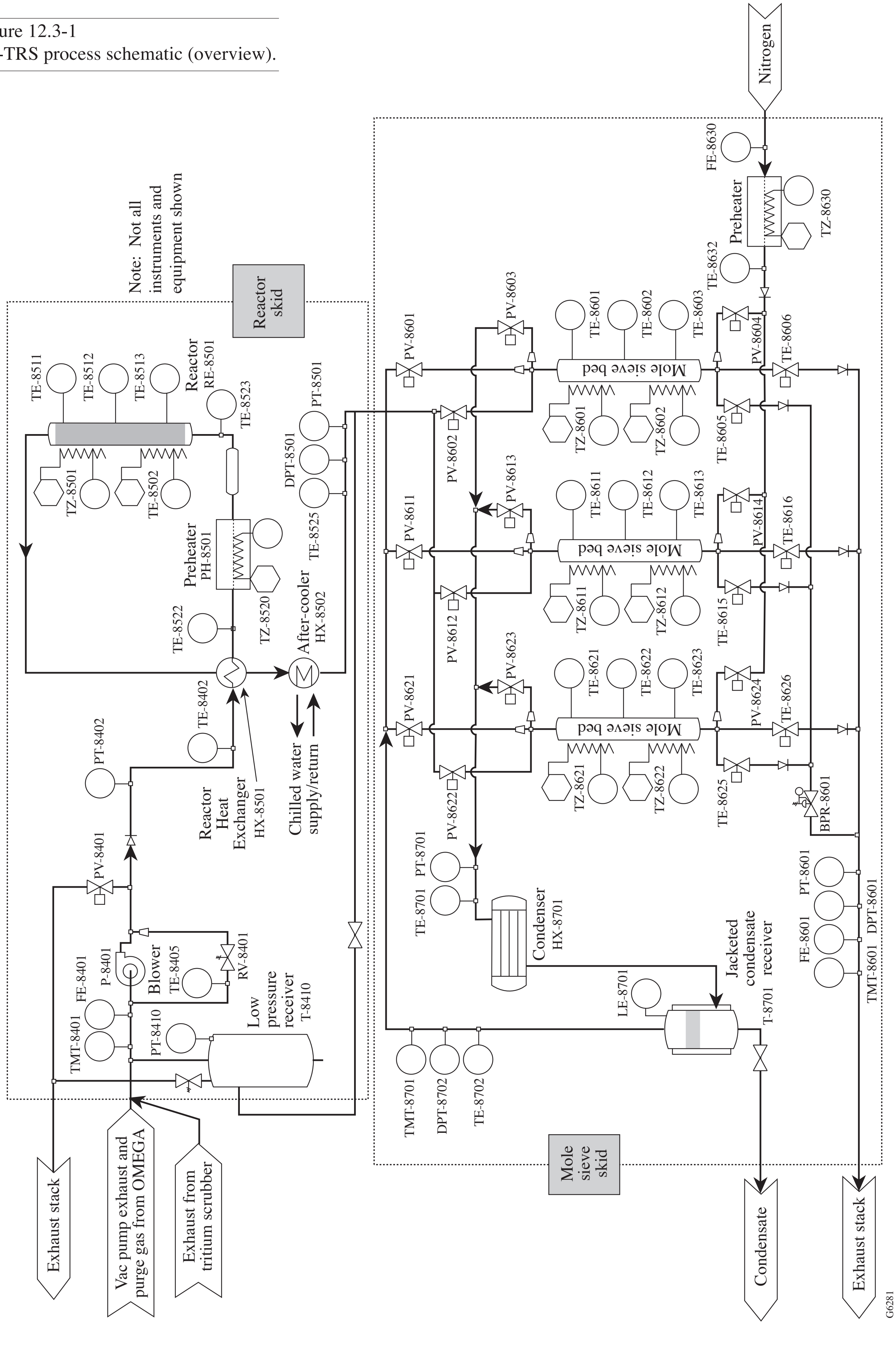
- There is a bypass line around the blower that includes a 15-psig pressure relief valve, RV-8401. If the pressure exceeds 15 psig on the discharge side, RV-8401 will automatically open and the effluent will return immediately to the suction side.

- If RV-8401 opens, the temperature of the bypass line will quickly increase due to flow. A temperature sensor in the bypass line, TE-8405, is used to shut off the blower if the temperature increases significantly above the operating temperature of the blower.

- A downstream pressure transducer, PT-8402, is used to automatically shut down the blower if the pressure exceeds 15 psig.

The blower heats up incoming gas via heat of compression. For every 1-psig increase in pressure, the gas (air) will heat up approximately 15°F. The blower is expected to be able to achieve at least 12 psig, which will result in a temperature increase of 150°F.

Figure 12.3-1
TC-TRS process schematic (overview).



The gas flow through the blower and reactor is held constant via the recycle line. A valve, FV-8500, automatically modulates the amount of gas flow in the recycle line when it is placed in automatic control. A low-pressure receiver (LPR) (T-8410) acts as a vacuum buffer.

The discharge head of the blower is approximately 6 psig at 60 scfm when gas is flowing through the molecular sieve bed. The flow curve for the system is shown in Fig. 12.3-2.

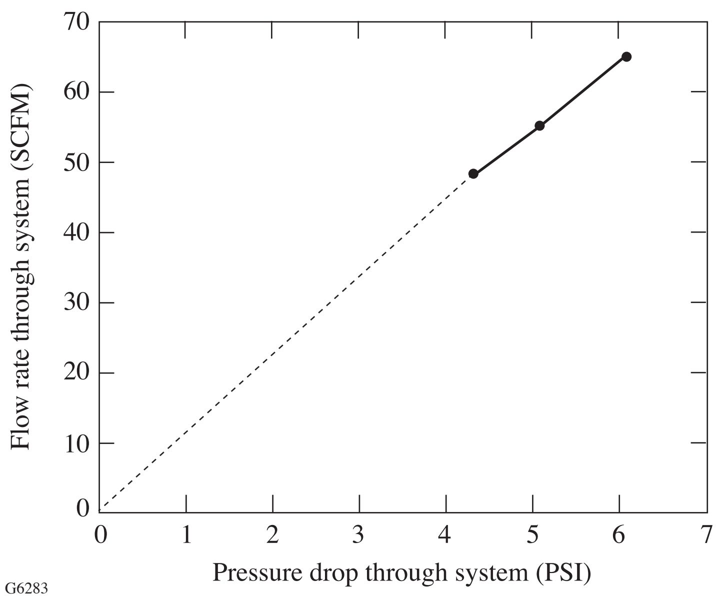


Figure 12.3-2
Overall flow characteristic of the TC-TRS.

12.3.2 CATALYTIC OXIDATION OF TRITIUM

The technology used in the TC-TRS to remove tritium from air streams relies on catalysts to oxidize elemental tritium and tritiated organic species in air to tritiated water and CO_2. This is a conventional method for removing tritium from air streams and has seen widespread use in the tritium industry. Palladium metal catalysts operating at temperatures up to 1000°F are utilized for this purpose. A drawback to this method is that high specific activity water can be formed.

One challenge in catalytic oxidation of tritium is ensuring that conditions are suitable to fully oxidize any organic species present. Trititiated methane is the most difficult specie to oxidize and will contaminate the downstream piping if it is not fully oxidized. It is important to operate the reactor at 932°F to maximize methane oxidation.

Figure 12.3-3 shows a schematic of the catalytic oxidation. The five process steps that result in steady-state catalytic oxidation are as follows:

1. First preheating of feed gas: regenerative heat exchanger HX-8501
2. Second preheating of feed gas: reactor preheater PH-8501
3. Catalytic oxidation: reactor RE-8501
4. First cooling of effluent: regenerative heat exchanger HX-8501
5. Second cooling of effluent: after-cooler HX-8502

The sections that follow discuss these process steps.

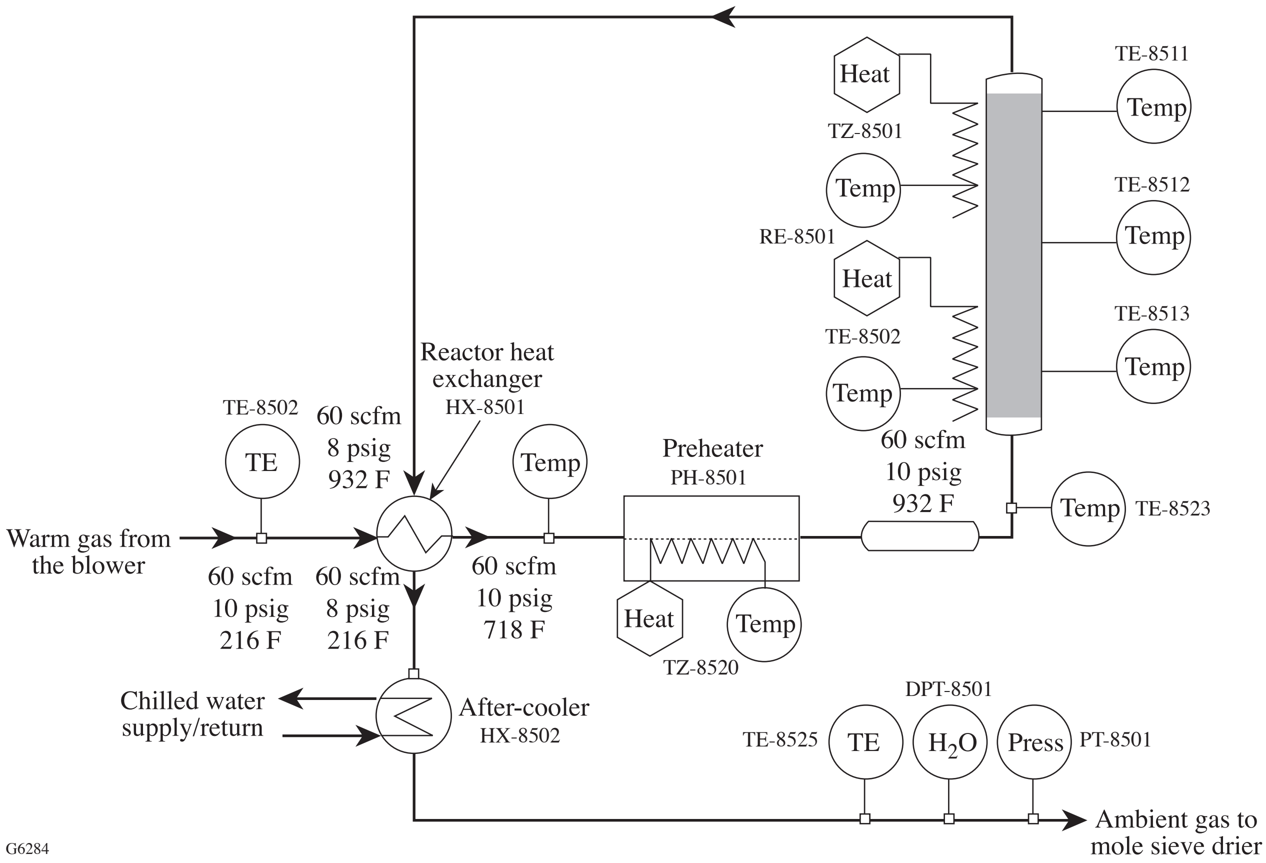


Figure 12.3-3
Schematic of the TC-TRS catalytic oxidation loop.

12.3.2.1 First Preheating Regenerative Heat Exchanger (HX-8501)

A regenerative heat exchanger is used both to preheat the feed to the reactor and to precool the effluent. The cold gas comes from the blower, where the gas is warmed by compressional heating to ≈216°F at 60 scfm. The hot gas enters from the outlet of the reactor at near 932°F (500°C). The overall pressure drops are less than 1 psig. The effluent from the blower is heated in the heat exchanger and then enters the preheater PH-8501 for additional heating, while the effluent from the reactor is cooled and then flows into the after-cooler HX-8502 for additional cooling.

12.3.2.2 Second Preheating: Reactor Preheater (PH-8501)

A preheater is used to further boost the temperature of the gas entering the reactor. This electrically energized preheater boosts the temperature of the gas from the regenerative heat exchanger, at 718°F, up to the temperature of the reactor, 932°F (500°C). This is accomplished using a single-pass, electrically heated, 12 KW (41,000 BTU/h) gas preheater. The power required to heat the gas from 718°F up to 932°F is approximately 5 KW (18,000 BT/h).

12.3.2.3 Catalytic Oxidation: Reactor (RE-8501)

The catalytic reactor oxidizes tritium and tritiated organics carried by air at elevated temperatures over a catalyst. The granular media are ≈1/8-in. beads that provide a large surface for the tritium and organic compounds to react while allowing gas to pass through it with little pressure drop.

Elemental tritium in air oxidizes rapidly over the catalyst, but the reaction rates for oxidizing tritiated hydrocarbons are much slower and decrease with decreasing molecular weight and temperature. Tritiated methane is the most-difficult hydrocarbon to oxidize. Figure 12.3-4 illustrates the expected conversion efficiency of methane as a function of temperature and pressure.

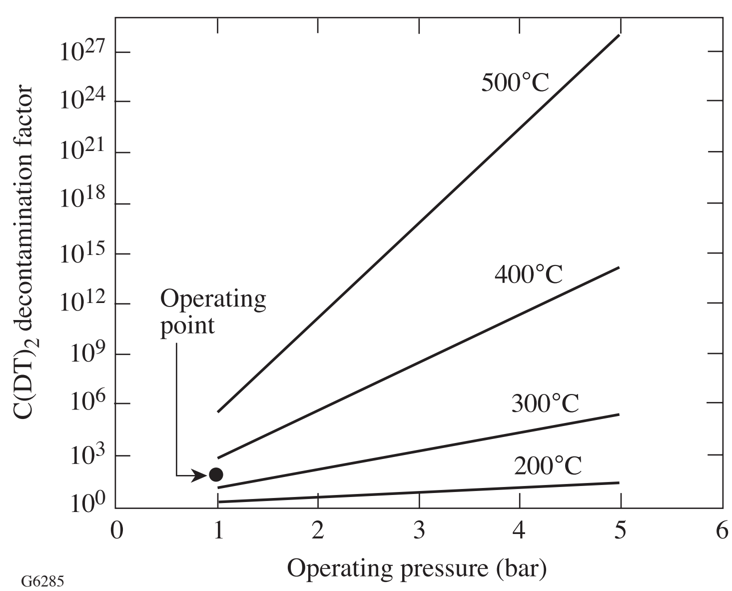


Figure 12.3-4
Detritiation of methane as a function of reactor temperature and pressure.

12.3.2.4 First Cooling: Regenerative Heat Exchanger

The gas that exits the reactor is first cooled using the regenerative heat exchanger. As described above, the relatively cool feed gas from the blower is used to cool the hot gas leaving the reactor.

12.3.2.5 Second Cooling: After-Cooler HX-8502

After leaving the regenerative heat exchanger, the gas must be further cooled to near room temperature before entering the molecular sieve driers. This is necessary because the molecular sieve capacity for adsorption of water is a strong function of temperature. The lower the temperature of the molecular sieves, the higher the water storage and the longer the duration between bed regenerations. To achieve this, gas passes through the water-cooled aftercooler. Chilled water flows through the tubes in two passes and cools gas passing through the shell. The sizing of the heat exchanger was based upon a heat exchange coefficient of 18 BTU/h-ft^2-°F. The overall pressure drops are less than 1 psig.

The after-cooler effluent from the shell side enters the molecular sieve skid. The temperature of the effluent is monitored and used to control the flow of coolant into the heat exchanger. The coolant is a mixture of glycol and water.

12.3.2.6 Reactor Temperature Transients

The ultimate measure of performance in the reactor is its ability to oxidize tritium and tritiated organics as indicated by the concentration of tritium in the air/water that exits from the system. To help guarantee performance, it is necessary to operate the system such that gas entering the reactor is at the desired temperature. The system is operated to achieve 932°F inlet temperatures from the preheater into the reactor with gas flowing at 48 scfm and a pressure of only 10 psig in the reactor.

Given the variations in the OMEGA effluent flow, it is not possible to achieve steady-state operation of the reactor loop at the design point outlined above while operating in a open loop.

This can be seen when transitioning from low flow (turbo effluent only) to high flow (target chamber purge). In the low-flow condition, the reactor heating requirements are low and the preheater and reactor temperature controllers are providing minimum power to the heaters. When the flow rate increases to maximum, the cold OMEGA effluent, flowing at 55 cfm, cools the reactor by ~100°F. The OMEGA effluent exiting the reactor is at a lower temperature and is not as effective in preheating the incoming OMEGA effluent in the heat exchanger.

In response to this temperature upset, the preheater and reactor-temperature controllers provide full power to the heaters in order to bring the temperatures to the specified operating range. However, due to the large process lag time (large amount of mass) the recovery process can take up to 2 hours.

12.3.3 Molecular Sieve Drying

Once tritium is converted to tritiated water in the catalytic reactor, the water must be removed from the gas stream by flowing the water-laden gas through large packed beds filled with molecular sieve 4A (MS4A) desiccant. The amount of water that can be adsorbed per unit mass of molecular sieve under equilibrium conditions is defined by the adsorption isotherm. The adsorption process is reversible.

During adsorption, gas is passed over the molecular sieve at ambient temperature. The molecular sieve desiccant can adsorb up to about 20% by weight of water. The packed bed has a long aspect ratio and becomes gradually saturated along the flow path until water begins to "break through" on the outlet side. When this occurs, the bed must be taken off-line and regenerated.

The molecular sieve beds were sized on the basis of the anticipated operating schedule for OMEGA. Approximately 36 kg of water is expected to be generated every three weeks. Each of the three drier beds is 16-in. diameter by 72-in. long and contains 320 lb of desiccant. Figure 12.3-5 shows a schematic diagram of the dryer bed subsystem.

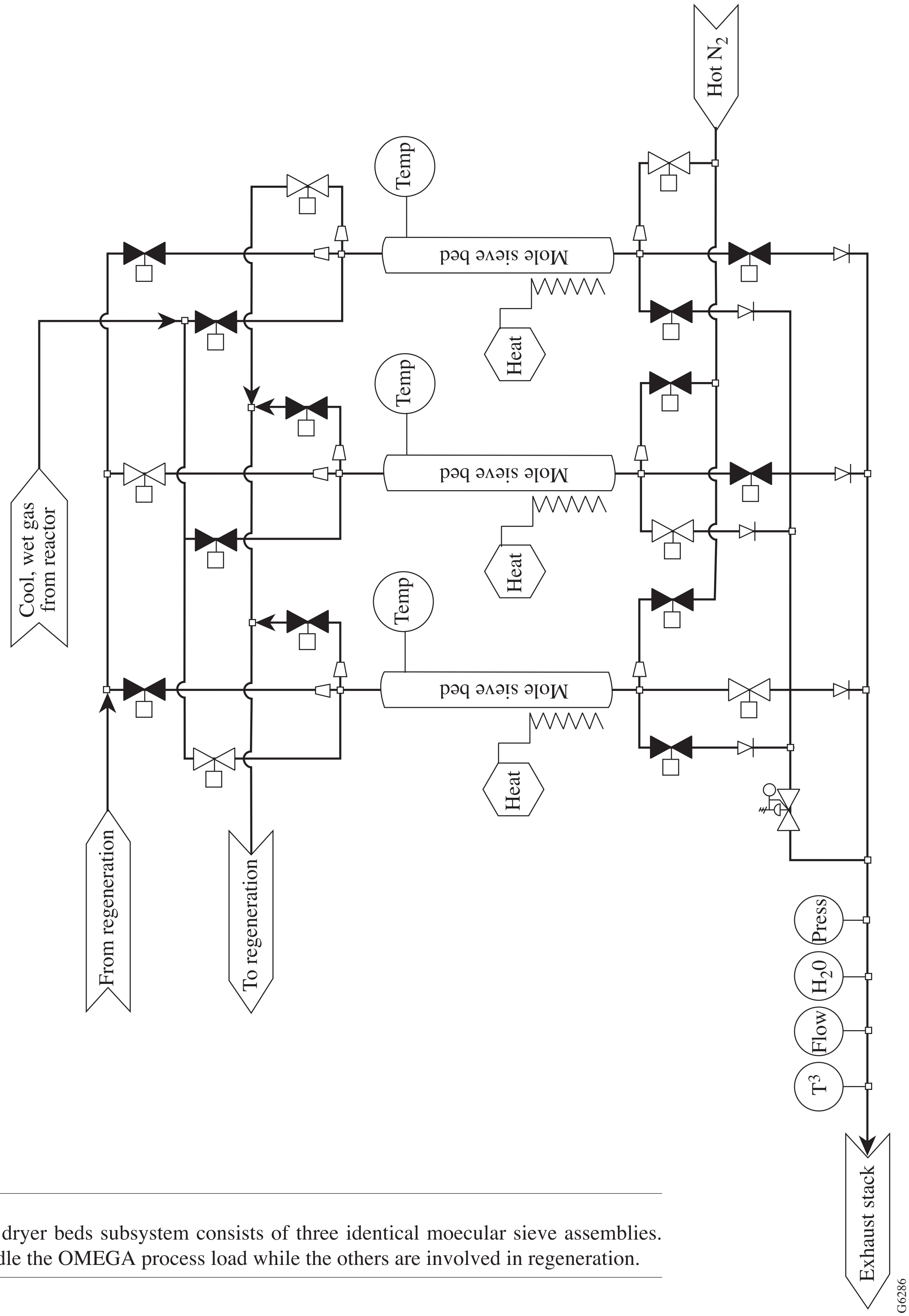


Figure 12.3-5
The TC-TRS dryer beds subsystem consists of three identical moecular sieve assemblies. Each can handle the OMEGA process load while the others are involved in regeneration.

12.3.4 Molecular Sieve Bed Regeneration

In the TC-TRS, the drier beds must occasionally be "regenerated" in order to drive off adsorbed water. When the effluent dewpoint (water exits the bed) or tritium level are unacceptably high, the bed is taken off-line for regeneration and a second bed is brought on-line. During regeneration, water is driven off the exhausted bed and collected, and the third bed polishes the resultant gas before it is sent to the exhaust stack. The time required to regenerate a single bed, depending on process conditions, is approximately 30 h. A schematic of the regeneration process is shown in Fig. 12.3-6. The five process elements to consider during steady-state regeneration are:

1. Preheating regen gas: nitrogen preheater PH-8630
2. Regeneration of mole sieve: molecular sieve bed in regen mode
3. Water condensation: condenser HX-8701
4. Water collection: condensate receiver T-8701
5. Drying of effluent gas: molecular sieve bed in trim mode

12.3.4.1 Preheating Regeneration Gas: Nitrogen Preheater PH-8630

Clean, dry nitrogen gas is preheated to ~600°F by a 10-KW electrical preheater. The gas flow rate is manually set and is monitored by a mass flow meter. The temperature of the gas is controlled by monitoring the effluent temperature and controlling power to the heater through a PLC. Temperature sensors inside the preheater protect the device from overtemperature.

12.3.4.2 Regeneration of Mole Sieve: Molecular Sieve Bed in Regen Mode

During regeneration, gas flows into the molecular sieve bed in a countercurrent (upward) direction relative to adsorption process flow. The regeneration gas is directed to the molecular sieve bed undergoing regeneration via the valve manifold at the bottom of the molecular sieve beds (see Fig. 12.3-6). The valves in this manifold are suitable for high-temperature and high-pressure operation.

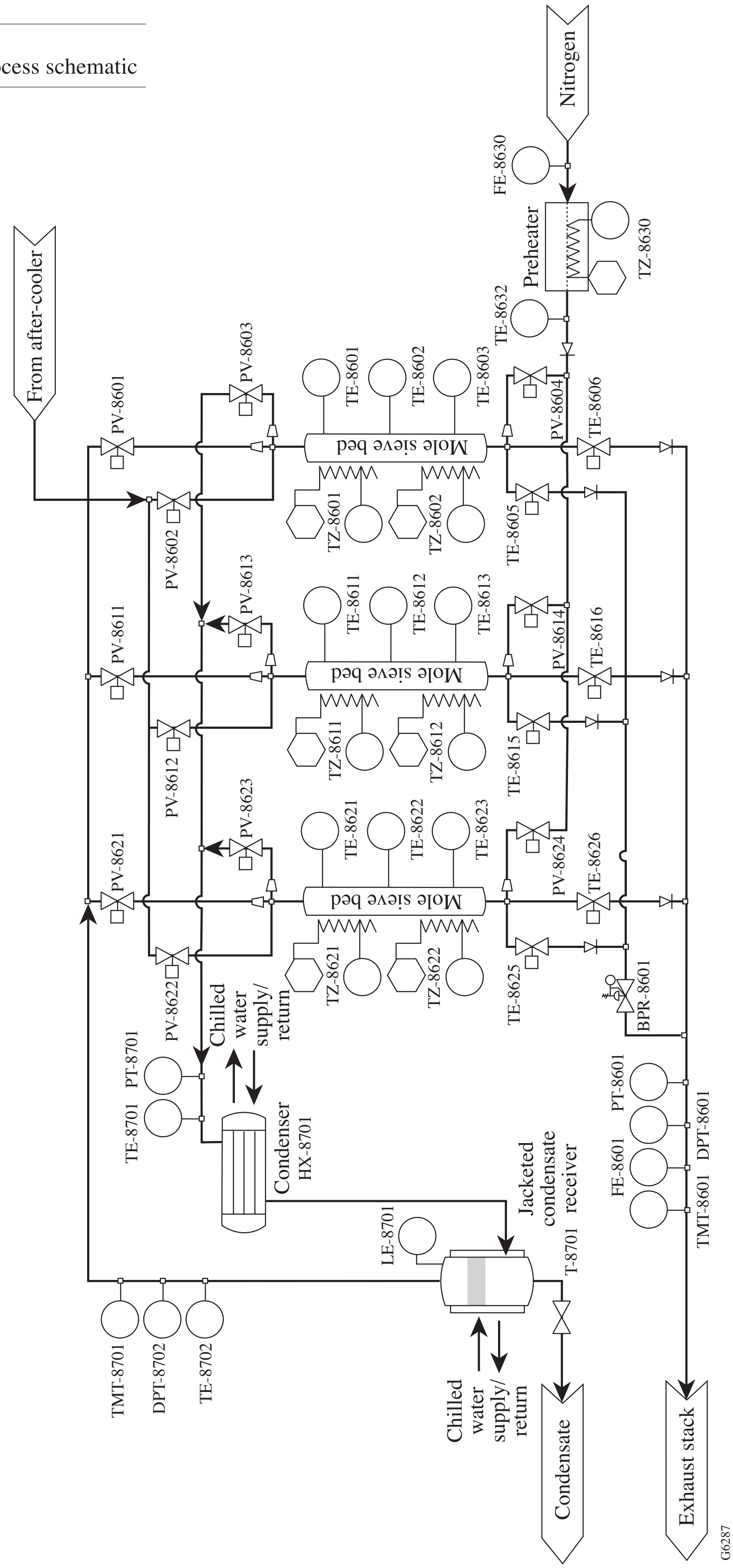
The molecular sieve beds are heated externally with a series of band heaters. These maintain the temperature of the shell at the regeneration temperature. Thermowells are used to monitor the bed media temperature.

At elevated temperatures, the ability of the molecular sieve desiccant to retain water is reduced. During regeneration a narrow front moves up the bed as the water is driven off. This front can be characterized by water content as well as by temperature. Figure 12.3-7 illustrates this phenomenon from an actual bed regeneration using the system. Water is progressively pushed downstream. Energy to desorb water from the mole sieve is taken from the hot gas. The stream cools as it moves to the exhaust. While the bed is preheated to regeneration temperatures and the shell is maintained at these temperatures, the bed downstream of the front is closer to ambient temperature until most of the water is removed.

The end of the regeneration process occurs when the front passes through the bed and the effluent stream, as measured by TE-8701, attains the regeneration temperature. The hot purge is continued for 3 hours after TE-8701 attains the setpoint. The regen flow rate is:

$$\text{regen vol} = \frac{\text{flow} \times t}{\text{Bed vol}} = \frac{60\ \text{scfm} \times 30}{8} = 225.$$

Figure 12.3-6
Molecular sieve regeneration process schematic



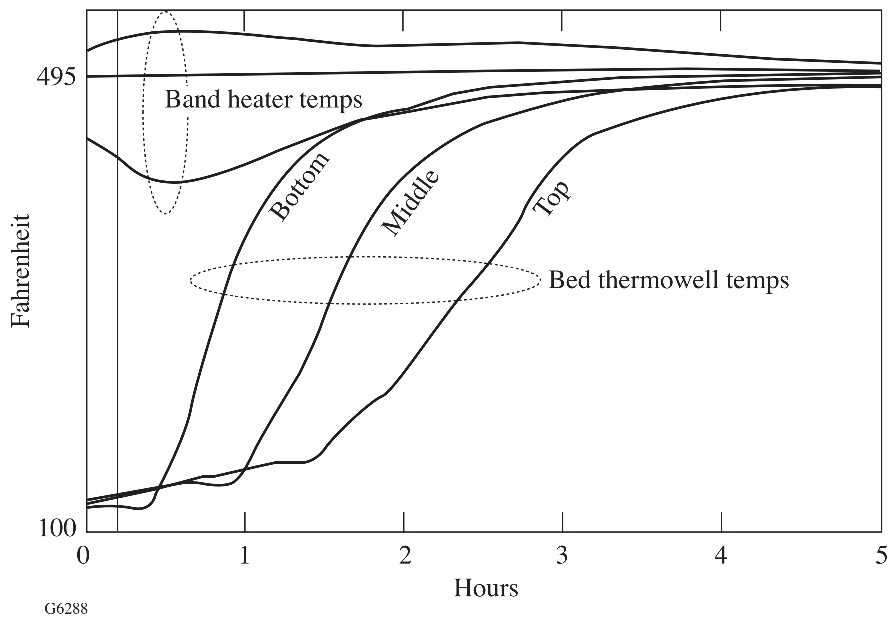


Figure 12.3-7
Typical regeneration temperature profile during regeneration.

Gas leaving the bed immediately travels straight up. It then encounters horizontal piping with a slight gradient toward the condenser. The orientation of flow during regeneration of a mole sieve bed is important. As the wet gas travels to the condenser, it will lose some heat and a portion may condense. By flowing upward, water can be carried to the highest points in the system rather than the lowest when it is liberated from the bed. Any condensation can then flow down toward the condenser by gravity. Otherwise, if wet gas exits the bottom of the bed, condensed liquid within the piping would not reach the condenser until it evaporated.

12.3.4.3 Water Condensation–Regen Condenser (HX-8701)

Water vapor in the effluent from the regenerated bed is condensed by the regen condenser. The regen condenser is a water-cooled heat exchanger that removes the latent heat of water and removes the specific heat of the condensate down to ambient temperature. Chilled water flows through the tubes in two passes to cool the gas and condense water vapor passing through the shell. Water vapor condenses on the cold tubes and flows down to the bottom of the shell and eventually flows out the bottom nozzle by gravity. Three cooling loads need to be accounted for in sizing the heat exchanger: condensing the water, cooling the gas, and cooling the water vapor (small). The cooling power needed to reduce the nitrogen temperature is 11,300 BTU/h, and the cooling required to condense the water is 4,600 BTU/h.

The condenser is 85% to 95% efficient in capturing water from the regeneration stream. The most-important process parameter is the temperature of the gas leaving the condenser. The gas leaving the condenser will be saturated with water at the temperature of the effluent. For 40°F air at atmospheric pressure, the amount of water in the gas will be about 0.0055 lb of water per lb of dry gas. This effluent is then sent to a mole sieve bed (third bed), where the residual water is removed.

This is a significant amount of water. This limitation on the effectiveness of capturing the water driven off of the dryer bed is the reason for using a third bed to further dry the regeneration flow.

12.3.4.4 Water Collection–Condensate Receiver (T-8701)

Nitrogen gas and condensed water flow downward to the condensate receiver. The condensate receiver is a jacketed cylindrical tank that collects liquid condensate, captures entrained water droplets from the gas phase, and maintains the condensate at a cool temperature. The condensate receiver utilizes a mesh screen to capture entrained water droplets (mist) that would otherwise travel on to the trim bed. The rate of water collection in the condensate receiver is constant for a constant gas flow and constant inlet gas temperature. The holding capacity of the condensate receiver is 1.2 ft^3 or 9.0 gal. This is equivalent to 34 kg of water.

The condenser/condensate receiver is only about 90% effective, resulting in an actual (max) mass of condensate of 32 kg. Condensate in the receiver is sampled to determine its activity. It is then drained to an approved receiving vessel for subsequent disposal. The receiving vessel is vented to the condensate receiver during this process to contain any HTO vapors.

12.3.4.5 Drying of Effluent Gas: Molecular Sieve Bed in Trim Mode

The gas leaving the condensate receiver flows to the designated “trim” bed. The gas must be dried because a significant portion of the water driven off the molecular sieve bed (5%–15%) remains in the gas. The water loading in the trim gas will be very similar to that in purge gas streams from OMEGA.

12.4 CONTROLS

The TC-TRS is controlled by a PLC that communicates with a supervisory server via TCP/IP Ethernet. The supervisory server consists of GE Fanuc Cimplicity software operating on a personal computer using the Windows operating system. The supervisory server package provides SCADA functions including operator interface, data logging, and alarms. The equipment is located within two enclosures mounted on the molecular sieve skid. The TC-TRS is operated primarily via a Cimplicity software application developed by Chemical Design, Inc.

PLC and I/O

The PLC is a GE Fanuc 90-30 series with a model-364 cpu. It is mounted in a GE Fanuc 10-slot I/O rack powered by a 120 VAC power supply. Two I/O racks house the PLC and I/O modules. The GE Fanuc I/O modules include digital and analog input and output modules for thermcouple input, voltage, and current input. There is one 4-20 current output module.

PLC Cabinet

The PLC cabinet houses the PLC and associated I/O equipment. The cabinet contains the fusing and electrical power supply for all of the control equipment. In addition to the PLC equipment, the cabinet contains the following equipment:

- Dew-point analyzer for DPT sensors
- 155 VDC tritium monitor power supply
- Alarm beacon
- Alarm annunciator
- System on/off hand switch (controls 120 VAC power)
- System on/off indicator light
- Emergency stop mushroom button

PC Cabinet

The PC is located within a Hammond 70-in. tall × 28-in. wide × 24-in. deep NEMA 12 industrial PC enclosure (see Fig 12.4-1). An Allen-Bradley 19-in. CRT monitor provides video.

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Figure 12.4-1
The operator workstation, PLC, and PC cabinets.

12.4.1 CIMPLICITY APPLICATION

GE Cimplicity software was used to develop a set of GUI screens that serve as the HMI. The GUI's are used to operate and interrogate the process; the main process GUI can be seen in Fig. 12.4-2.

12.4.2 TRS STATUS

The TC-TRS has a number of status bits that allow/disallow operation. One of the key bits is the READY bit. The following conditions must be met by this bit before automatic operation can proceed:

TRS READY

- Reactor at temperature
- Preheater at temperature
- Chiller ready
- Molecular sieve beds have feed and product valve open on at least one vessel
- TRS Start selected on HMI

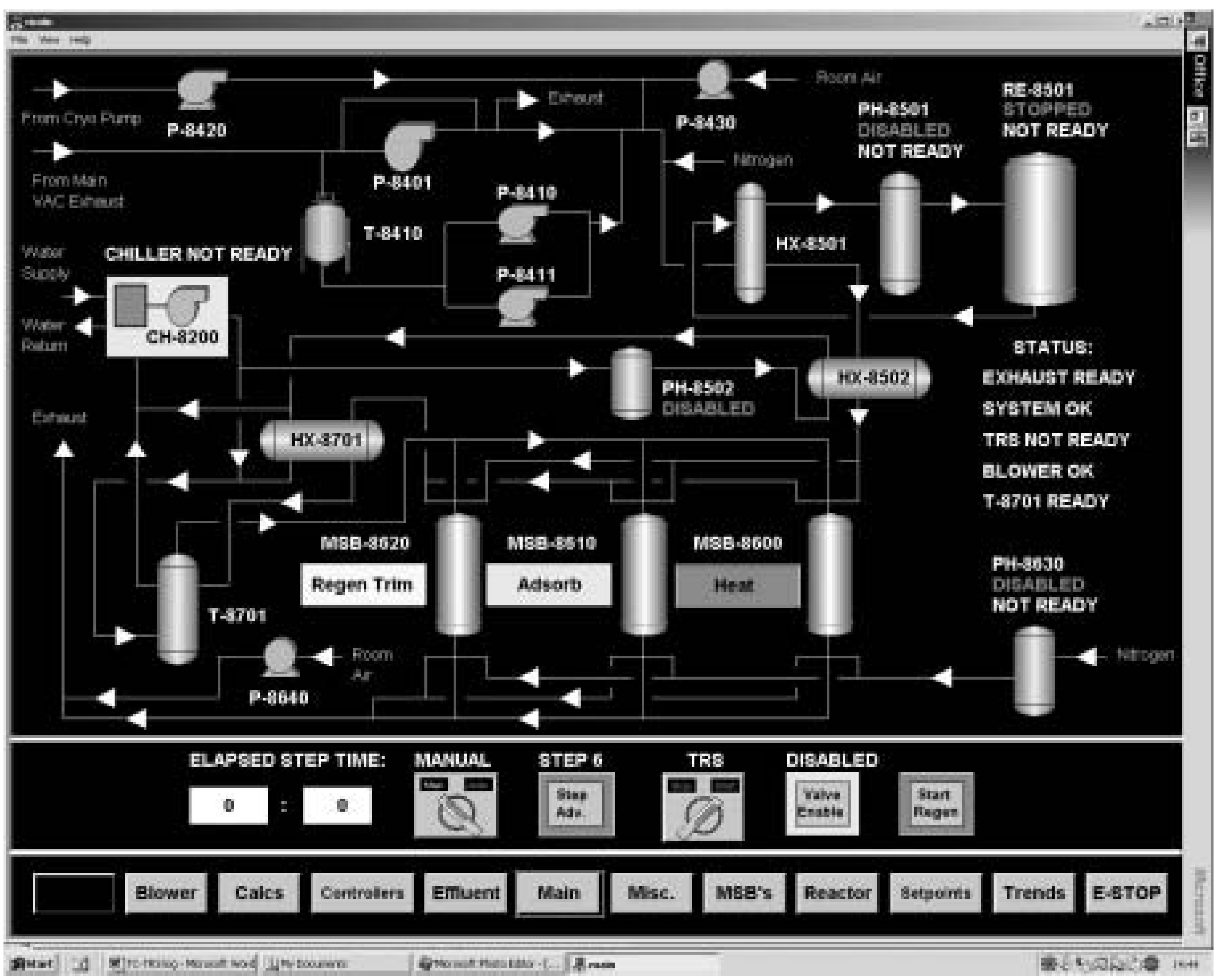

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Figure 12.4-2
Example of a Graphical User Interface Screen.