S-AA-M-31

Cryogenic Target Handling System Operations Manual Volume IV–CTHS Description

Chapter 12: Tritium Removal System (TRS)

Table of Contents

12.1 INTRODUCTION 1
  12.1.1 Tritium Specific Activity 3
  12.1.2 Feed Streams 3
    12.1.2.1 Glovebox Effluent/GCS 5
    12.1.2.2 Process Equipment Effluent/ Tritium Cleanup System 6
    12.1.2.3 Secondary Containment Effluent/DSCCS 7
    12.1.2.4 Air Effluent/Air Vacuum Cleanup System 8
  12.1.3 Regeneration 9
  12.1.4 TRS Technology Overview 10
  12.1.5 TRS Design Objectives 10

12.2 EQUIPMENT OVERVIEW 11
  12.2.1 TRS Modules Summary 13
  12.2.2 Subsystem and Component Summary 15
  12.2.3 Component Description 20
    12.2.3.1 TRS Main Enclosure 20
    12.2.3.2 TRS Pump Enclosure 20
    12.2.3.3 Process Piping 20
    12.2.3.4 Process Valves 20
    12.2.3.5 Pumps 20
    12.2.3.6 Recirculation Tanks 22
    12.2.3.7 Adsorption Beds 22
    12.2.3.8 Cryotrap 26
    12.2.3.9 Catalytic Reactor 28

12.2.3.10 Catalytic Reactor Cooler Specifications 28
12.2.3.11 N_2 Preheater 28
12.2.3.12 Condenser 28
12.2.3.13 Secondary Containment Volumes 29
12.2.3.14 Gloveboxes 29
12.2.3.15 Tritium Monitors 29
12.2.3.16 Miscellaneous Instrumentation 29
12.2.4 Materials 32

12.3 TRITIUM REMOVAL PROCESS DESCRIPTION 33
12.3.1 Zirconium-Iron Adsorption Train 34
12.3.1.1 Process Operating Conditions 35
12.3.1.2 Performance of ZrFe in Glovebox Cleanup Operation 35
12.3.2 Tritium Cleanup Subsystem (TCS) 36
12.3.3 Air Vacuum Cleanup Subsystem 38
12.3.4 Glovebox Cleanup Subsystem 39
12.3.4.1 Cryotrap Train 40
12.3.4.2 Glovebox Pressure Control 40
12.3.5 DTHPS Secondary Containment Subsystem 40

12.4 REGULAR PROCESS MAINTENANCE ACTIVITIES 42
12.4.1 Bed Regenerations Subsystem 42
12.4.2 Molecular Sieve Drier Regeneration 42
12.4.3 Nickel Bed Regeneration 44
12.4.4 Zirconium-Iron Bed Regeneration (TCS) 45
12.4.5 Cryotrap Regeneration 46
12.4.6 Tritium Monitor Decontamination Subsystem 47
12.4.7 Removal of Tritiated Water Condensate 47

12.5 CONTROLS 48
12.5.1 Controls System Components 48
12.5.2 Human–Machine Interface (HMI) 48
12.5.3 Alarms 50

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Chapter 12: Tritium Removal System (TRS)

Table of Contents

12.1 INTRODUCTION 1
  12.1.1 Tritium Specific Activity 3
  12.1.2 Feed Streams 3
    12.1.2.1 Glovebox Effluent/GCS 5
    12.1.2.2 Process Equipment Effluent/ Tritium Cleanup System 6
    12.1.2.3 Secondary Containment Effluent/DSCCS 7
    12.1.2.4 Air Effluent/Air Vacuum Cleanup System 8
  12.1.3 Regeneration 9
  12.1.4 TRS Technology Overview 10
  12.1.5 TRS Design Objectives 10

12.2 EQUIPMENT OVERVIEW 11
  12.2.1 TRS Modules Summary 13
  12.2.2 Subsystem and Component Summary 15
  12.2.3 Component Description 20
    12.2.3.1 TRS Main Enclosure 20
    12.2.3.2 TRS Pump Enclosure 20
    12.2.3.3 Process Piping 20
    12.2.3.4 Process Valves 20
    12.2.3.5 Pumps 20
    12.2.3.6 Recirculation Tanks 22
    12.2.3.7 Adsorption Beds 22
    12.2.3.8 Cryotrap 26
    12.2.3.9 Catalytic Reactor 28

12.2.3.10 Catalytic Reactor Cooler Specifications 28
12.2.3.11 N_2 Preheater 28
12.2.3.12 Condenser 28
12.2.3.13 Secondary Containment Volumes 29
12.2.3.14 Gloveboxes 29
12.2.3.15 Tritium Monitors 29
12.2.3.16 Miscellaneous Instrumentation 29
12.2.4 Materials 32

12.3 TRITIUM REMOVAL PROCESS DESCRIPTION 33
12.3.1 Zirconium-Iron Adsorption Train 34
12.3.1.1 Process Operating Conditions 35
12.3.1.2 Performance of ZrFe in Glovebox Cleanup Operation 35
12.3.2 Tritium Cleanup Subsystem (TCS) 36
12.3.3 Air Vacuum Cleanup Subsystem 38
12.3.4 Glovebox Cleanup Subsystem 39
12.3.4.1 Cryotrap Train 40
12.3.4.2 Glovebox Pressure Control 40
12.3.5 DTHPS Secondary Containment Subsystem 40

12.4 REGULAR PROCESS MAINTENANCE ACTIVITIES 42
12.4.1 Bed Regenerations Subsystem 42
12.4.2 Molecular Sieve Drier Regeneration 42
12.4.3 Nickel Bed Regeneration 44
12.4.4 Zirconium-Iron Bed Regeneration (TCS) 45
12.4.5 Cryotrap Regeneration 46
12.4.6 Tritium Monitor Decontamination Subsystem 47
12.4.7 Removal of Tritiated Water Condensate 47

12.5 CONTROLS 48
12.5.1 Controls System Components 48
12.5.2 Human–Machine Interface (HMI) 48
12.5.3 Alarms 50

Chapter 12
Room 157 Tritium Removal System (TRS)

12.1 INTRODUCTION

This chapter describes the Room 157 Tritium Removal System (TRS) and covers the objective, design, construction, and operation of the system.

Figure 12.1-1 illustrates the overall Cryogenic Target Handling System (CTHS) as it is integrated with the OMEGA facility. Note that the Room 157 TRS is one of two tritium removal systems that support inertial confinement fusion experiments using cryogenic tritium in the facility. The Room 157 TRS supports the target-filling and characterization activities that take place in Room 157 by collecting and treating gas that is exhausted from the CTHS equipment. The other system—the Target Chamber Tritium Removal System (TC TRS)—deals with releases that may occur after targets are delivered to the Target Chamber.

Figure 12.1-2 is a composite photograph of the Room 157 TRS equipment that was manufactured by Zeton, Inc., Burlington, Ontario, Canada. Mechanical design was performed by Zeton, and process design was performed by Tyne Engineering and LLE. The TRS system was delivered to LLE in December 2002 and will begin operation in 2004.

The objective of the Room 157 TRS is to minimize airborne tritium effluent releases to well below the permit limit of 2.2 curie (Ci) * per year. In addition, the system is designed to minimize tritium exposure to staff by maintaining low levels of tritium in the CTHS equipment.

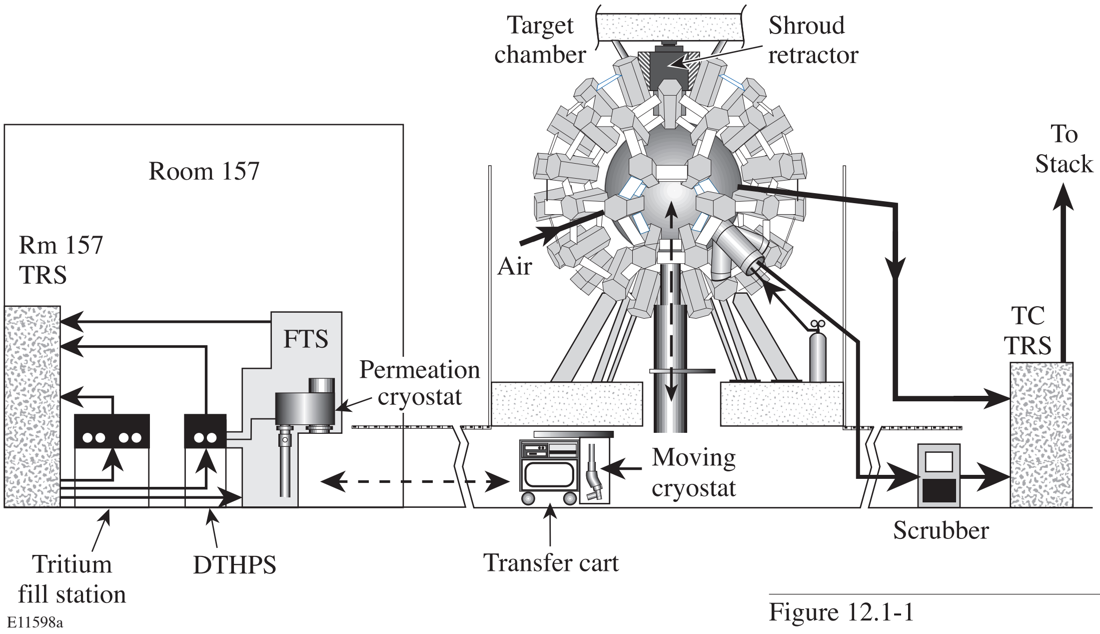

Figure 12.1-1
Equipment integration interconnection diagram.

(* 1 g of tritium gas = 9619 Ci.)

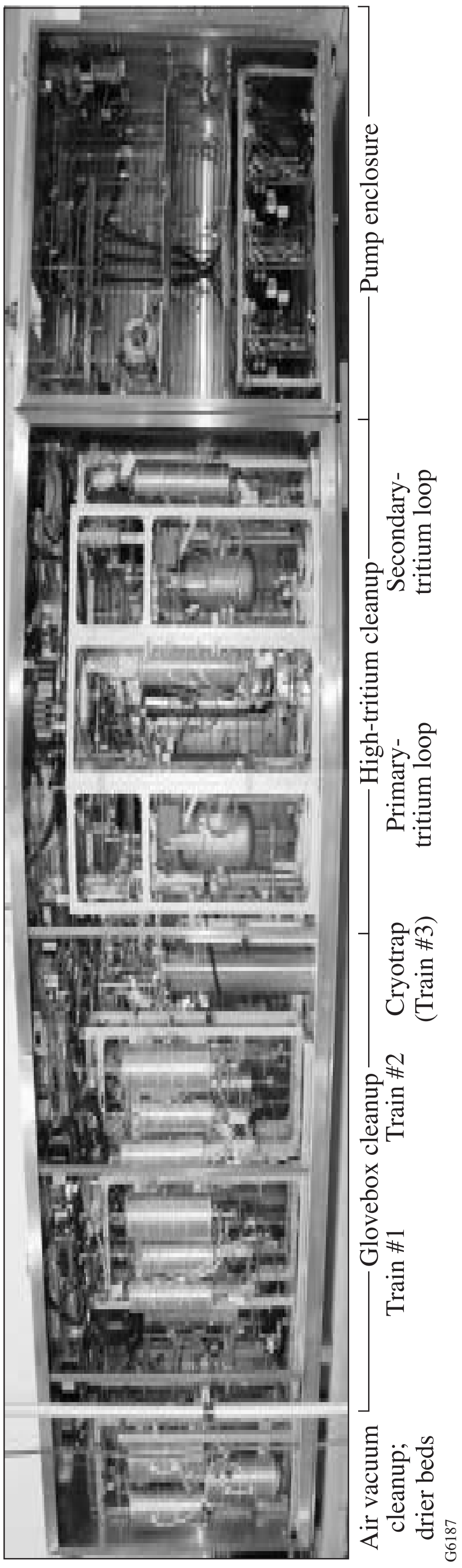

Figure 12.1-2
Room 157 Tritium Removal System.

Table 12.1-1 lists the CTHS equipment in Room 157 that is served by the TRS. This includes the TFS, which contains LLE's entire inventory of tritium except during cryogenic target fills. The DTHPS and FTS-1 handle the tritium during cryogenic fills and each of the MCTC's can contain one filled target and may be positioned at the FTS or either of the two Characterization Stations. (FTS-2 will not be exposed to tritium).

Table 12.1-1: Summary of Key Equipment that handles tritium in Room 157.

Equipment	Acronym	Count	Purpose
Tritium Fill Station	TFS	1	Reservoir of tritium and filling station for room-temperature tritium targets
DT High-Pressure Fill Station	DTHPS	1	Increases the tritium pressure for FTS filling
Fill and Transfer Station #1	FTS-1	1	Target filling and target transfer
Moving Cryostat Transport Cart	MCTC	5	Transfers targets from station to station
Characterization Station	CS	2	Characterizes filled targets

12.1.1 Tritium Specific Activity

The TRS processes gas streams that are characterized by two levels of specific activity.

- High Specific Activity: The activity level of this effluent can exceed 1 Ci/m^3 and must be reduced by a factor of 10^6.

- Low Specific Activity: The activity level of this effluent is typically in the mCi/m^3 range and must be reduced by a factor of 10^3.

Since the tritium reduction capability of one of the cleanup trains used in the TRS is typically in the 10^3 range, the high-specific-activity cleanup systems utilize two tritium-removal trains in series (Primary and Secondary Loops) to achieve the desired reduction. The high-specific activity cleanup trains are getter-based technology for tritiated helium and oxidation-based molecular sieve dryer technology for tritiated air (see Fig. 12.1-3).

The low-specific-activity cleanup system achieves the desired reduction with one train. Both a getter bed and a cryotrap are provided and either may be used. The low-specific activity train services the glovebox effluent (see Fig. 12.1-3).

12.1.2 Feed Streams

Four types of feed streams are processed by the TRS (Fig. 12.1-4): glovebox effluent, process equipment effluent, secondary containment effluent, and air (from the passbox and docking operations). Each type of feed stream requires a specific technology for processing the tritiated gas. The effluents and the associated technology are described in more detail below.

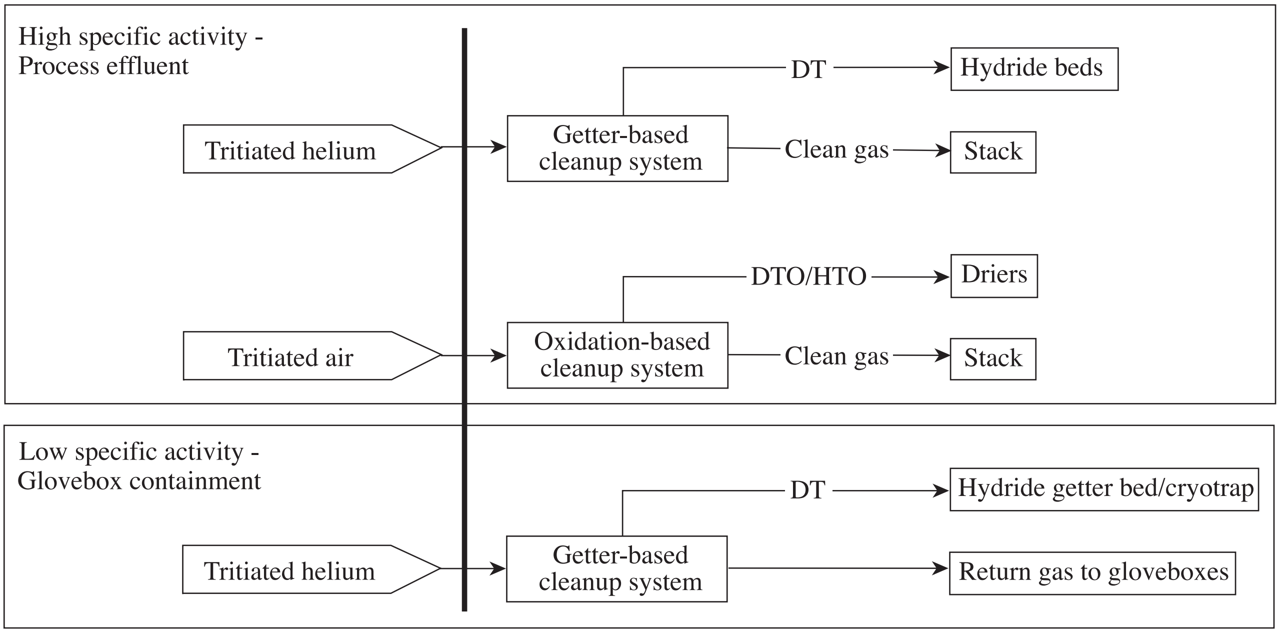

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Figure 12.1-3
High- and low-specific-activity cleanup systems.

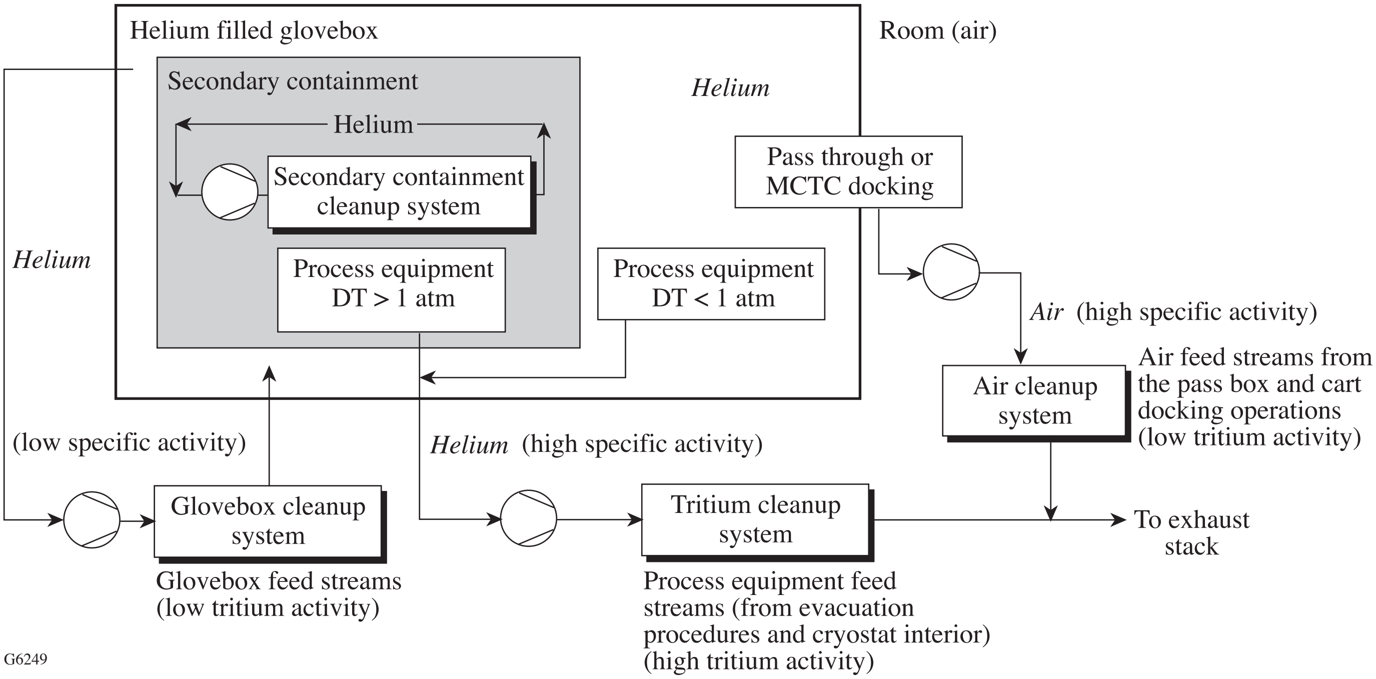

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Figure 12.1-4
Four types of feed streams are processed by the TRS. Four types of clean-up trains are used to clean up effluents.

12.1.2.1 Glovebox Effluent/GCS

The three glovebox enclosures that are serviced by the TRS are the DTHPS, FTS, and TRS gloveboxes. Helium gas within these enclosures is circulated continuously through the TRS glovebox cleanup system. The cleanup train removes moisture, volatile tritiated organic species, and elemental tritium from the gas stream. An independent glovebox cleanup system in the TFS has been in operation since 1996.

The primary technology used to remove tritium from the gloveboxes consists of a mole sieve bed for water removal, a nickel bed for cracking tritiated organic species, and a zirconium-iron (ZrFe) bed for absorbing elemental tritium (see Fig. 12.1-5). The nickel bed breaks down volatile hydrocarbons and trace water vapor. Elemental hydrogren and tritium are released from the nickel bed and captured by the ZrFe bed. Trace tritium that remains in the Ni bed is recovered as HTO when the Ni bed is regenerated. Tritium absorbed by the ZrFe bed is eventually transferred to a uranium bed. HTO vapor collected by the mole sieve beds is regenerated and stored as tritiated water in a containment vessel.

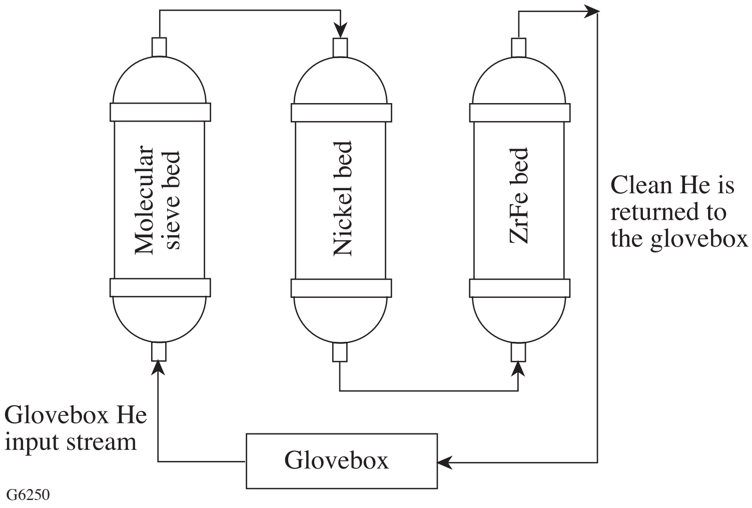

Figure 12.1-5
The glovebox cleanup system.

Two glovebox cleanup trains utilize the technology shown in Fig. 12.1-5. A third glovebox cleanup train utilizes cryogenic adsorption technology. This experimental technology utilizes a molecular sieve to adsorb moisture and a cryotrap to collect tritium and volatile tritiated organics (see Fig. 12.1-6).

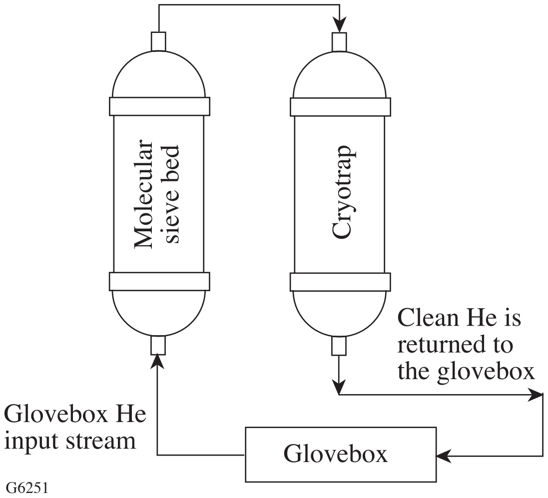

Figure 12.1-6
The glovebox cleanup system that utilizes the experimental cryotrap.

12.1.2.2 Process Equipment Effluent/Tritium Cleanup System

Process effluent is generated during various operations of the fill process. The exhaust from process loop evacuation, trace amounts of tritium that cannot be captured by the uranium bed, and the gas released within the cryostat interior are examples of the process effluents. These are gathered into the three feed streams listed in Table 12.1-2. Water, tritiated organic species, and elemental tritium are removed from the exhaust streams before discharging to the stack.

Table 12.1-2: Tritium Cleanup System (TCS).

Feed Streams (Vacuum Manifold)	Source of the Gas	Operation that Generates the Gas
High DT	TFS DTHPS FTS	Target filling Target transfer to MCTC
Low DT	MCTC	Docking stations
Clean helium (flows to stack or TRS)	FTS base FTS dome FTS cooling module	Continuous Continuous Continuous

The technology used to remove tritium from the process effluent consists of a mole sieve bed for water removal, a nickel bed for cracking tritiated organic species, and two zirconium-iron beds (one each for the Primary and Secondary Loops) for absorbing elemental tritium. A simplified diagram of the process flow is shown in Fig. 12.1-7. Elemental tritium absorbed by the ZrFe beds is eventually transferred to a uranium bed. HTO collected by mole sieve beds is regenerated and stored as tritiated water in a containment vessel.

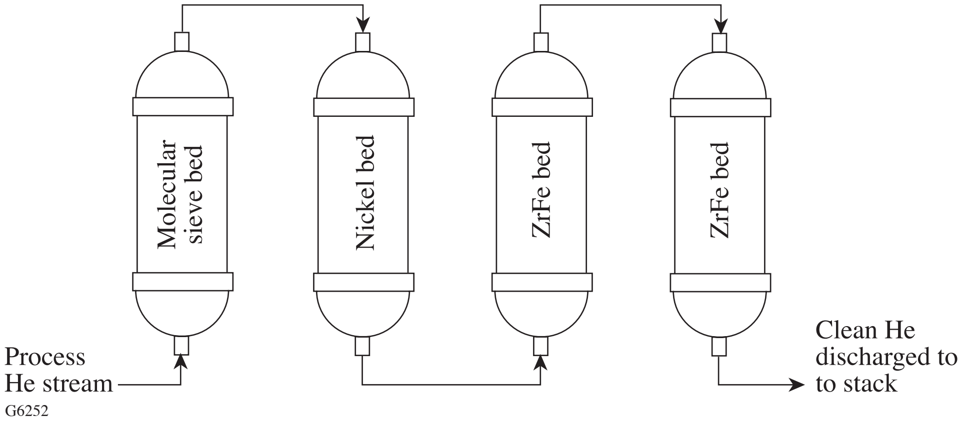

Figure 12.1-7
The tritium cleanup system for the process effluent uses dual absorbing beds.

12.1.2.3 Secondary Containment Effluent/DTHPS Secondary Containment Cleanup System

The tritium pressure exceeds 1 atm inside several components within the DTHPS. These are housed in the three secondary containment volumes listed in Table 12.1-3. Helium is continuously circulated from the secondary containment enclosures through the TRS secondary containment cleanup system to remove tritium from the helium purge gas stream. The technology used consists of a zirconium-iron bed and a uranium bed for absorbing tritium. A simplified diagram of the process flow is shown in Fig. 12.1-8. Elemental tritium absorbed in the ZrFe beds is eventually transferred to a uranium bed.

Table 12.1-3: DTHPS Secondary Containment Cleanup System (DSCCS).

Feed Streams (Vacuum Manifold)	**Secondary Containment**	**Operation that Generates the Gas**
Containment volumes (3)	High-pressure valve High-pressure gauge Condensation tube, valves, and piping	Continuous cleaning of containment atmosphere

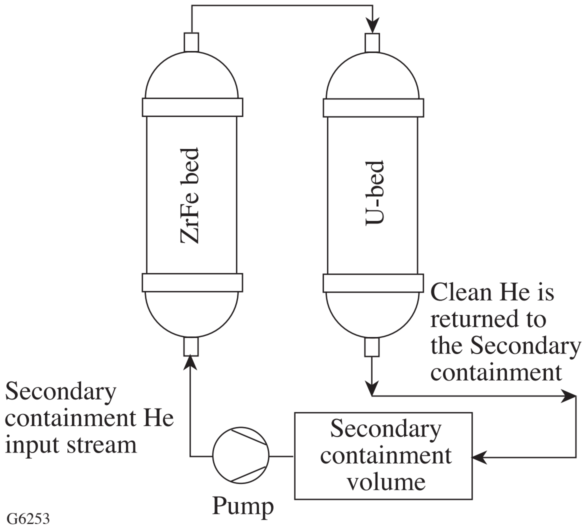

Figure 12.1-8
The DTHPS secondary containment cleanup system.

12.1.2.4 Air Effluent/Air Vacuum Cleanup System

During certain operations, including passbox and MCTC docking operations, the CTHS equipment must be opened to air. When the air is subsequently evacuated from the process equipment, tritiated water, organic species, and any elemental tritium are removed from the exhaust streams by the air cleanup system before discharging to the stack. Table 12.1-4 lists the volumes supported.

Table 12.1-4: Air Vacuum Cleanup System (AVS).

Feed Streams (Vacuum Manifold)	Source of the Gas	Operation that Generates the Gas
Air	FTS passbox	Inserting/removing target racks
	FTS interspace	Connecting MCTC with FTS
	Characterization station	Pumping down characterization chamber from air

The technology used to remove tritium from air consists of a mole sieve bed for water removal, a catalytic reactor for converting tritiated organic species and elemental tritium into HTO vapor and a second mole sieve bed for the final water removal (see Fig. 12.1-9). The tritium removed is ultimately stored as HTO liquid in a containment vessel.

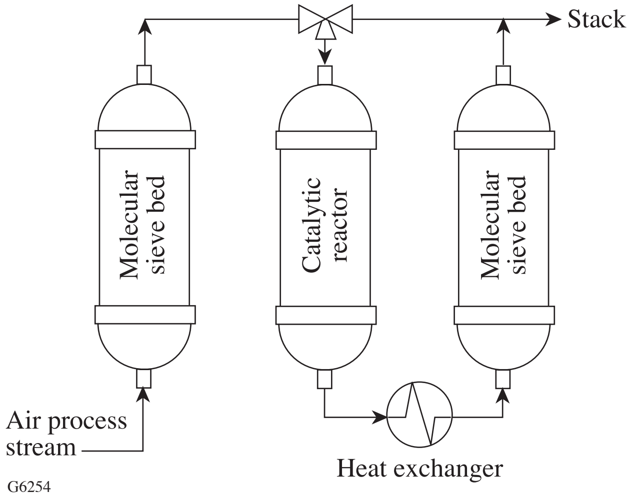

Figure 12.1-9
The TRS air cleanup system.

12.1.3 Regeneration

The beds become saturated with water and must be regenerated periodically. The TRS is designed to regenerate the beds *in situ*. This reduces the radiological hazard by reducing the need to break into contaminated process lines. High-specific-activity tritium (concentrations exceeding 100 μCi/L) is collected with the condenser and is shipped off-site for enrichment and reuse. Isotopic enrichment entails removing protium and deuterium atoms from the H-D-T mixture to yield 99.8% pure elemental tritium gas. Low-specific-activity tritium is immobilized in a sorbent and packaged for land disposal. All tritium collected on the uranium bed is isotopically enriched off-site for reuse (see Fig. 12.1-10).

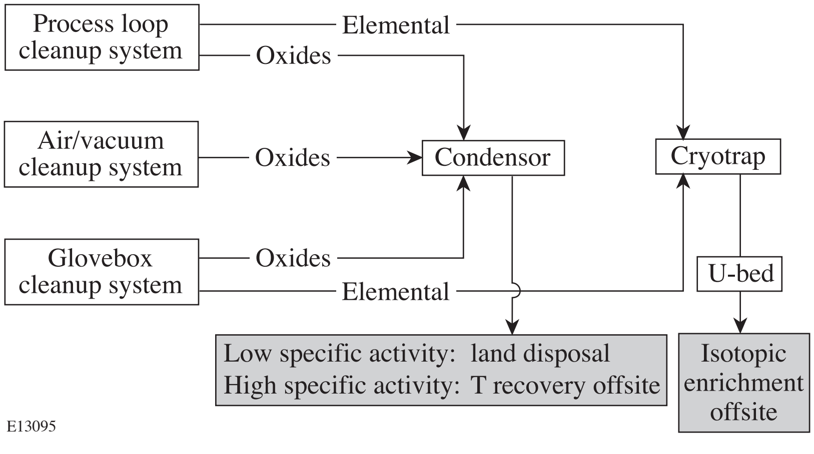

Figure 12.1-10
An overview of the TRS regeneration process.

12.1.4 TRS Technology Overview

The tritium fill station cleanup system has been operating successfully since 1996. ZrFe, Ni, and molecular sieve drier adsorption beds are the heart of the TFS cleanup system. The Room 157 TRS utilizes the same proven technology in a modularized integrated system (see Fig. 12.1-11).

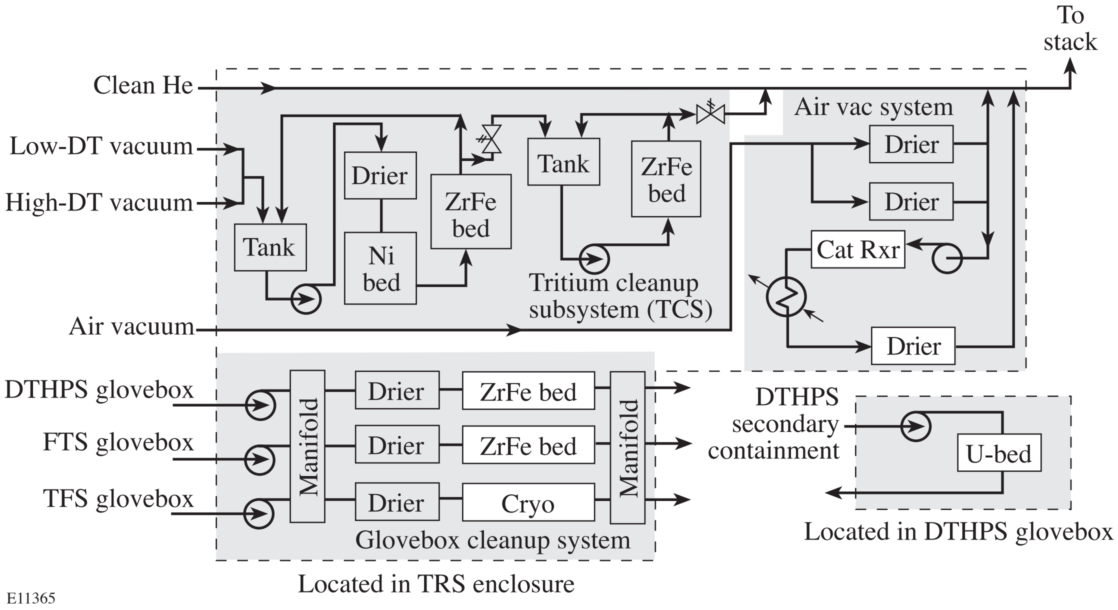

Figure 12.1-11
The Room 157 TRS process overview.

12.1.5 TRS Design Objectives

The tritium handling design objectives are as follows:

- Operate with a site inventory of up to 10,000 Ci
- Maintain airborne tritium release from the facility to <2 Ci/year
  - Wastewater disposal limit: 10 μCi/L (22 kDPM/ml) (based on 50 mred/a)
  - Airborne tritium concentrations <0.1 μCi/m^3 in public areas; to <20 mCi/m^3 in tritium work areas
- Maintain accessible exposed surface contamination levels to <1000 dpm/100 cm^2
- Maintain chronic glove box activities to below 1 μCi/m^3
- Reclaim elemental tritium where possible to minimize handling of DTO and HTO
- *In-situ* bed regenerations

12.2 EQUIPMENT OVERVIEW

Most of the process equipment associated with the TRS is mounted in the 24-ft-long equipment enclosure shown in Fig. 12.1-2. Several important supporting components are located outside the enclosure and distributed throughout Room 157. Table 12.2-1 lists all the equipment associated with the TRS, and Fig. 12.2-1 illustrates the location of the equipment in Room 157.

Table 12.2-1: List of Major Components of TRS.

Equipment	Description
TRS Main Enclosure	Houses the bulk of TRS process equipment; 18-ft-long × 7-ft-tall × 41-in.-deep stainless steel enclosure.
TRS Pump Enclosure	Houses FTS system vacuum pumps and TRS system glovebox recirculation pumps; Pump enclosure is bolted to the main enclosure; 6-ft-long × 7-ft-long × 35-in.-deep stainless steel enclosure.
TRS Heater Control Cabinet	Electrical cabinet for high-voltage heaters for adsorption and catalytic reactor beds; 6-ft-tall × 42-in.-wide × 18-in.-deep.
TRS Pump Control Cabinet	Pump electrical control cabinet for three-phase vacuum and recirculation pumps; 6-ft-tall × 42-in.-wide × 18-in.-deep.
TRS PLC Control Rack	Main computer controlling TRS process; Consists of PLC, several process analyzers, and a UPS (universal power supply).
TRS HMI Computer	Personal computer used by operators to monitor and control the TRS.
DTHPS Secondary-Containment Subsystem	Dedicated cleanup system for the DTHPS secondary containment; Consists of beds, pumps, valves, instrumentation, and controls.
Field-Mounted Equipment	Miscellaneous field-mounted instrumentation for glovebox cleanup subsystem

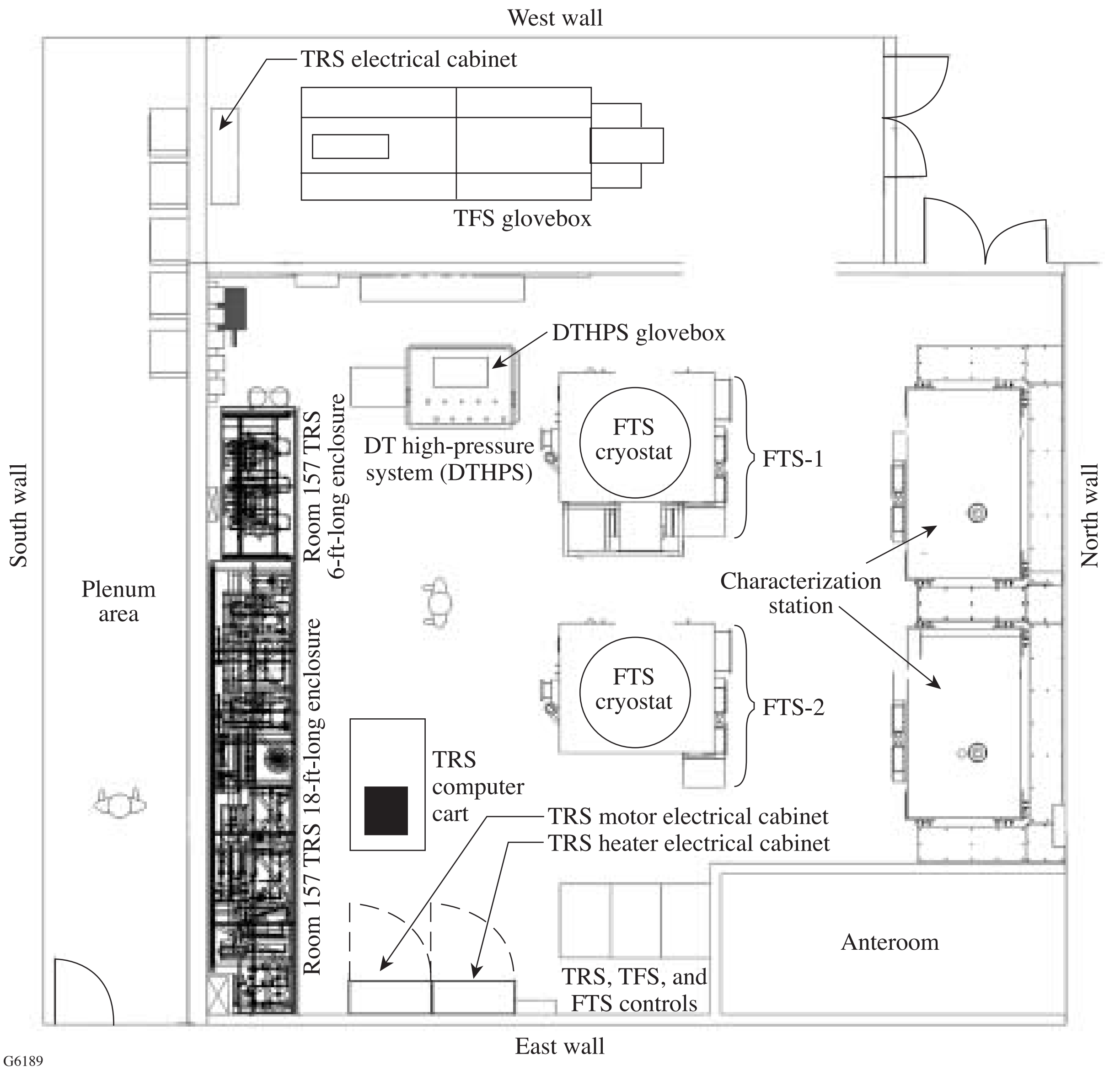

Figure 12.2-1
Layout of Room 157 showing TRS equipment.

12.2.1 TRS Modules Summary

Fifteen modules comprise the TRS process equipment within the main enclosure. The modules correspond very closely to the TRS subsystems. Table 12.2-2 lists and describes the TRS modules. Figures 12.2-2 and 12.2-3 illustrate the modular nature of the TRS.

Table 12.2-2: TRS Modules and Description.

Module Number	Description	TRS Subsystem
M-1	Air vacuum cleanup driers and instrumentation	Air Vacuum Cleanup
M-2	Condenser CD-88-01 and condensate tank T-88-01	Air Vacuum Cleanup
M-3	Catalytic reactor and air vacuum recirculation pump	Air Vacuum Cleanup
M-4	Glovebox cleanup adsorption train #1	Glovebox Cleanup
M-5	Glovebox cleanup adsorption train #2	Glovebox Cleanup
M-6	Drier for glovebox cleanup train #3 (cryotrap)	Glovebox Cleanup
M-7	Glovebox return valve manifold and instruments	Glovebox Cleanup
M-8	Regeneration pump, U-bed, instruments, and valves	Regeneration
M-10	Cryotrap	Glovebox Cleanup
M-11	Primary-Loop tank T-86-10 and pump P-86-10	Tritium Cleanup
M-12	Primary-Loop adsorption train	Tritium Cleanup
M-13	Secondary-Loop tank T-86-10 and pump P-86-10	Tritium Cleanup
M-14	Secondary-Loop ZrFe bed	Tritium Cleanup
P-17	Glovebox recirculation pumps and valve manifold	Glovebox Cleanup

Figure 12.2-2
Module M-1 during the build phase showing the underlying structure and modular nature of the TRS.

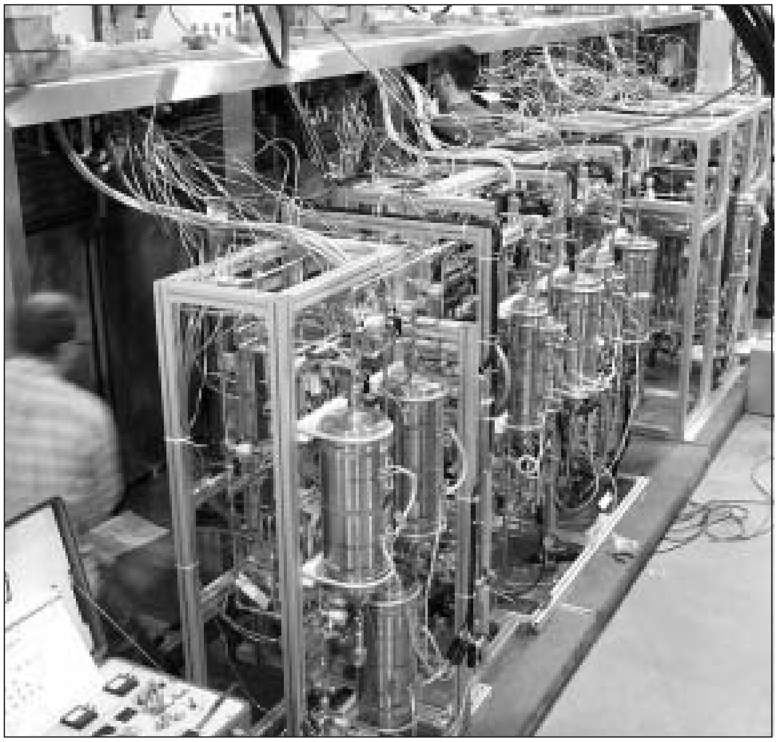

Figure 12.2-3
The modules of the TRS prior to installation.

12.2.2 Subsystem and Component Summary

The TRS is comprised of numerous subsystems that utilize various components.

The following provides an overview of the subsystems:

1. **Tritium Cleanup Subsystem**–This subsystem removes tritium from the processed He. The following components are utilized:

    - *Recirculation Tanks:* The receiver vessels that provide surge capacity and buffering.
    - *Mole Sieve Bed:* Removes moisture from the tritiated He effluent.
    - *Ni Bed:* Cracks organic molecules to free tritium and hydrogen.
    - *ZrFe Bed*: Absorbs tritium from the He effluent.

2. **Air Vacuum Cleanup Subsystem**–This subsystem removes tritium from the process air. The following components are utilized:

    - *Reactor Preheater:* Preheats the gas before entering the reactor.
    - *Catalytic Reactor:* Oxidizes tritium to form water and CO_2.
    - *Mole Sieve Bed (3):* One bed removes tritiated water from the air; the other two beds allow for redundancy and regeneration.
    - *Pump:* Provides the pressure required to process the gas through the catalytic reactor and mole sieve beds.

3. **Glovebox Cleanup Subsystem**–This subsystem removes tritium and moisture from the glovebox atmosphere (He). The following components are utilized:

    - *Pumps (3):* Circulate the glovebox He atmosphere (TRS, DTHPS, and FTS) through the cleanup train.
    - *Mole Sieve Bed:* Removes moisture from the tritiated He.
    - *Ni Bed:* Cracks organic molecules to free tritium and hydrogen.
    - *ZrFe Bed:* Absorbs tritium from the He effluent.
    - *Cryotrap:* Absorbs tritium from the He effluent.

4. **DTHPS Secondary-Containment Cleanup Subsystem**–This system removes tritium from the secondary containment atmosphere (tritiated He). The following components are utilized:

    - *Secondary Containment Volumes:* All process equipment operated above 1 atm is contained in metal enclosures. There are three of these contained volumes.
    - *Pump:* Circulates He through the containment volumes and the cleanup train.
    - *Uranium Bed:* Removes potentially large quantities of tritium from the He effluent.
    - *ZrFe Bed:* Removes the residual tritium from the He effluent.

5. **Regeneration Subsystems**–The mole sieve beds, Ni beds, ZrFe beds, and cryotrap must be regenerated periodically. Various combinations of following components are used for regeneration processes:

   - *Bed Undergoing Regeneration:* The bed being regenerated.
   - *Pump:* Circulates the effluent through the regeneration train.
   - *Uranium Bed:* Absorbs the vast majoritiy of tritium in the regeneration stream.
   - *Cryotrap:* Absorbs the residual tritium in the regeneration stream.
   - *Air Vacuum Cleanup System:* Utilized during the nickel bed regeneration.
   - *Mole Sieve Beds (3):* All three mole sieve beds are used during the mole sieve regeneration process.
   - *N_2 Preheater:* Heats N_2 effluent for the mole sieve regeneration process.
   - *Condenser:* Condenses tritiated water during the mole sieve regeneration process.
   - *Condensate Receiver*: Tritiated water from the condenser is stored in this vessel.
   - *Reactor Preheater*: Preheats the effluent prior to entering the reactor.
   - *Catalytic Reactor*: Oxidizes tritium to form water.

Most of the components outlined above can be seen in Figs. 12.2-4 to 12.2-7.

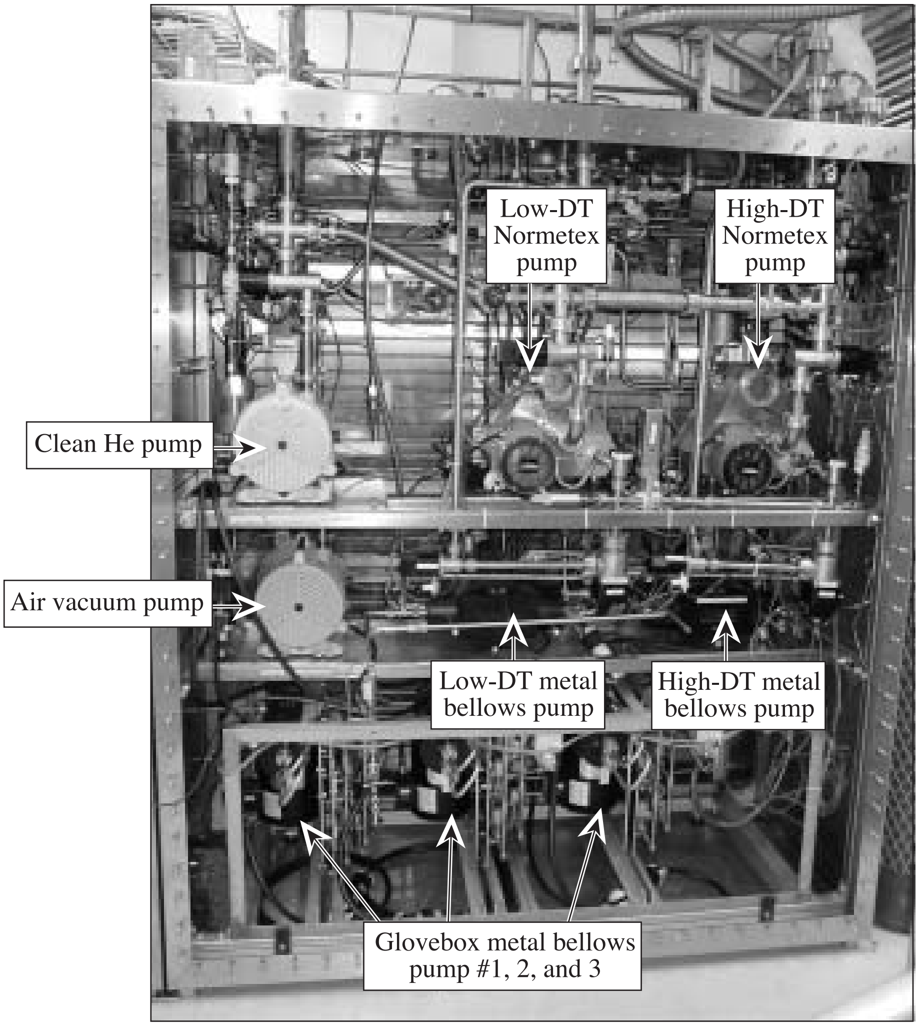

Figure 12.2-4
TRS pump enclosure.

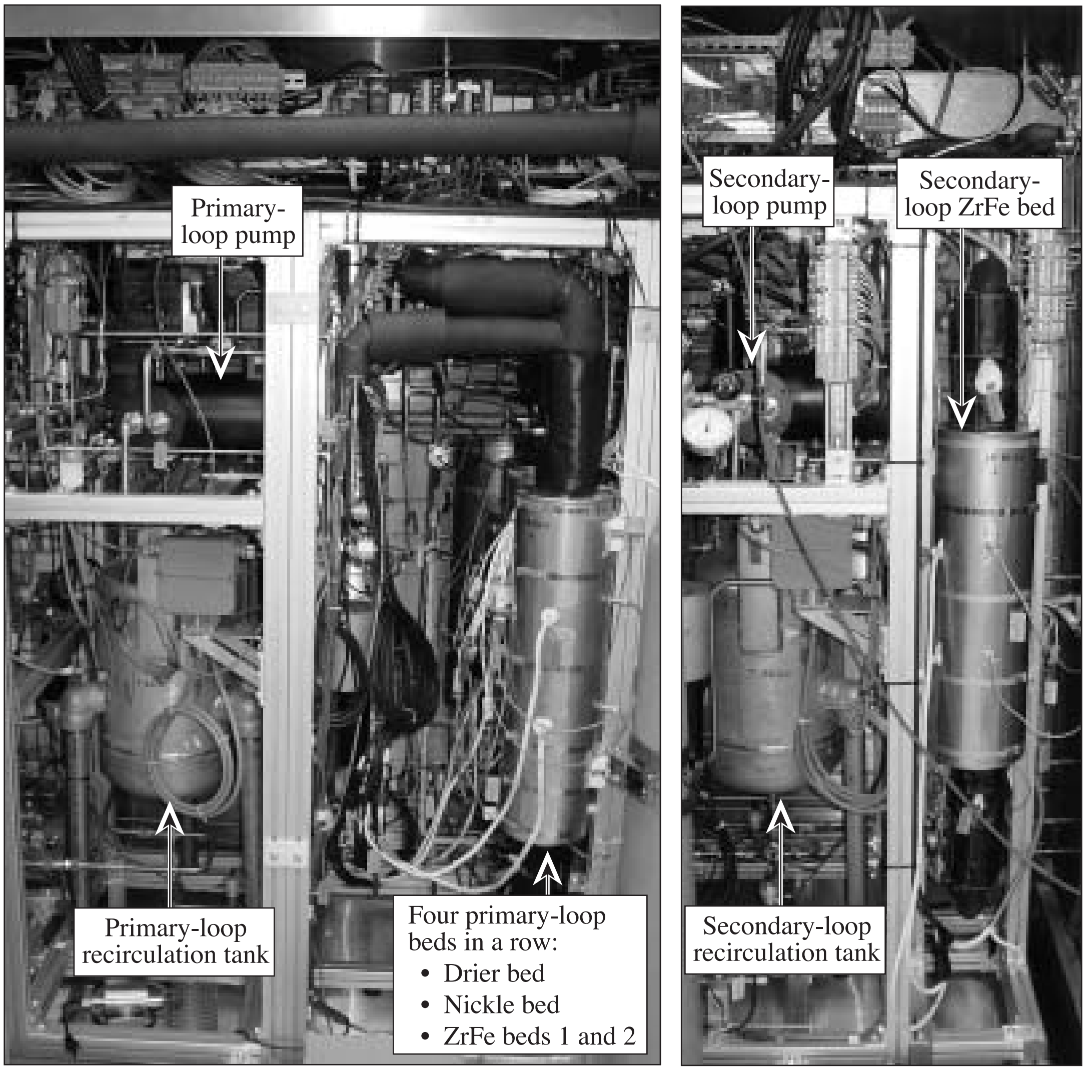

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Figure 12.2-5
Tritium Cleanup System.

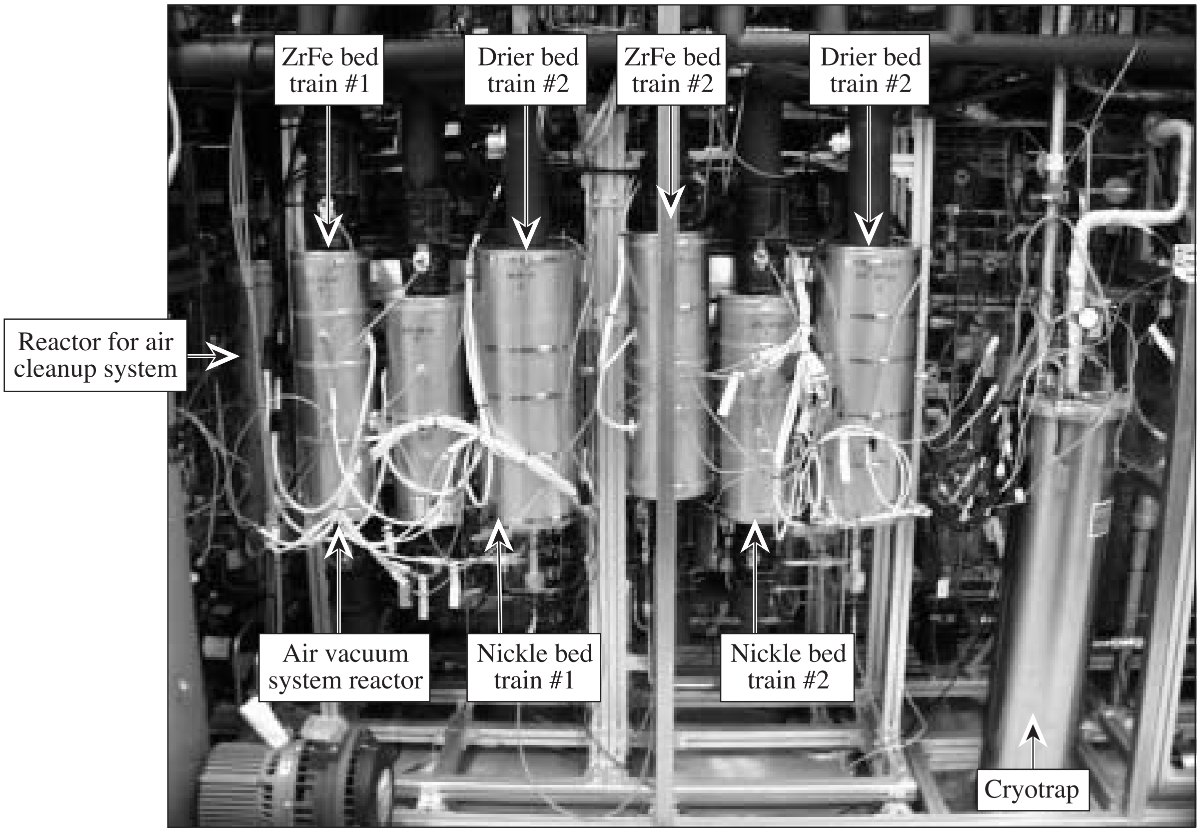

Figure 12.2-6
Glovebox Cleanup System and Air Vacuum Cleanup System.

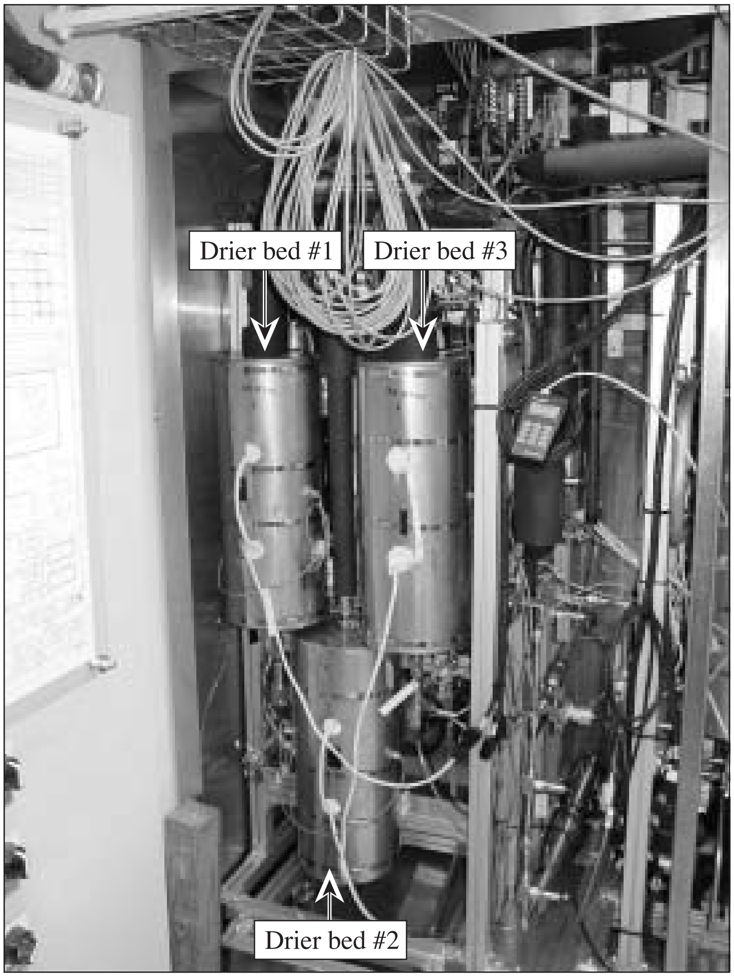

Figure 12.2-7
Air Vacuum Cleanup System.

12.2.3 Component Description

12.2.3.1 TRS Main Enclosure

The Main Enclosure is connected to the Pump Enclosure and forms a leak-tight seal in readiness for converting the enclosure into a glovebox, if necessary. Connections and supports inside the enclosure do not penetrate the containment envelope and do not cause traps, or inaccessible areas, where moisture can accumulate. All external connections, both electrical and mechanical are made via sealed passthroughs through the top of the enclosure. Feedthrough leak rates meet the 1×10^{-5} cc/s leak-tightness criteria of a glovebox. The entire unit can easily be fitted with suitable closure windows to allow it to operate.

12.2.3.2 TRS Pump Enclosure

The Pump Enclosure houses the FTS vacuum pump manifold and the TRS glovebox recirculating pumps. The pump enclosure utilizes leak-tight feedthroughs and process connections, which allows the enclosure to operate as a glovebox.

The FTS vacuum pump manifold includes pressure transducers and automatic valves as well as vacuum pumps. The entire FTS vacuum pump manifold is controlled by the FTS PLC even though it is located within the TRS.

12.2.3.3 Process Piping

All process piping is fabricated from smooth-bore 316 stainless steel tubing that was precleaned prior to installation. All process connections are made using VCR fittings with copper gaskets. The piping integrity was verified using helium leak testing. The system demonstrated leak tightness to below 7.6×10^{-6} Torr-liter/s. All welds were performed using automatic orbital welding equipment. All pipe unions were made using butt welds and welds tested to 10^{-9} Tl/s.

12.2.3.4 Process Valves

High-integrity, low-leak-rate valves are utilized in this system. The valves are tritium compatible. They are resistive to DT degradation and do not contain fluorinated materials. A stainless steel bellows is used in the bonnet to isolate the wetted areas from the upper stem; no packing is used. Three types of valves are used:

- **Nupro BK:** utilizes Vespel™. The stem tips can be replaced in these valves. Most of the valves used in the system are BK valves.
- **Nupro BG:** the Vespel™ stem tips can be replaced in these valves.
- **Nupro BW:** these valves are used in high-temperature applications. Welded bellows are used in these valves. The stainless steel stem tips cannot be replaced. These valves are used for manual isolation of the adsorption bed.

12.2.3.5 Pumps

The process pumps used throughout the TRS are modified metal bellows pumps from Senior Flexonics. These pumps employ reciprocating metal bellows and metal reed valves to compress gas. The pumps have been modified by the vendor to include induction motors that allow for the use of inverters to control pump speed. Pump speeds from 20% to more than 100% of normal speed are available.

The two types of metal bellows pumps used in the TRS are single (MB-158) and dual reciprocating bellows (MB-601). The MB-601 pumps are plumbed in parallel to allow for throughput up to 5 cfm with atmospheric input and zero head pressure. The GE speed controllers for the pumps are located within the Pump Electrical Enclosure. An MB-601 pump is shown in Fig. 12.2-8; Table 12.2-3 lists the pumps used in the TRS.

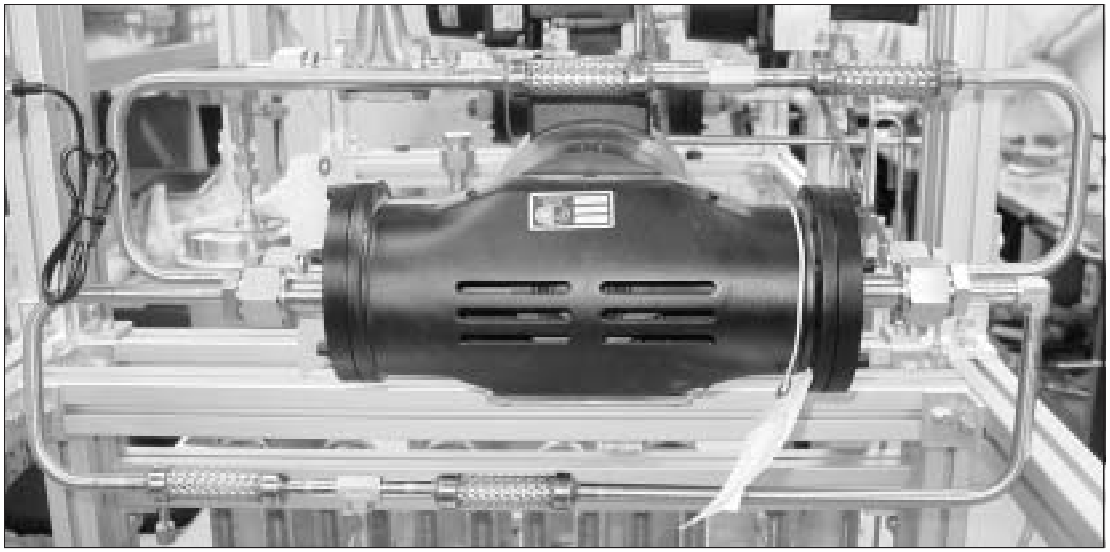

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Figure 12.2-8
Senior Flexonics MB-601 Metal Bellows Pump. The MB-601 employs dual flexible metal bellows to compress process gas. The pump is plumbed in a parallel arrangement for higher throughput.

Table 12.2-3: Metal Bellows Pumps Employed in the TRS.

Pump Tag Number	Speed Control (yes/no)	Pump Model	Pump Number (Modified for Tritium Service)
P-88-01	no	MB 158	41419
P-86-10	yes	MB 601 Parallel	43394
P-86-20	yes	MB 601 Parallel	43394
P-87-01	no	MB 601 Parallel	43394
P-89-01	yes	MB 601 Parallel	43394
P-89-02	yes	MB 601 Parallel	43394
P-89-03	yes	MB 601 Parallel	43394

12.2.3.6 Recirculation Tanks

There are three tanks in the TRS. Two of these tanks are 40-liter recirculation tanks that support the tritium cleanup system. The third tank is a 1-liter tank that stores tritiated water from the regeneration condenser.

12.2.3.7 Adsorption Beds

The beds are certified for a maximum-allowable working pressure (MAWP) of 116 psig at 1022°F (550°C). All welds were radiographed. The outside surface of the shell (pipe) has two wide-area, mineral-insulated, band heaters capable of achieving 550°C. The band heaters occupy more than 75% of the bed outside the surface area. Two thermocouples monitor bed temperatures for each heater: one is for control and the other is hardwired to the heater controller and acts as a safety shut-off. Thermocouples on the inlet tubing and on the outlet tubing measure the bed inlet and outlet gas temperatures. Figures 12.2-9 and 12.2-10 illustrate a typical bed.

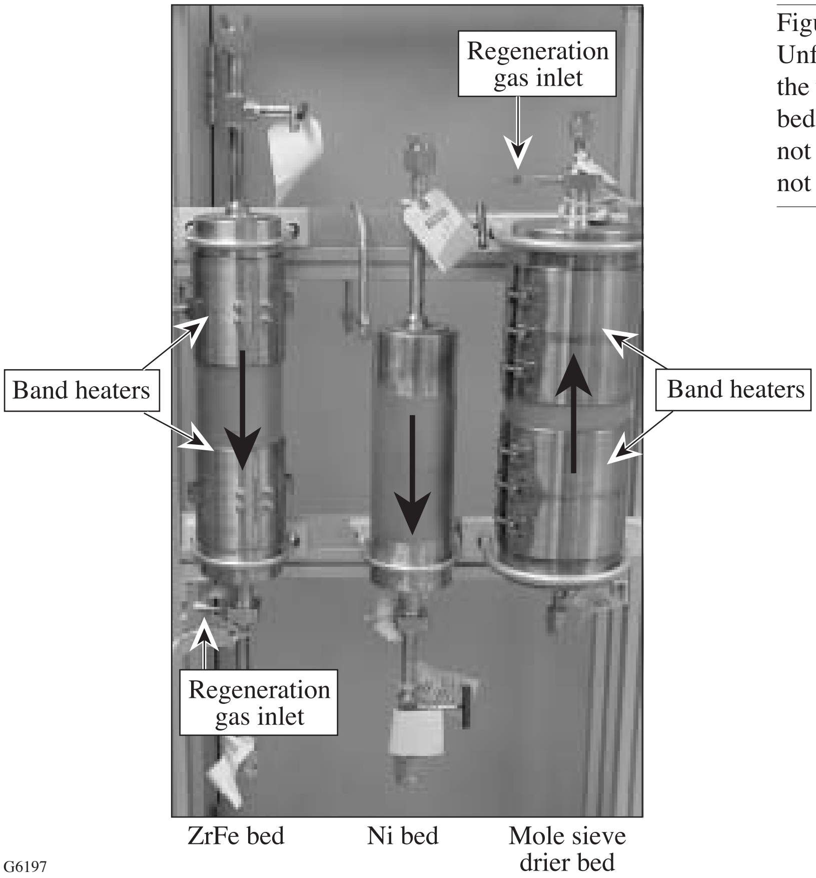


Figure 12.2-9
Unfinished Adsorption Beds. The image shows the underlying construction of the the adsorption beds used in the TRS. The beds, as shown, are not equipped with the integral pre-heater and are not insulated.

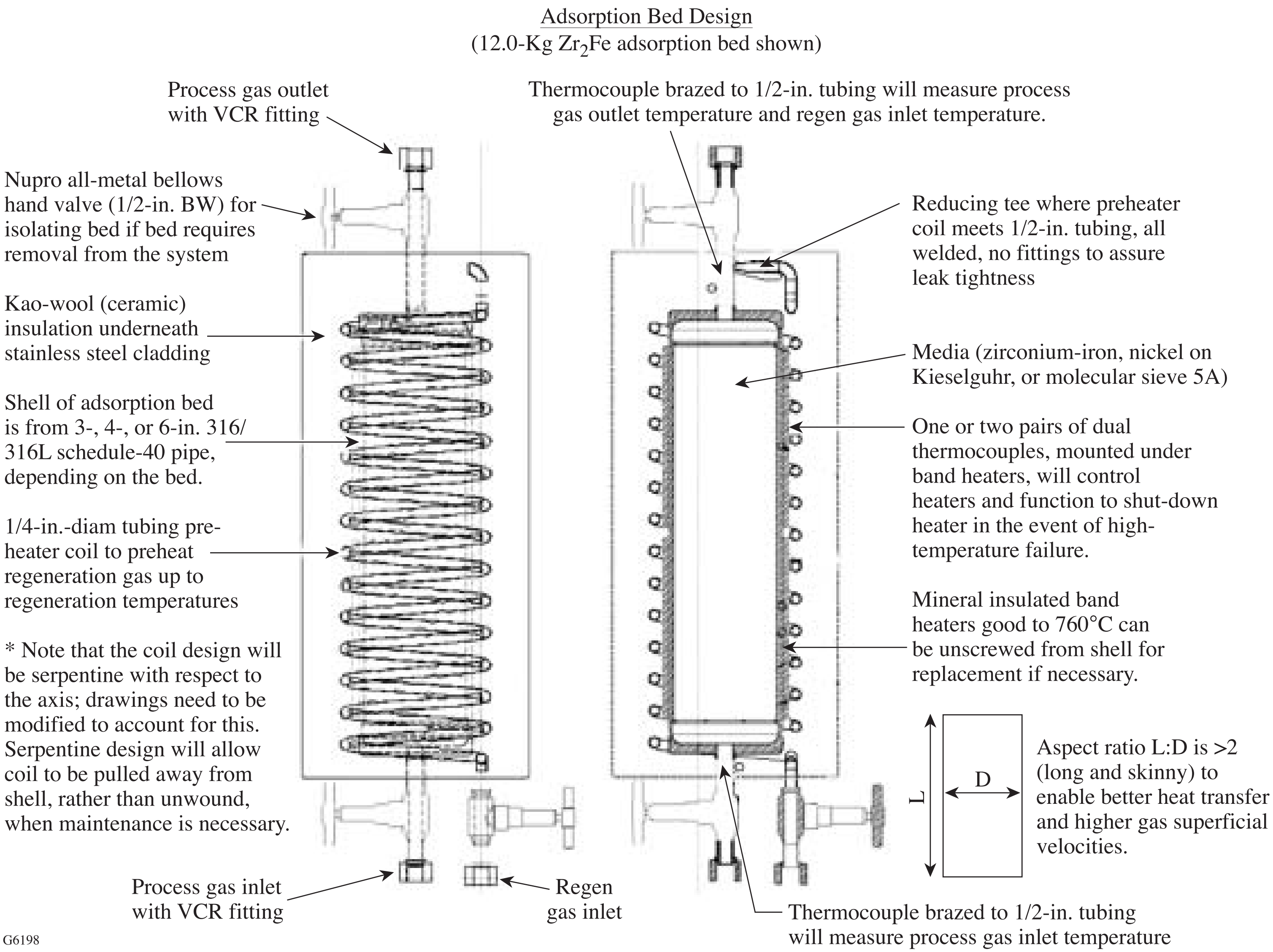


Figure 12.2-10
Design of Adsorption Beds. This diagram shows design elements of the TRS adsorption beds.

The beds include an integral preheater for bed regeneration. The preheater consists of small-diameter (1/4-in.) stainless steel tubing wrapped around the outside of the band heaters.

The bed is insulated using 1-in.-thick insulation covered with a stainless steel shell. The insulation covers the entire preheater assembly and covers both end caps. Table 12.2-4 lists all the filled beds. The dimensions of the various size beds have been selected so that they all have approximately the same length/diameter ratio.

Table 12.2-4: TRS Filled Bed Schedule.

Vessel	Vessel Drawing Number	Vessel Tag Number	Current Rev	Total Length (in.)	Number of Vessels
5.0-kg Molecular Sieve Drier	LLE: D-TR-C-34 ALL-WELD: 3471-1	DR-86-11 DR-87-01 DR-87-02 DR-87-03 DR-89-01 DR-89-02 DR-89-03	C	26.75	7
0.9-kg Molecular Sieve Drier for Cryotrap	LLE: D-TR-C-35 ALL-WELD: 3568-1	CT-DR-01 CT-DR-02 CT-DR-03	B	16.6	3
1.6-kg Nickel Catalyst Bed	LLE: D-TR-C-38 ALL-WELD: 3470-1	NB-86-10 NB-89-10 NB-89-20	B	34.5	3
12-kg Zirconium-Iron Bed	LLE: D-TR-C-37 ALL-WELD: 3466-1	ZB-86-10 ZB-86-11 ZB-86-20 ZB-89-10 ZB-89-20	B	40.0	5
3-kg Zirconium-Iron Bed	LLE: D-TR-C-39 ALL-WELD: 3467-1	ZB-89-30	B	18.0	1
300-g Uranium Getter Bed	LLE: D-TR-C-36 ALL-WELD: 3472-1	GB-88-01 GB-89-01	D	20.75	2

Four types of adsorption beds utilized in the TRS. The following provides more details on these beds:

Mole Sieve Bed

The TRS employs seven (7) drier beds. The drier beds are identical to the general adsorption beds described above except for the following:

- 5 kg of molecular sieve 5A is used as the media.
- The bed bodies employ 6-in. Sch 40 pipe.
- The media is held in place by 100-μm Iconel frits.

Ni Bed

The TRS includes three (3) nickel beds. The nickel catalyst beds are identical to the general adsorption bed described above except for the following:

- 1.6 kg of 1/8-in. pellets of 60-wt% nickel catalyst on Kieselguhr carrier.
- The bed bodies employ a 4-in. Sch 40 pipe.
- The media is held in place by 10-μm stainless steel frits.

A different form of catalyst was used in these nickel beds than the material historically used at LLE. A 1/8-in. pellet form was used as opposed to a powder form. The latter would have resulted in an unacceptably large pressure drop since longer beds were being fabricated and higher flow rates were planned. The material is otherwise the same.

ZrFe Bed

A total of six (6) ZrFe beds are installed in the system—five are 12-kg beds and one is a 3-kg bed. The ZrFe beds are identical to the general adsorption bed described above except for the following:

- SAES ST-198 ZrFe pellets will be used as the media.
- The 12-kg beds employ a 4-in. Sch 40 pipe.
- The 3-kg beds employ a 3-in. Sch 40 pipe.
- The media is held in place by 100-μm stainless steel frits.

The ZrFe can remove tritium from inert gas with great efficiency. Purification factors, the ratio of the partial pressures for inlet versus outlet concentrations of tritium on the order of 10,000 have been demonstrated. For ZrFe beds with low loadings, outlet concentrations well under 1 mCi/m^3 can be attained.

ZrFe is a material sold by SAES Getters under the trade name of ST-198. Its chemical composition is predominantly $ZrFe_2$ but “ZrFe” is used here for shorthand. It was developed as a “getter” or “scavanger” to remove trace impurities in incandescent light bulbs. At elevated temperature, it is very reactive with and has a large capacity to adsorb hydrogen isotopes. It is also very reactive with water and oxygen, so these species must be excluded from gas streams where ZrFe is used. ZrFe does not react with the helium used in the CTHS for glovebox atmospheres and process operations. Figure 12.2-11 illustrates the adsorption isotherm of ZrFe with hydrogen.

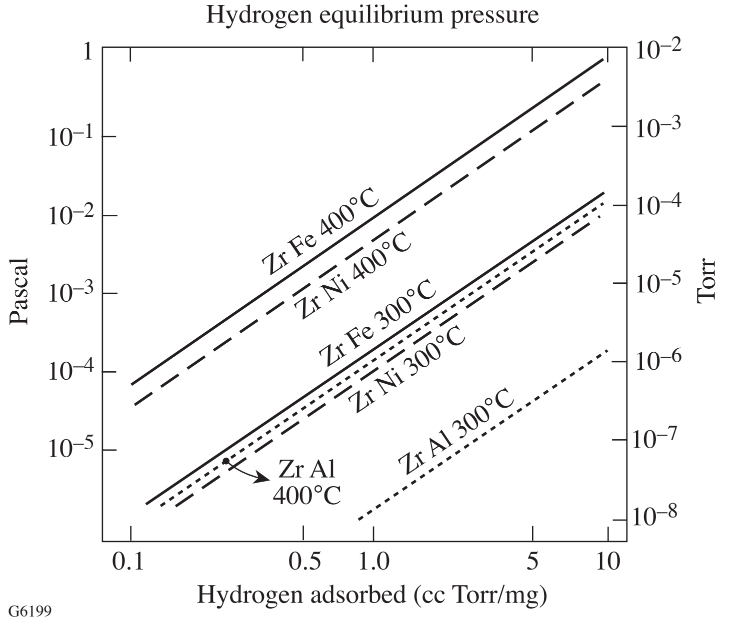


Figure 12.2-11
Adsorption isotherm for hydrogen on ST-198 ZrFe (from SAES Getters, USA). Note that, with regard to the abscissa of the figure, there are 3.4 × 10^{-3} Ci in 1 Torr-cc.

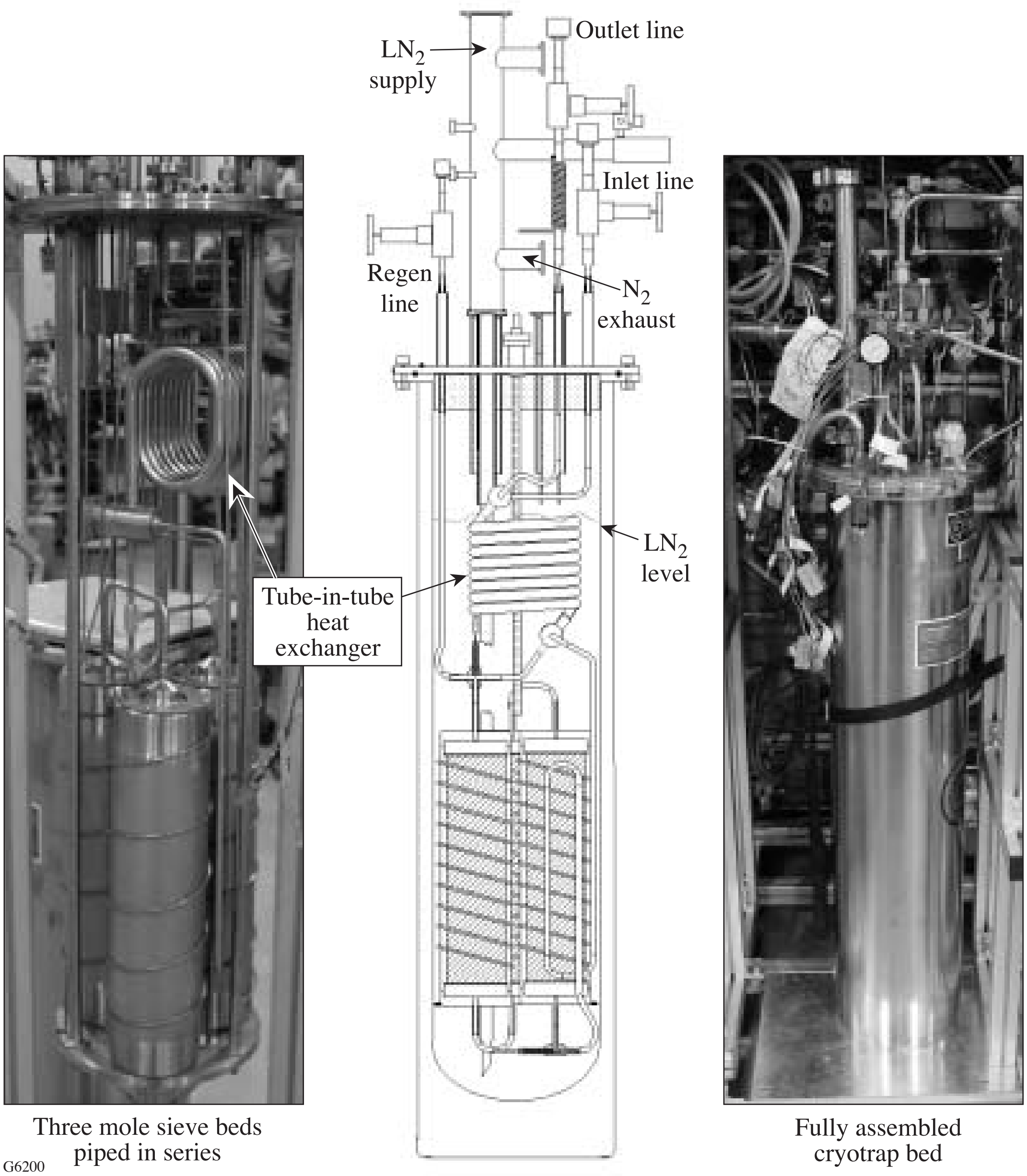
Uranium Bed

The two (2) uranium getter beds are fabricated out of stainless steel, and each contains 300 g of depleted uranium. The bed diameters are approximately 2 in., and the beds are divided into two compartments of equal length, each containing 150 g of uranium. Frits with a pore size of 2 μm are placed at the top and bottom to contain the uranium fines, and a supported 100-μm frit separates the two chambers.

12.2.3.8 Cryotrap

This method of removing tritium from gas streams employs molecular sieves operating at liquid nitrogen (LN_2) temperatures. In this technique, packed beds of molecular sieve 5A are immersed in a dewar filled with liquid nitrogen. Process gas, precooled to 77 K, is passed over the beds, and tritium is physically adsorbed by the molecular sieve. The advantage of this process is that the adsorbed tritium can easily be released from the bed by raising the bed temperature to 120 K. A molecular sieve drier is used to remove water from the effluent stream before it arrives at the cryostat. Water will saturate the cryotrap and restrict the process lines with ice formation.

The cryotrap consists of three smaller molecular sieve beds in a series (see Fig. 12.2-12) that are contained within a stainless steel dewar. Each bed contains 0.9 kg of molecular sieve 5A. A tube-in-tube heat exchanger contained within the dewar connects the beds to the process inlet and outlet. The heat exchanger functions to cool down the incoming warm gas and to warm up the exiting gas.



Three mole sieve beds piped in series

Fully assembled cryotrap bed

Figure 12.2-12
Cryotrap beds (left), drawing of the cryotrap (center), and final installed unit in the dewar (right).

Each of the three beds has a cable heater that is used for regeneration. Thermocouples measure in-line gas temperature and the bed outer temperature. A continuous level sensor in the 18-in. space above the top of the beds controls the LN_2 supply.

A vacuum-jacketed feed line and valve supply LN_2 to the dewar. A vacuum-jacketed exhaust line carries the cold nitrogen gas away. The dewar employs a permanent vaccum jacket and is rated to temperatures up to 350°C.

Process heaters throughout the cryotrap prevent cold spots that might lead to condensation. Heaters are also installed on the top of the dewar and on the outlet line. A preheater is installed on the inlet regeneration gas line.

12.2.3.9 Catalytic Reactor

Catalytic reactors are utilized in air streams. The catalytic reactor oxidizes tritium in the presence of air to form tritiated H_2O. This is a common method for removing tritium from air streams and is used throughout the tritium industry.

The catalytic reactor employs a palladium metal catalyst that operates at temperatures up to 550°C. The catalyst causes hydrogen molecules to react with oxygen to form water and organic molecules to react with oxygen to form carbon dioxide and water. Downstream of the reactor, molecular sieves are employed to dry the gas. The tritiated water (e.g., HTO) is periodically recovered from the driers by regeneration.

The catalytic reactor contains 1/8-in. spheres of palladium-coated alumina contained in a 4-in.-diam Sch 40 pipe of 316/304L stainless steel. The vessel is heated by band heaters, which can raise the temperature to about 500°C within 2 h and maintain this temperature at process gas-flow rates. The reactor is wrapped with 1-1/2 in. of heat insulation. A preheater coil upstream of the reactor heats the incoming gas to operating temperature**.** The unit is sized to oxidize 99.9% hydrogen from a concentration of 0.1% in air at an overall flow rate of 130 SCFH with a pressure drop of 1 psig.

12.2.3.10 Catalytic Reactor Cooler Specifications

The catalytic reactor cooler cools the gas leaving the reactor before it enters the molecular sieve beds. The cooler is capable of cooling a nitrogen gas stream with up to 1% water vapor from 500°C to 20°C, given a chilled water flow of 3 gpm and an inlet temperature of 7°C. The design gas-flow rate is 130 SCFH and the pressure drop is less than 1 psi.

12.2.3.11 N_2 Preheater

An electrical preheater heats the regeneration nitrogen gas.

12.2.3.12 Condenser

The condenser is a water-cooled, single-pass heat exchanger used to condense water from the warm, wet gas exiting a molecular sieve bed undergoing regeneration. Water condenses on the tubes cooled by 35°F water. The gas leaves the condenser at ambient temperature.

12.2.3.13 Secondary Containment Volumes

All DTHPS parts that contain DT at more than 1 atm are housed within three secondary vacuum containers. The DTHPS glovebox provides tertiary containment. Helium gas at ~0.5 atm is circulated through all three chambers via a circulation pump. The volumes in the secondary-containment chambers are sufficient to contain the entire DT inventory of 0.34 mole (10,000 Ci) at a pressure below 1 atm at room temperature.

12.2.3.14 Gloveboxes

The glovebox's atmosphere is dry He gas and is the final containment in the event of a DT release. The helium performs the following functions:

1. The ZrFe beds react exothermally with oxygen; purging the environment within the glovebox with He provides an oxygen barrier in the event of a leak in a vacuum process line.
2. Moisture irreversibly consumes the ZrFe and uranium beds; the dry He gas acts as a barrier to moisture.
3. The He gas prevents condensation and ice buildup in the FTS glovebox (due to cryogenic temperatures).

The glovebox uses Plexiglas windows with gloveports for maintenance access. Each glovebox has a passbox for material transfer operations.

12.2.3.15 Tritium Monitors

Tritium monitors from Tyne Engineering are used throughout the TRS. These devices measure the number of ion pairs generated by the β particles (electrons) from tritium decay. The monitors are used to detect the ocurrence of abnormal conditions in the CTHS process. The monitors work by passing process gas through a biased annulus where capture of a decay electron causes a small current to flow. This femto-amp current is measured by the electronics of the device or by an external electrometer. The ion pairs are separated by the impressed field and collected to register as a current.

The tritium monitors report tritium concentrations in units of curies per cubic meter. Two general types of tritium monitors are employed: ITM and ITS. ITM units can measure over an extremely wide range of tritium concentrations, while ITS units are set up for a narrower select range. The ITM units feature "autoranging." These units require external monitors to deconvolute the autorange signal. Four 2-channel, ITM analyzers in the TRS, located in the TRS instrument panel. The ITS units are stand alone and provide a direct-voltage output. Another difference in the monitors includes the volume of the detection region. One liter chambers reduce the detection limit twofold over 20-cc chambers. Table 12.2-5 lists the tritium monitors used in the system. An illustration and a photo of a 1-liter ITM are provided in Figs. 12.2-13 and 12.2-14.

12.2.3.16 Miscellaneous Instrumentation

Other instruments of note in the TRS include the following.

- Dewpoint instruments (Panametrics) measure moisture concentration.
- Coriolis mass flowmeters (Micromotion) are all-stainless-steel mass flow meters.

Table 12.2-5: Tritium Monitors in the TRS.

Subsystem	Identifier	Description	Sensor Type[a]	Autorrange Analyzer Required	Range of Tritium Concentration Exp (per cubic meter)
Tritium Cleanup System	TMT-86-01	Primary-Loop Monitor #1	I	yes	0.1 mCi to 150 Ci
Tritium Cleanup System	TMT-86-02	Secondary-Loop Monitor	II	no	100 μCi to 1.5 Ci (R3)
Tritium Cleanup System	TMT-86-03	Effluent Monitor	II	no	10 μCi to 150 mCi (R2)
Tritium Cleanup System	TMT-86-04	High-DT Vacuum Manifold Monitor	I	yes	0.1 mCi to 150 Ci
Tritium Cleanup System	TMT-86-05	Clean He Vacuum Outlet Activity	II	no	1.0 μCi to 15 mCi (R1)
Tritium Cleanup System	TMT-86-06	Primary-Loop Monitor #2	II	no	100 μCi to 1.5 Ci (R3)
Air Vacuum Cleanup	TMT-87-01	Air Vacuum System Inlet Activity	II	no	1.0 μCi to 15 mCi (R1)
Air Vacuum Cleanup	TMT-87-02	Primary Drier Outlet Activity	II	no	1.0 μCi to 15 mCi (R1)
Air Vacuum Cleanup	TMT-87-03	Oxidation Drier Outlet Activity	II	no	1.0 μCi to 15 mCi (R1)
Regeneration	TMT-88-01	U-Bed Inlet Monitor	I	yes	0.1 mCi to 150 Ci
Regeneration	TMT-88-02	U-Bed Outlet Monitor	I	no	0.1 mCi to 15 Ci (R5)
Regeneration	TMT-88-03	Cryotrap Effluent Monitor	II	yes	1.0 μCi to 1.5 Ci
Glovebox Cleanup	TMT-89-11	DTHPS Glovebox Inlet Activity	I	yes[b]	0.1 mCi to 150Ci
Glovebox Cleanup	TMT-89-12	DTHPS Glovebox Outlet Activity	II	no	1.0 μCi to 15 mCi (R1)
Glovebox Cleanup	TMT-89-21	TFS Glovebox Inlet Activity	I	yes[b]	0.1 mCi to 150 Ci
Glovebox Cleanup	TMT-89-22	TFS Glovebox Outlet Activity	II	no	1.0 μCi to 15 mCi (R1)
Glovebox Cleanup	TMT-89-31	FTS Glovebox Inlet Activity	I	yes[b]	0.1 mCi to 150 Ci
Glovebox Cleanup	TMT-89-32	FTS Glovebox Outlet Activity	II	no	1.0 μCi to 15 mCi (R1)
Glovebox Cleanup	TMT-89-41	DTHPS Secondary-Containment Outlet Activity	II	yes[b]	1.0 μCi to 1.5 Ci

[a] Type I = 20 cc, high activity; Type II = 1000 cc. low activity.

[b] Autorange analyzer is located outside of the enclosure.

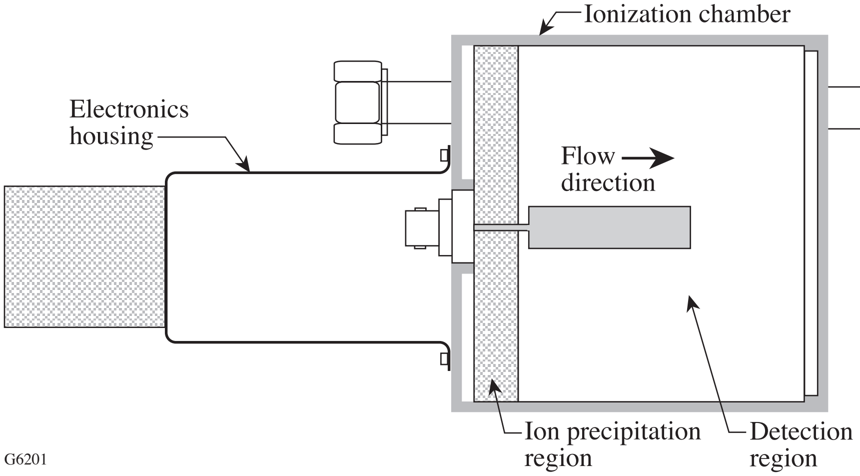


Figure 12.2-13
A 1-liter in-line tritium monitor (ITM) from Tyne Engineering.

Figure 12.2-14
In-line tritium monitor.

12.2.4 Materials

Materials of construction are 316L or 304L stainless steel. This applies to all process lines and vessels. Aluminum is used in the enclosure and module supports and for nonprocess equipment. Where possible, plastics and elastomers are not used in areas that may contain tritium. Vespel™, a polymer from Dupont, is used for the soft valves in the Nupro BK valves. Vespel is recognized in the tritium industry for its moderate resistance to tritium. Table 12.2-6 lists some properties of the materials used in the TRS vessels.

Table 12.2-6: Active materials used in the TRS.

Material	Form	Vendor	Bed Number	Comments
Zirconium-Iron (ST-198)	6-mm × 4-mm L pellets	SAES Getters	ZB-86-10, -11, 20; ZB-89-10, -20; ZB-89-41	A flammable material. In the presence of water, liberates hydrogen gas.
Molecular Sieve 5A	3.2-mm-diam pellets	Aldrich	DR-87-01, -02, -03; DR-86-10; DR-89-01, -02, -03	
Nickel (60 wt%) on Kieselguhr	1/8-in. pellets	Engelhard Corp. Part #Ni-0104 T 1/8-in.	NB-86-10; NB-89-10, 20	A suspected carcinogen. Spent catalyst can be pyrophoric.
Palladium, 0.5 wt% on Alumina	1/8-in. pellets	Aldrich	CR-87-01	
Depleted Uranium		Tyne Engineering	GB-88-01; GB-89-01	

12.3 TRITIUM REMOVAL PROCESS DESCRIPTION

The TRS is a collection of subsystems that clean gas streams of various compositions and tritium levels. To this end several technologies are employed in the TRS to remove tritium:

- **Chemical adsorption of tritium by zirconium-iron (ZrFe) at 350°C:** The general approach taken in designing the TRS was to minimize the amount of tritiated water produced because it is more toxic than gaseous tritium. Reversible chemisorption using ZrFe is used for storing tritium until the adsorbent is regenerated. The ZrFe technique is discussed in more detail in the next section.

- **Catalytic oxidation of tritium followed by adsorption of tritated water on the molecular sieve:** Catalytic oxidation is used for streams where air is present. Tritium is oxidized to water, and then the water is subsequently removed. This is done because oxygen and nitrogen are not compatible with ZrFe, so this adsorbent cannot be used in air.

- **Physical adsorption of tritium using molecular sieve at 77 K (cryotrap):** Adsorption on a cryogenic molecular sieve is also a reversible process.

The application of each of these technologies to the four tritium removal tasks are detailed in the sections following the ZrFe discussions. The TRS subsystems are listed in Table 12.3-1 and are discussed in detail in the sections that follow. The subsystems can be identified on the Process and Instrument Diagrams (P&ID's) via the equipment subsystem number.

Table 12.3-1: Overview of the TRS Subsystems.

Subsystem	Primary Purpose	Equipment Subsystem Number
Tritium Cleanup (Sec. 12.3.3)	Removes tritium from FTS vacuum pump effluent from the low- and high-DT manifolds.	8600
Air Vacuum Cleanup (Sec. 12.3.4)	Removes tritium from vacuum pump effluent from the air vacuum manifold.	8700
Glovebox Cleanup (Sec. 12.3.5)	Removes tritium and water from glovebox atmospheres.	8900
DTHPS Secondary Containment (Sec. 12.3.6)	Removes tritium from key equipment in the DTHPS glovebox.	8900
Regeneration (Sec. 12.3.7)	Process for the regeneration of adsorption beds.	8800
Tritium Monitor Decontamination (Sec. 12.3.8)	Process for the decontamination of tritium monitors.	8800

12.3.1 Zirconium-Iron Adsorption Train

The Tritium Cleanup System, the Glovebox Cleanup System, and the DTHPS Secondary Containment utilize zirconium iron adsorption trains. The zirconium-iron adsorption trains are used in the TCS and glovebox cleanup system. A requirement with ZrFe is to exclude oxygen, water, and hydrocarbons because they will irreversibly and negatively influence the ability of the material to adsorb hydrogen-isotopes. These impurities must be first removed from the gas stream by using a molecular sieve to adsorb water, followed by a nickel catalyst bed to crack organic species. The nickel catalyst bed adsorbs the resultant oxygen and carbon and releases hydrogen to the ZrFe bed. This adsorption train (Fig. 12.3-1) is used throughout the TRS and is discussed in detail here.

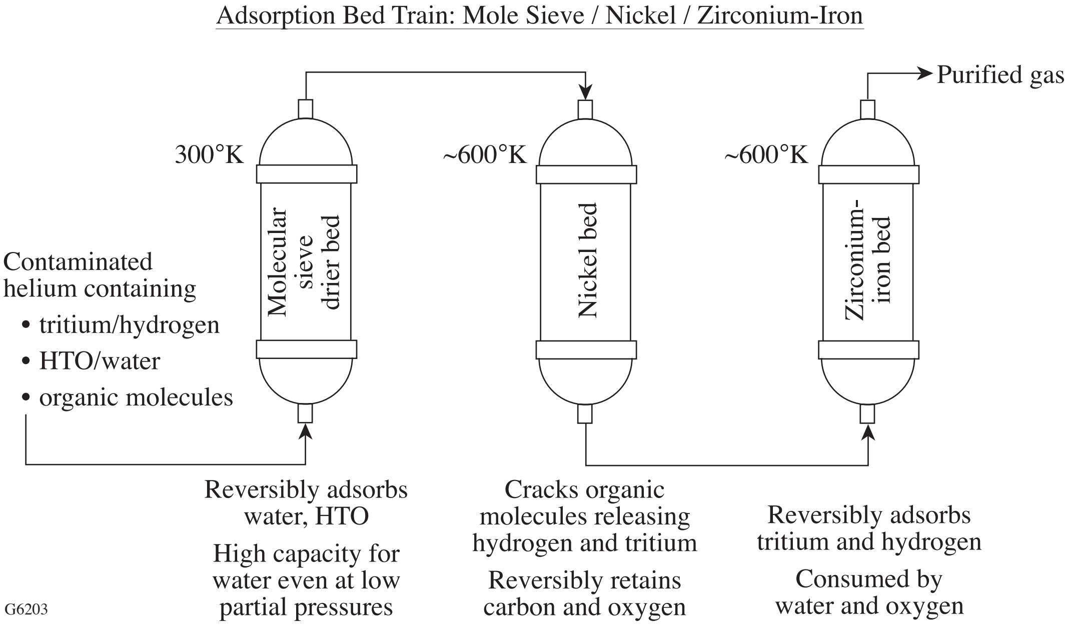


Figure 12.3-1
A typical ZrFe adsorption train used throughout the TRS.

Molecular Sieve

The purpose of the molecular sieve is to remove trace amounts of water vapor from the helium streams that would otherwise consume the ZrFe bed. Molecular sieves are a class of synthetic alumino-silicate dessicants that have a relatively high adsorption capacity for water at low concentrations. The outlet water concentration from the driers with dew points of the order of –80°C are easily attainable.

Nickle Bed

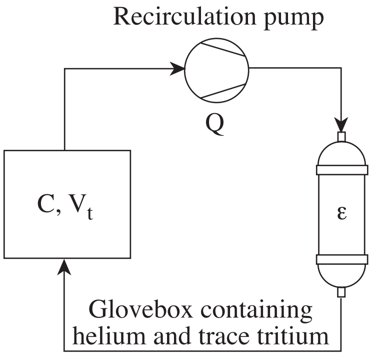
Nickel catalyst reduces organic molecules (e.g., CH_4, CH_3–T, etc.) to produce tritium and hydrogen, retaining the carbon as nickel carbide, Ni_3C. Elemental tritium and hydrogen that result are passed on to the zirconium-iron bed. In addition, water molecules are converted to nickel oxide (absorbed in the bed) and hydrogen or tritium (passing through the bed), so the nickel bed not only cracks organic species, but acts as a secondary defense against water and carbon intrusion.

12.3.1.1 Process Operating Conditions

Gas is pumped through the ZrFe adsorption train by means of bellows pumps. The range of flow rates of gas in the TRS is from 0.5 to 5.0 scfm. The Ni and ZrFe beds operate at a nominal temperature of 350°C, while molecular sieve driers operate at room temperature. The ZrFe bed can adsorb hydrogen and tritium over a range from 250°C up to 400°C. Tritium and moisture monitors are used to measure the amount of tritium and water that enters and leaves the beds. Flowmeters and pressure indicators are used to assess bed hydraulic properties. When the tritium and/or moisture levels at the outlet of the adsorption train begin to rise, the beds are taken off-line and regenerated.

12.3.1.2 Performance of ZrFe in Glovebox Cleanup Operation

ZrFe beds used at LLE in glovebox applications have proven very efficient at reducing tritium concentrations when tritium levels rise due to target-processing activities. A simple model, illustrated in Fig. 12.3-2, has been used to show that the rate of reduction in concentration is directly related to the gas throughput through the adsorption train and to the volume of the glovebox that it is serving. Figure 12.3-3 illustrates typical performance experienced at LLE. From this model it is apparent that



$C = C_i e^{-(1/\tau)t}$ $\tau = V/(Q\varepsilon)$ half-life

Q = circulation flow rate

E = capture efficiency (≈1.0)

V = glovebox volume

C_i = initial glovebox activity

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Getter cleanup beds

1. The activity level follows an exponential decay.
2. This model applies specifically to getter beds.
3. The metal getter system works like an ideal adsorber — the rate of decay depends on how fast tritium can be recirculated through the system.
4. The glovebox is considered an ideally mixed volume.

Figure 12.3-2
A simple model to describe the performance of ZrFe adsorption in a closed-loop system.

the larger flow rate will lead to faster response times. If the flow rate is too fast through the beds, however, the residence time in the adsorption beds may not be sufficient to capture the tritium (and water) and some breakthrough might occur.

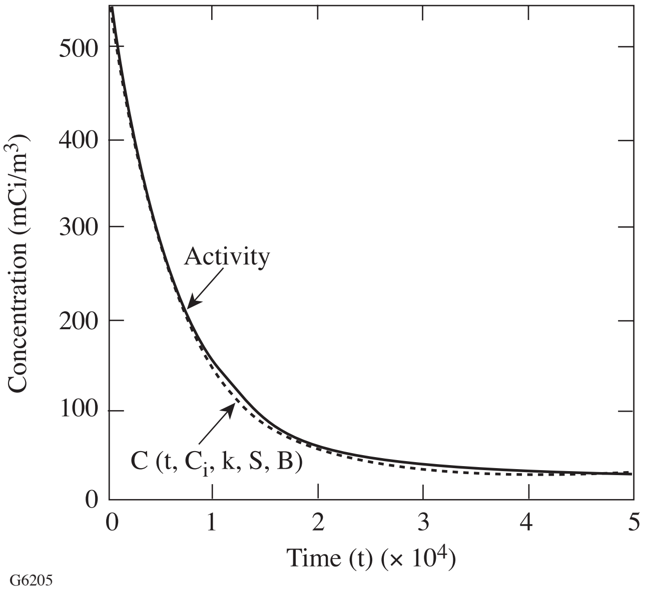

Figure 12.3-3
Example of the performance of a ZrFe cleanup system on an LLE glovebox. Model predictions shown as a solid line and actual data as a dashed line. Concentration units in mCi/m^3.

12.3.2 Tritium Cleanup Subsystem (TCS)

The Tritium Cleanup Subsystem (TCS) utilizes the ZrFe adsorption train to recover tritium from helium gas streams pumped from the High- and Low-Tritium Vacuum manifolds of the CTHS. The TCS is the primary tritium cleanup system for the CTHS equipment that sees the highest concentrations of tritium. The effluent from the TCS is stacked to atmosphere. The recovered tritium is temporarily held within adsorption beds in the subsystem and transferred to a uranium bed during the regeneration process.

This system employs two interconnected recirculating loops—the Primary Loop and the Secondary Loop (Fig. 12.3-4). Each loop consists of adsorption beds, a recirculating pump, recirculation tank, instrumentation, and piping. The adsorption beds remove tritium and other contaminants from the helium stream.

The TCS is designed to process volumes of contaminated gas in a passive manner relative to the operation of the CTHS. The TCS operates continuously to accept and clean the gas regardless of the gas flow generated by the CTHS. The Primary Loop is connected to the CTHS vacuum pump and exhausts through a solenoid valve that is normally open. The Secondary Loop is connected to the Primary Loop by means of a low-pressure check valve. The stack exhaust is connected to the Secondary Loop by means of another low-pressure check valve. Thus, gas volumes that enter the Primary Loop will displace an equal volume of gas from that loop into the Secondary Loop. That gas, in turn, will displace gas out to the stack exhaust. While the Primary Loop contains the full battery of the ZrFe adsorption train, the Secondary Loop contains only a ZrFe bed.

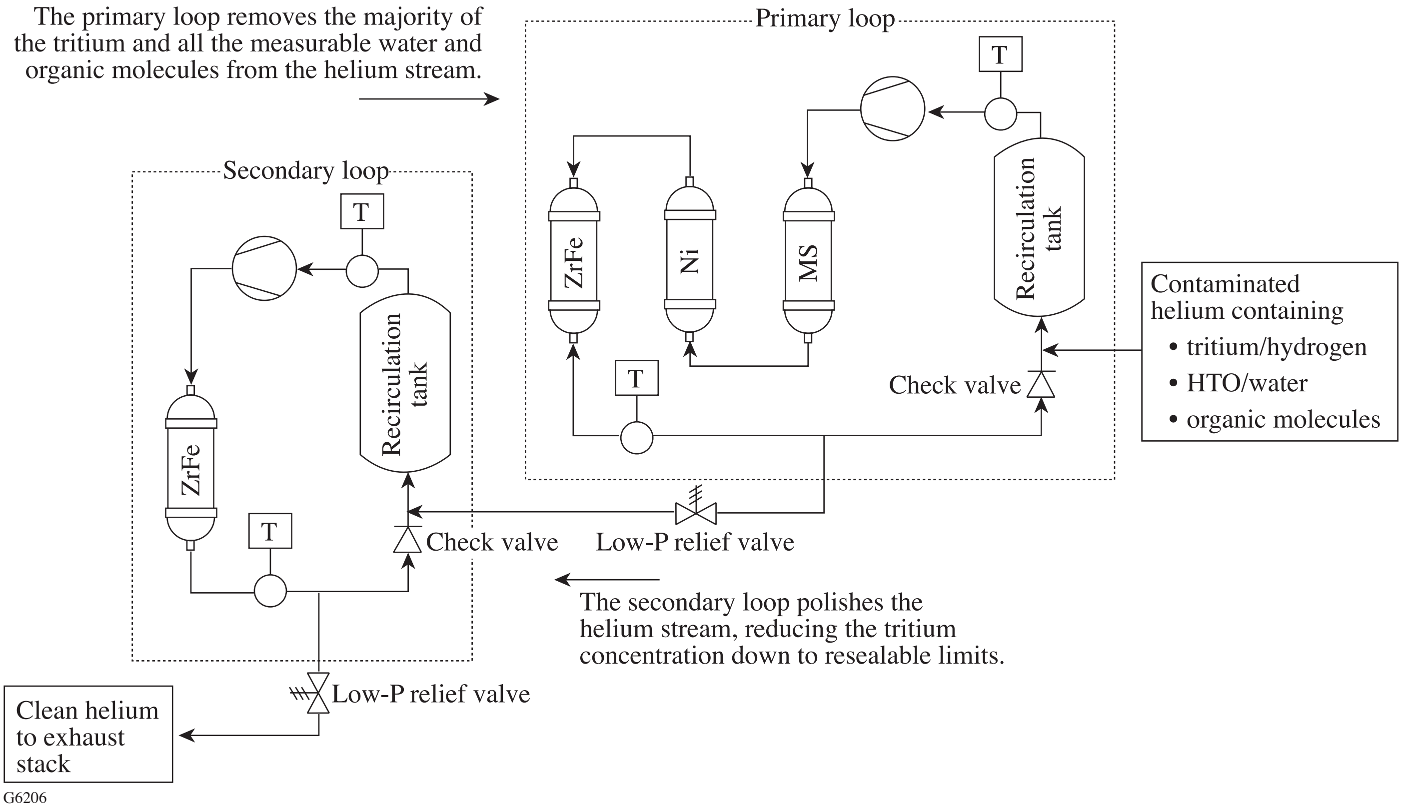

Figure 12.3-4
Schematic diagram of the Tritium Cleanup Subsystem.

The objectives of the Primary Loop and Secondary Loop differ in that the concentrations of tritium in the Primary Loop are normally much greater than that in the Secondary Loop. The Primary Loop removes the bulk of the tritium from the helium gas stream, while the Secondary Loop polishes the gas stream to remove trace amounts of tritium. The contaminated gas is initially pumped into the Primary Loop, where the concentration of tritium is reduced by orders of magnitude, from the tens of Ci/m^3 down to about 10 mCi/m^3. In the Secondary Loop, the concentration is reduced further down to below 1 mCi/m^3, to levels where the effluent can be sent to the exhaust stack.

The purpose of employing recirculation loops and holding tanks is to increase the contact time between the gas and adsorption beds. While the rate of contaminant uptake by the adsorption beds is high, a finite amount of contaminants will make it past the beds in a single pass. Employing multiple passes helps ensure low effluent concentrations.

The holding tank also allows gas to be processed in a batch mode in the event that a large release of tritium occurs in the High- or Low-Tritium Vacuum manifold. The Primary Loop could then be isolated to process this volume of gas separately, recirculating it over the beds many times, releasing the gas to the Secondary Loop only after the tritium concentrations fall to an acceptable level.

The TCS is fully instrumented to measure the real-time performance of the system

- Tritium monitors measure inlet- and outlet-tritium concentrations for each loop.
- Dewpoint monitors measure inlet and outlet concentrations of water for each loop.
- Mass flowmeters measure the mass flow of gas in each loop.
- Pressure transducers measure the pressure drop across individual beds and pump suction/ discharge pressure.
- Temperature sensors are provided throughout the system.

12.3.3 Air Vacuum Cleanup Subsystem

The Air Vacuum Cleanup Subsystem removes tritium from contaminated air streams. Figure 12.3-5 graphically illustrates this subsystem. It is comprised of three identical mole sieve driers, a catalytic reactor, a booster pump, and related piping and instrumentation. The exhaust stream will be monitored for tritium and, if the tritium levels are within limits, the stream will be vented directly to stack. If tritium levels exceed preset limits, clean up is required and the air stream is directed through a molecular sieve drier. If this does not sufficiently reduce the tritium activity of the stream, the primary molecular sieve exhaust stream will then be directed through a catalytic oxidizer CR-87-01 to convert any non-oxide tritium species to HTO. This tritiated water is removed using the secondary molecular sieve drier.

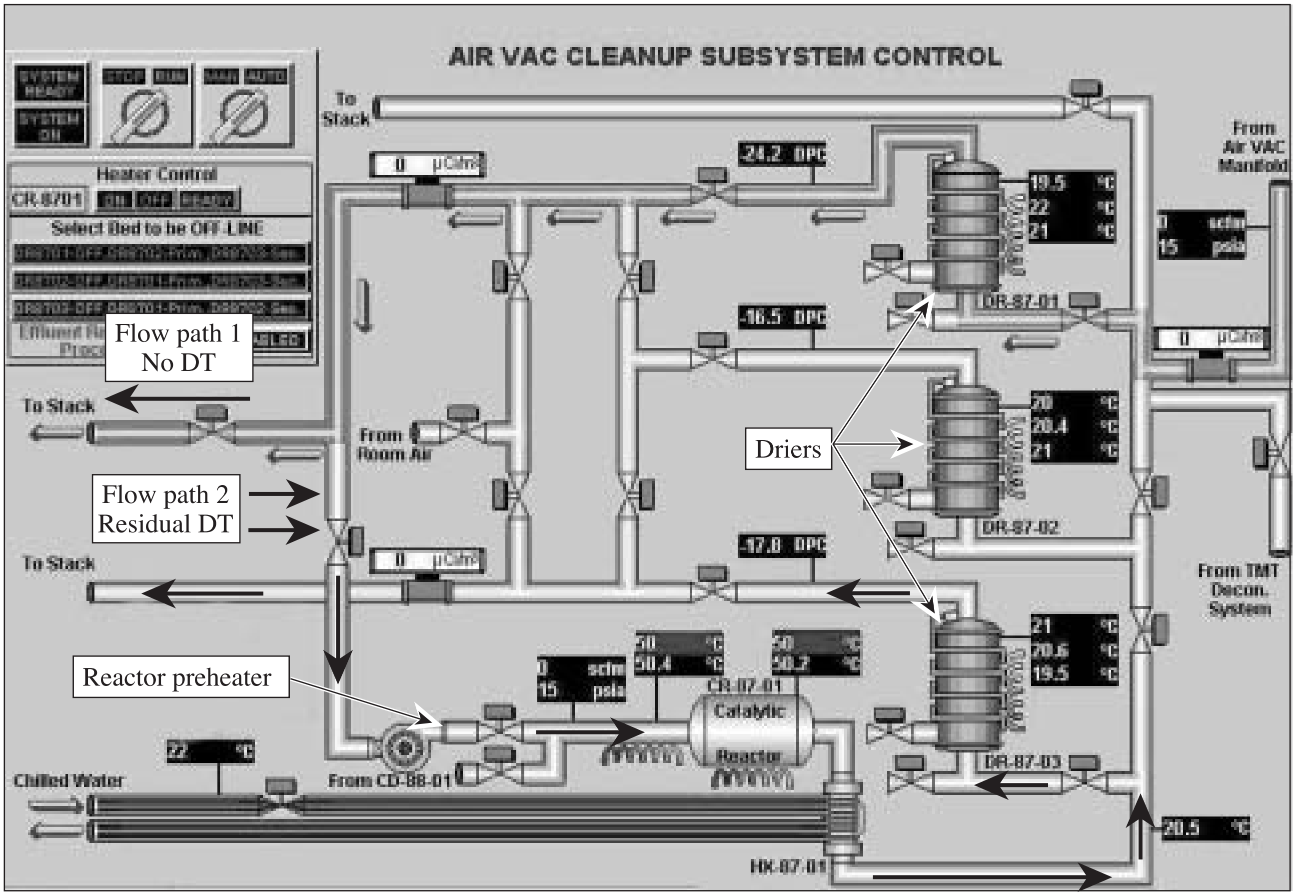

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Figure 12.3-5
Process schematic for the Air Vacuum Cleanup Subsystem.

There are three molecular sieve driers in the subsystem. Two are always in use, and one is always free for regeneration. One drier handles the initial removal of water and the second drier supports, if necessary, water removal following the catalytic reactor. A dew-point sensor will detect when driers are loaded, and the subsystem will alert the operator to switch beds. The control system automatically performs valve lineups.

12.3.4 Glovebox Cleanup Subsystem

The glovebox volumes in Room 157 require removal of tritium from their helium atmospheres by continuous recirculation through adsorption beds. This system uses a ZrFe adsorption train and an experimental ZrFe cryotrap adsorption train.

A total of three recirculating gas cleanup loops service the three gloveboxes (FTS, TFS, and DTHPS) in Room 157. These three cleanup loops are not three distinct loops, but rather a system of recirculating pumps and adsorption bed trains interconnected by automatic valves and piping. The system is flexible and interconnected, allowing many permutations of equipment arrangements. Figure 12.3-6 illustrates the design of the system.

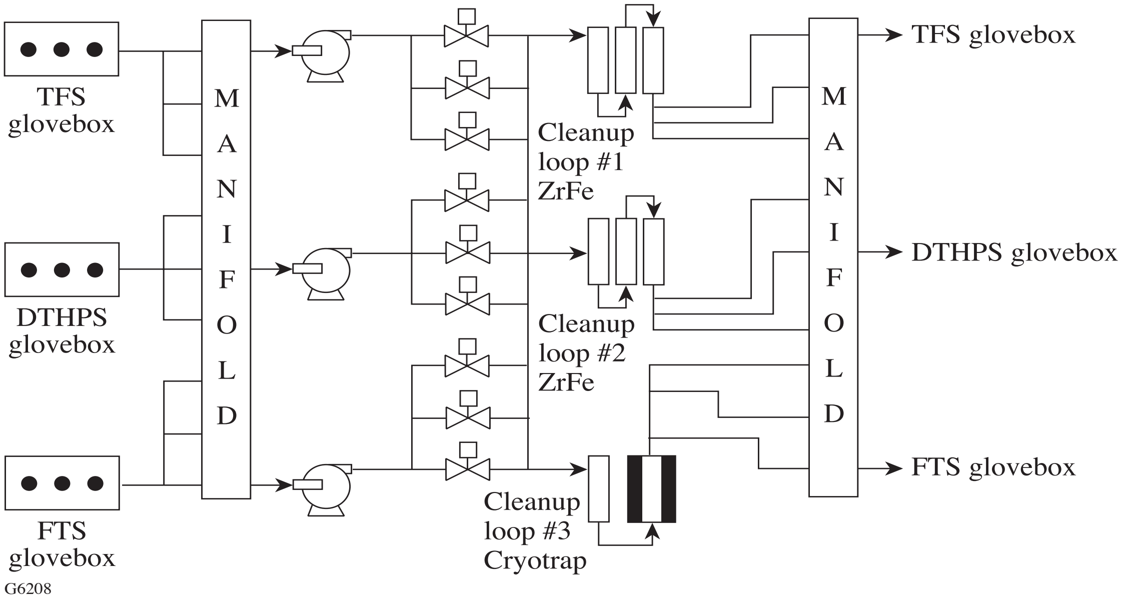


Figure 12.3-6
Glovebox Cleanup System Process schematic.

Three identical metal bellows pumps are provided to recirculate gas through these loops. Any combination of the glovebox, pump, and adsorption bed chain can be arranged. For example, all three pumps and adsorption bed chains can be brought to bear on one glovebox. The most common combination employed connects one glovebox to one pump and one bed. The glovebox recirculation loops, when operating, also serve to control the pressure in the gloveboxes. The recirculation pumps have speed controllers that provide flow rates from about 1 cfm to a maximum of 5 cfm.

12.3.4.1 Cryotrap Train

The cryotrap train consists of a mole sieve bed and a cryotrap bed, which operates at 77 K. The glovebox effluent is first pumped through the mole sieve bed where the moisture content is removed. The effluent then passes through the cryotrap. The tritium and organic compounds are removed from the He stream via condensation.

The cryotrap is instrumented to help ensure constant temperature. It is supplied with a constant source of liquid nitrogen (LN_2) from the CTHS LN_2 system. An automatic valve supplies the cryotrap dewar. A pressure-relief valve, the only one in the TRS, is connected to the effluent line on the cryotrap, to prevent overpressurization. If LN_2 flow is lost for a long enough period of time, the cryotrap is automatically taken off-line. The pressure drop across the cryotrap is constantly monitored to ensure that ice is not building up in the internal piping.

12.3.4.2 Glovebox Pressure Control

In addition to the cleanup function, the Glovebox Cleanup Subystem also controls glovebox pressure from +0.2 to –5.0 in. w.c. (with respect to the ambient pressure) by either discharging some glovebox gas to stack or by adding clean helium makeup as required. In the event of a substantial release of tritium into the glovebox, the pressure will be reduced to –0.2 in.

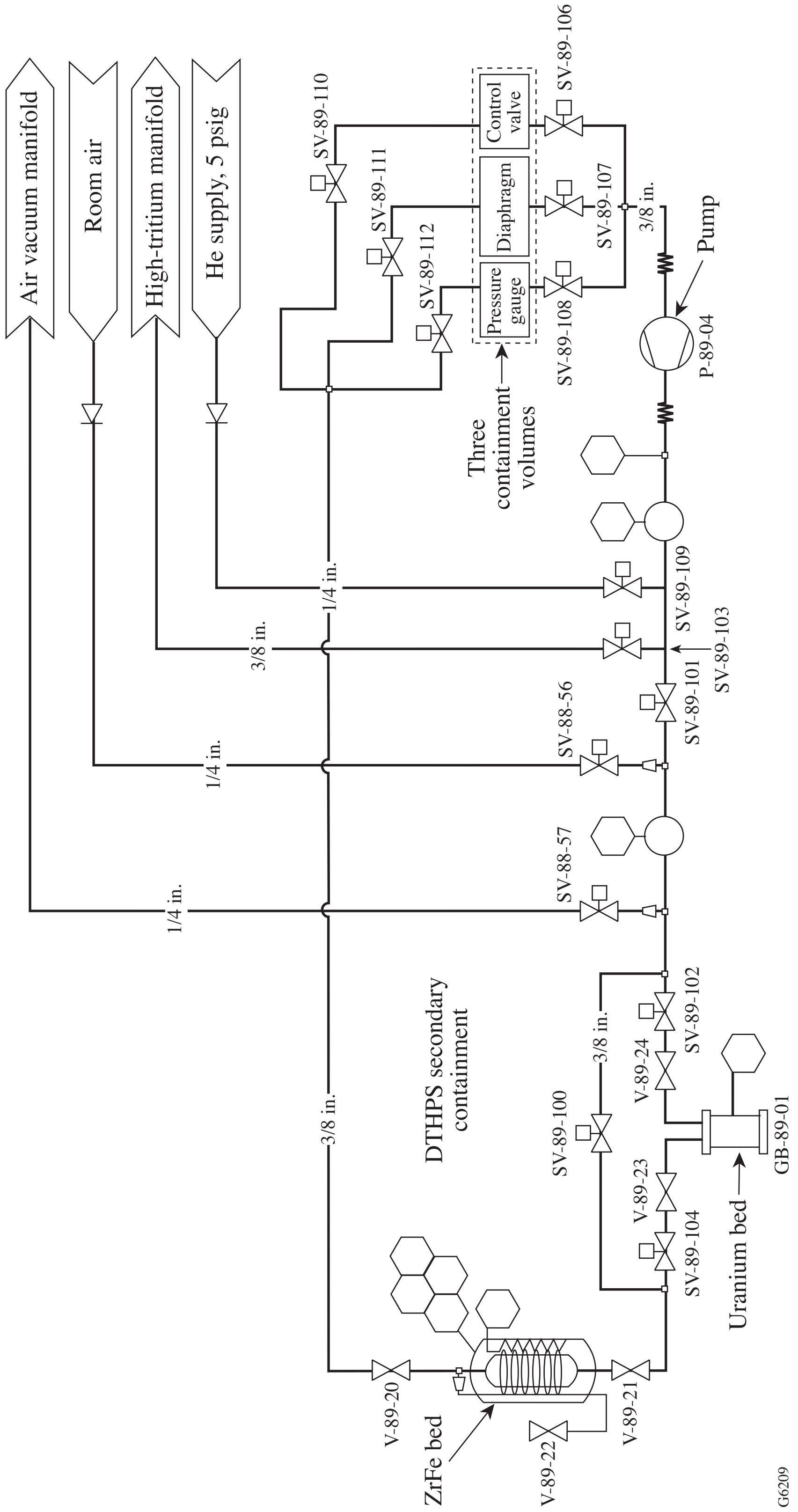
12.3.5 DTHPS Secondary Containment Subsystem

The DTHPS Secondary-Containment Cleanup Subsystem (DSCCS) employs ZrFe technology in a small, closed-loop, recirculation system, separate from the TRS main enclosure in the DTHPS glovebox. It differs from the other subsystems in that the ZrFe bed is used alone without an adsorption train to exclude impurities. In addition, the subsystem contains a uranium bed in the event that a very large release of tritium occurs. The subsystem is illustrated in Fig. 12.3-7.

A small recirculation pump (1-cfm) is used to circulate gas through three containment volumes. The total volume is about 50 liters. The system takes suction from the containment volumes, passes the flow through the zirconium-iron bed, and returns the gas to the containment volume(s). Flexibility in the control systems allows the volumes to be purged individually or in parallel.

Since the DTHPS secondary containment is fully contained in the dry He atmosphere of the DTHPS glovebox, there is essentially no moisture. This eliminates the need for a Ni bed and molecular sieve drier to support the ZrFe bed. In this specific subsystem, no provision has been made to allow for the ZrFe bed to be regenerated *in situ*. It must be removed to be regenerated.

Figure 12.3-7
DTHPS Secondary Containment Cleanup Subsystem.



12.4 Regular Process Maintenance Activities

Three types of regular process maintenance activities will occur with the TRS:

- adsorption bed regeneration
- tritium monitor decontamination
- removal of tritiated water condensate

These are discussed in detail in the following sections.

12.4.1 Bed Regenerations Subsystem

In situ regenerations decrease the potential spread of contamination and increase personnel safety. Removal and shipment of the beds can expose operators to high specific activity elemental tritium and tritiated oxides. Additional removal and re-installation of the units can lead to a loss of system integrity. For these reasons, the TRS was designed to regenerate adsorption beds *in situ*. There are four types of beds that require regeneration are:

- **Molecular sieve driers:** The drier beds are regenerated with hot nitrogen purge. At elevated temperatures, the adsorption capacity for water is greatly reduced, and the water desorbs into the flowing gas.

- **Nickel catalyst beds:** The nickel beds are regenerated with a combination of helium and hydrogen at elevated temperatures. The hydrogen reacts with the chemisorbed oxygen to form water, and the chemisorbed carbon combines with the chemisorbed oxygen to form CO_2, which is carried off by the hot gas.

- **ZrFe beds:** The ZrFe beds are regenerated using a hot helium purge. At elevated temperatures, ZrFe has a reduced capacity for tritium, which desorbs and is carried off by the gas stream.

- **Cryogenic-molecular sieve (cryotrap) beds:** The cryotrap bed regeneration process employs hot nitrogen purge. At elevated temperatures, the adsorption capacity for water is greatly reduced and the water desorbs into the flowing gas.

Table 12.4-1 summarizes the regeneration method, frequency, threshold, and other information.

12.4.2 Molecular Sieve Drier Regeneration

The flow configuration required for the drier regeneration process is illustrated in Fig. 12.4-1. Note that in addition to the mole sieve bed that is being serviced, the condenser, one of the nickel beds, and a second mole sieve bed are involved. This means that the entire Tritium Cleanup System (TCS) must be taken offline while a drier bed is being serviced. The regeneration nitrogen flow is heated to 350°C by the preheater and then enters the drier, which is also heated to 350°C. The N_2 purge gas then flows through the condenser CD-88-01, where the moisture is removed via condensation. The regeneration gas flow is in the opposite direction of the process flow.

Table 12.4-1: Bed regenerations that are required in the TRS.

Bed Type	Anticipated Frequency	Regeneration Trigger Point	Regeneration Method
Molecular Sieve Drier	3 to 6 months	Effluent dewpoint rises above –40°C	Countercurrent flow of hot nitrogen gas at 350°C drives off water; water is condensed.
Nickel Catalyst Bed	yearly	No measure of bed exhaustion	Countercurrent flow of hot helium/ hydrogen gas mixture at 500°C reacts with carbon, oxygen to form CO_2 and water, which is driven off; water is condensed.
Zirconium-Iron Bed	3 to 6 months	TBD	Countercurrent flow of hot helium gas at 500°C drives off tritium; tritium is adsorbed by uranium bed.
Cryogneic Molecular Sieve (cryotrap)	TBD	Background effluent tritium concentration rises above 1 mCi/m^3.	Cold regen: countercurrent flow of helium gas at bed temp of 120 K driving tritium off; tritium is collected over uranium bed trace and collided with ZrFe.

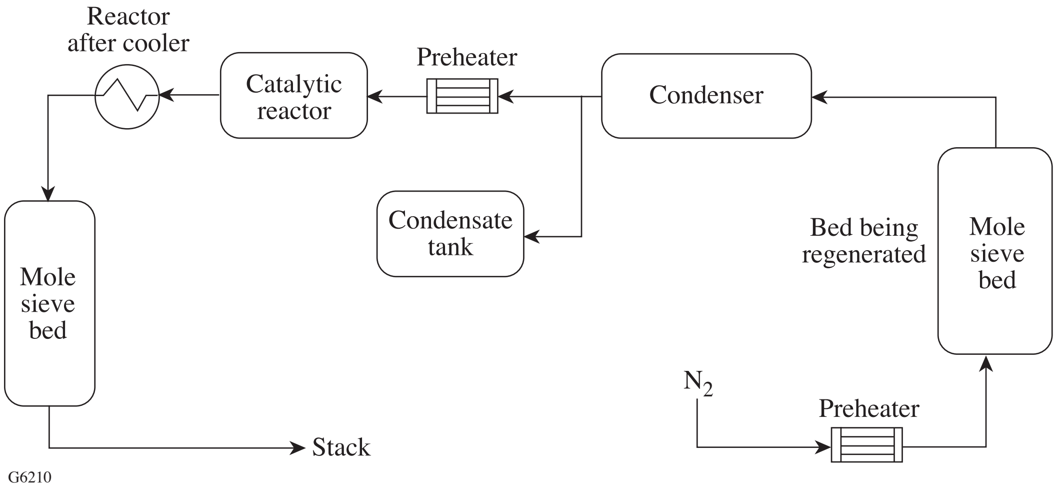


Figure 12.4-1
Molecular sieve drier bed regeneration loop.

To ensure that no hydrocarbons containing tritium are emitted, the gas is routed through the catalytic reactor (CR-87-01) to oxidize them and through a drier (DR-87-03) to remove any residual moisture. The regen condenser is capable of cooling a nitrogen gas stream with up to 5% water vapor from 350°C to 9°C, given a chilled water flow of 3 gpm and an inlet temperature of 7°C.

12.4.3 Nickel Bed Regeneration

Nickel bed regeneration is accomplished by purging the bed with clean He and subsequently with a hydrogen gas mixture at 500°C. The hydrogen gas reacts with the nickel carbide and nickel oxide, resulting in methane and water. He is used to purge the bed following regeneration. The nickel bed is regenerated on a periodic basis since there is no instrumentation that can detect when the bed is spent. The TCS must be taken off-line for Ni bed regeneration.

The exhaust gas containing helium, methane, and water is directed to the Air Vacuum Cleanup System where the drier will adsorb the water and the rest of the gas will pass through the catalytic reactor/drier train (see Fig. 12.4-2).

$$\mathrm{Ni_3C + H_2 \rightarrow 3Ni + CH_4}$$

For a flow rate of 100% H_2 gas at 5 slpm, the 1.6-Kg Ni bed regeneration requires 4 h, assuming that the bed is fully loaded. Mass-flow controllers control the ratio and flow rates of hydrogen and helium gases.

The hydrogen regeneration gas will be supplied to the TRS via an external size D, or smaller, bottle. Hydrogen is a flammable gas, and precautions must be taken to minimize any chance of ignition. The bottle is located in Room 157 near the TRS. The gas enters the TRS through a feedthrough in the top of the TRS. The flow of gas is controlled via a mass-flow controller located within the TRS and controlled by the TRS PLC. A hydrogen detector continuously monitors the atmosphere in the TRS. The lower explosive limit for hydrogen is 4% by volume in air. If the concentration exceeds 1%, the TRS will alarm and the mass-flow controller and the flow valve to the bed under regeneration will automatically close.

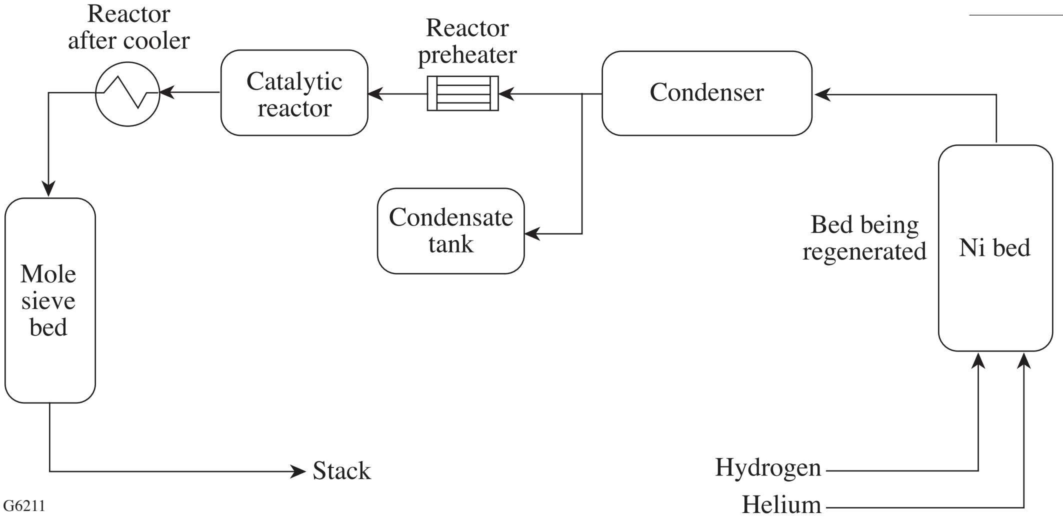


Figure 12.4-2
Nickle bed regeneration loop.

12.4.4 Zirconium-Iron Bed Regeneration (TCS)

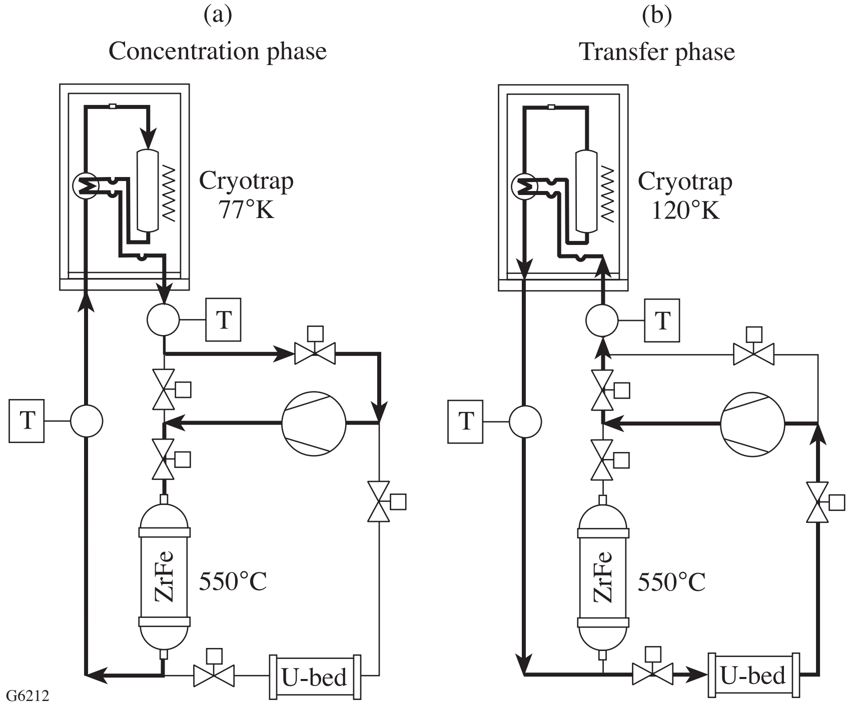
The TCS has been designed to allow for regeneration of ZrFe beds without interruption to the process. To accomplish this, a pair of ZrFe beds has been provided in the Primary Loop and a bypass feature has been added to the Secondary Loop. This way, regenerations of the beds can proceed (in place) while the TCS continues to operate.

The tritium adsorption sites on these beds gradually fill up from the process gas inlet to the outlet of the bed. Tritium monitors on the inlet and outlet sides of the beds measure the relative amount of tritium being recovered. When the outlet concentration of tritium rises above a preset value, the bed is fully loaded and the tritium bed must be regenerated.

Purge is started before the heat up. ZrFe bed regeneration is accomplished by first heating the bed to 550°C. He is then passed through the bed in the direction opposite to the process flow. The flow is recirculated in a closed-loop through the cryotrap where tritium is removed via cryo-condensation [see Fig. 12.4-3(a)].

After the ZrFe bed has been regenerated, the tritium is transferred from the cryotrap to the U-bed. The the flow direction is reversed and the He gas is recirculated through the U-bed [see Fig. 12.4-3(b)]. The cryotrap is heated to 120 K and the tritium is released in a concentrated "burst" that is absorbed by the U-bed.

A metal bellows pump (P-88-01) is used to circulate the gas during these processes at approximately 1 scfm. Once the ZrFe bed is at temperature, the regeneration process requires about 8 h to complete. Tritium monitors are used to determine when the process is complete.


(a)
Concentration phase

(b)
Transfer phase

Figure 12.4-3
(a) ZrFe bed regeneration utilizing the cryotrap as a tritium condenser.
(b) The condensed DT is released from the cryotrap and absorbed by the U-bed.

Since there are no provisions for *in situ* regeneration of the smaller 3-kg bed in the DTHPS glovebox, it will be removed from the DTHPS glovebox to be regenerated. The longest dimension of the bed is 18.0 in., so that it may be possible to remove it using the glovebox antechamber.

12.4.5 Cryotrap Regeneration

Cryotrap regeneration is accomplished by first circulating He (using pump P-88-01) through the cryotrap (CT-89-10) and U-bed (GB-88-01). The cryotrap is then heated to 120 K. The tritium is released in a concentrated "burst" that is absorbed by the U-bed. The concentrated release is necessary because the U-bed will not absorb the lower concentration levels of tritium (see Fig. 12.4-3). Once the DT removal is complete, additional steps can be taken for full regeneration or the cryotrap can be cooled and returned to service.

For full regeneration following the 120 K regen, clean, dry N_2 is flowed in a countercurrent direction through both the mole sieve bed and the cold trap (coil) as the entire dewar (i.e., mole sieve bed and moisture trap) is heated to 300°C.

The gas is then passed through the regen condenser (CD-88-01) to remove moisture, and the catalytic reactor (CR-87-01) and the drier (DR-87-03) to oxidize any hydrocarbons that may be present and to trap any residual moisture. Finally, the gas flows to the stack (see Fig. 12.4-4). When the cryotrap has been dried, the residual N_2 is evacuated to the air vacuum system. The cryotrap is then refilled with LN_2 and cooled to 77 K for return to service.

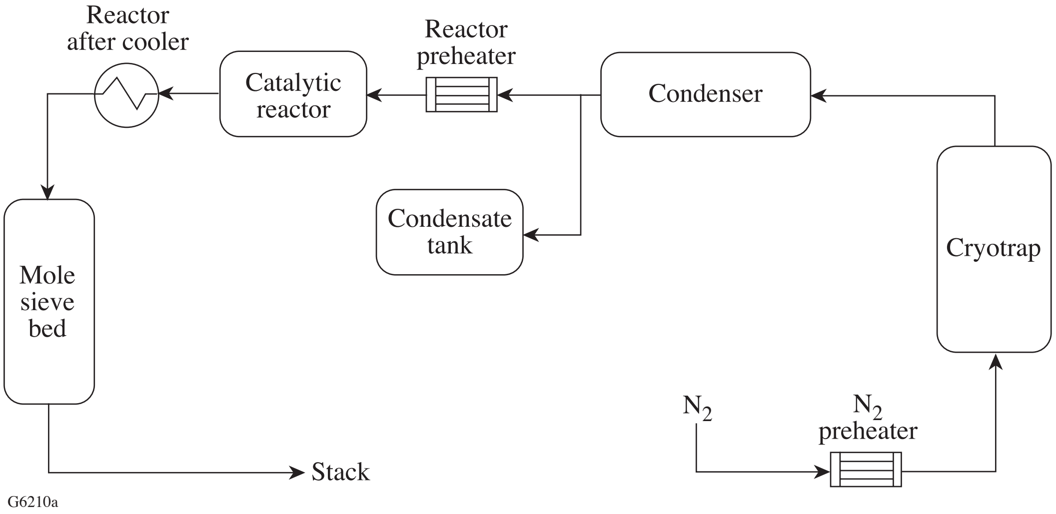


Figure 12.4-4
Full regeneration of the cryotrap.

12.4.6 Tritium Monitor Decontamination Subsystem

Tritium-measurement monitors employed in the TRS are susceptible to contamination due to the presence of adsorbed tritium on the internal wetted surfaces. The contamination results in a positive bias on the meters that causes false high readings. This occurs especially when the water content of the gas being measured is very low. Tritium monitors can be cleaned by flushing with moist air. In the TRS, room air will be used.

A pump supplies room air to monitors through dedicated supply lines. When a monitor needs to be decontaminated, the monitor is bypassed and isolated. The exhaust gas from the decontamination process can either be directed to the Air Vacuum Cleanup System or be sent directly to stack, depending on the level of decontamination.

The monitor will be purged for a prescribed length of time **(overnight)**. The process is automatic once manually invoked by an operator. After the flushing is complete, the air left in the monitor will be evacuated from the monitor and lines and then backfilled with clean helium. The tritium monitor decontamination will be a regularly scheduled preventative maintenance operation. Only one tritium monitor can be decontaminated at one time.

12.4.7 Removal of Tritiated Water Condensate

Following the regeneration of certain adsorption beds in the system, tank T-8801 (Fig. 12.4-5) will need to be removed from the system and tritiated water discarded safely. This requires that a VCR connection be broken. The tank and fitting have shutoff valves to help prevent operators from being exposed to tritiated water. The volume of the tank is 1 liter. The tank has a vent on one end to facilitate draining. The water collected by this tank is assumed to contain very high specific activity unless demonstrated otherwise. Liquid transfers are carried out in a ventilated hood using sealed plumbing and a pressure differential.

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Figure 12.4-5
1-liter condensate bottle.

12.5 CONTROLS

The TRS control system is based upon General Electrical (GE) programmable logical controllers (PLC's) and GE Cimplicity software for the human–machine interface (HMI). The PLC controls and monitors the TRS automatically.

12.5.1 Control System Components

The control system comprises the following elements:

- *Main PLC Rack:* This contains the Room 157 TRS PLC and is the main switchboard for the TRS control system. It is the conduit of all output control signals and data from the process.

- *Remote PLC Racks:* These are installed in the Main Enclosure, Pump Enclosure, and the DTHPS Secondary-Containment Cleanup Subsystem Control Panel. The remote racks provide control and data connections to the process equipment. The remote racks are connected to each other and the main PLC via a GE proprietary communications system.

- *Heater Controls Cabinet:* This cabinet houses all the control equipment to provide power to the band heaters for the adsorption beds, catalytic reactor, and various other heaters in the TRS.

- *Pump Controls Cabinet:* This cabinet houses all the control equipment to provide power and speed control to metal bellows pumps used throughout the TRS.

- *Process Analyzers:* Four tritium-concentration monitors and two dewpoint monitors are located in the instrument rack near the main PLC rack. These are connected to the main PLC rack and interpret input signals from tritium monitors and dewpoint monitors, and convey process information to the main PLC.

- *TRS Personal Computer/HMI:* A personal computer is used as the HMI for the TRS. This computer runs a customized GE Cimplicity software package that allows operators to control and monitor the TRS.

12.5.2 Human–Machine Interface (HMI)

The operator interface relies on a TRS personal computer. The features of the HMI are described as follows:

- There is one main screen through which all other screens are accessible.
- All screens in the HMI have overlay windows featuring navigation keys and system status windows (see Fig. 12.5-1 for a typical screen).
- There are main process screens for each of the following subsystems (see Fig. 12.5-2):
  - Tritium Cleanup Subsystem
  - Air Vacuum Cleanup Subsystem
  - Glovebox Cleanup Subsystem
  - DTHPS Secondary Containment Cleanup Subsystem

- The maintenance activities screens include (see Fig. 12.5-2):
  - bed regenerations
  - tritium-monitor decontamination
- There is a manual and an automatic mode for each subsystem (see Fig 12.5-2):
  - In automatic mode, equipment can be operated automatically as per the controls specification. Software interlocks exist to prevent certain activities from occurring, such as bed regeneration. Valves cannot be actuated manually. In automatic mode, valve lineups are made automatically.
  - In manual mode, equipment can be turned on or off manually. There is no automatic control or interlocking. In manual mode, buttons appear, allowing solenoid valves to be manually actuated.

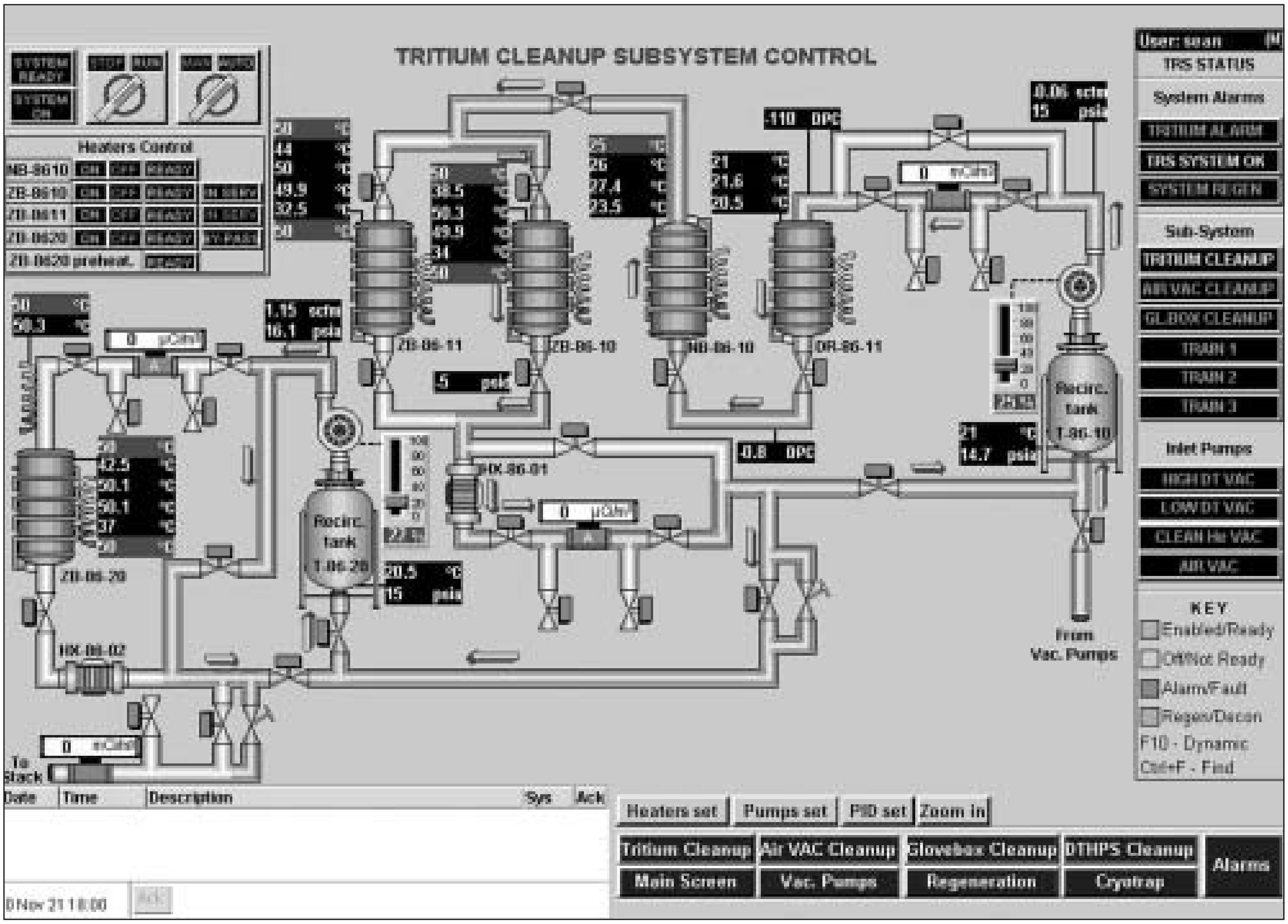

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Figure 12.5-1
Example of an HMI screen. This screen is from the Tritium Cleanup Subsystem. Note the overlay screens along the bottom and right-hand side. On the bottom left is the alarm window; the bottom right contains the navigation buttons. The status windows are located along the right-hand side of the screen.

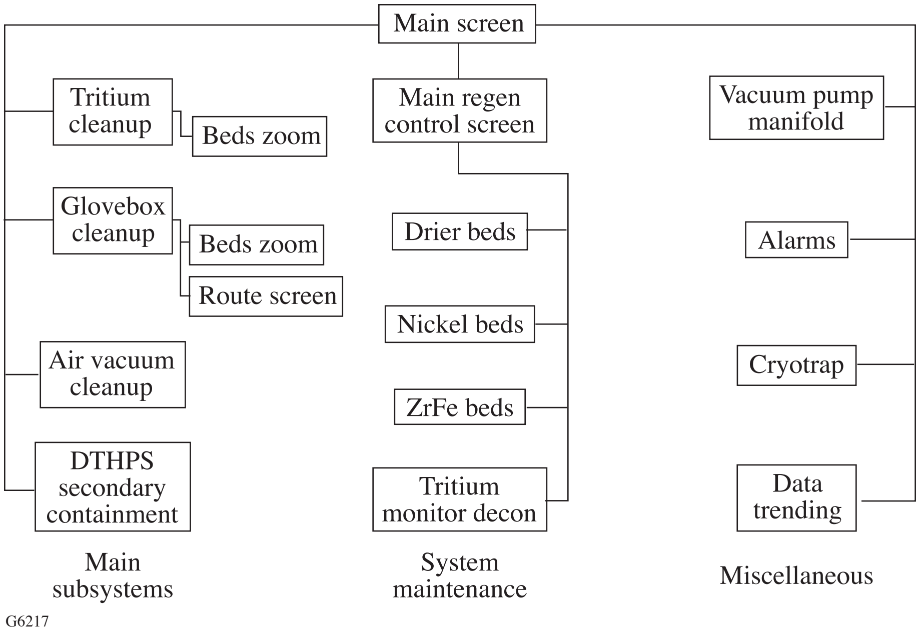

Figure 12.5-2
HMI screen organization.

- Regeneration processes are batch processes that progress step-wise. At each step, the operator is prompted to continue the process or abort.
- Trend screens are available to view real-time or historical process data.
- An alarm window and an alarm screen exist to alert the operator of fault or warning conditions. In addition, status overlay windows alert the operator to major system and subsystem faults.

12.5.3 Alarms

The TRS control system provides audio and visual notification in the event that an alarm condition occurs. The audio alarm is located on the TRS heater control panel. The HMI screens provide status windows for alarm conditions.

The TRS control system monitors process performance and constantly measures process values against upper and lower limits. A partial list of process sensors that have alarm limits includes:

- adsorption bed thermocouples (heaters and bed temps),
- pressure transducers,
- tritium monitors, and
- dew-point (moisture) sensors.

When the lower or upper limits are exceeded, an alarm will be generated and the operator will be notified as described above. Depending on the alarm, the subsystem in which the alarm occurs may undergo a partial or full shutdown. For example, if the pump effluent pressure reaches the upper limit (40-psig), the pump will cease operation.