S-AA-M-31

Cryogenic Target Handling System Operations Manual Volume IV–CTHS Description

Chapter 5: Tritium Fill Station (TFS)

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Chapter 5
Tritium Fill Station (TFS)

5.0 INTRODUCTION

LLE and Ontario Hydro have collaborated since FY86 to construct a facility at LLE to fill polymer shells with DT. The Tritium Fill Station (TFS) was delivered during FY91 and reconfigured to fill stalk-mounted OMEGA targets during FY95. The TFS is used for room-temperature, low-pressure fills and in conjunction with the DTHPS for cryogenic, high-pressure fills.

For room-temperature, low-pressure fills, a maximum of 18 targets, divided into three batches of six, can be filled with DT in a fill cycle. Each batch can be filled to a different pressure, up to a maximum of 150 atm. The required fill pressure, the thickness of the target wall, and the permeation time constant of the Al barrier layer determines the length of the cycle. Typically, 1-mm-diam targets with 10-μm walls are filled to 10 atm in 1 day. Thicker-walled targets are filled to higher pressures in two days.

For cryogenic, high-pressure fills, the TFS is used to supply tritium to the DTHPS to fill a maximum of four targets. The high-pressure DT fill process is described in Chap. 13. These high-pressure fills require 18 h to pressurize targets and 2 days to cool targets.

As illustrated in Fig. 5.0-1, the tritium-handling equipment is housed entirely in a helium glovebox that has an integral tritium-decontamination unit and a backup tritium scrubber. The system is computer controlled throughout the multiple-day filling sequence. All the safety devices are passive fail-safe components.

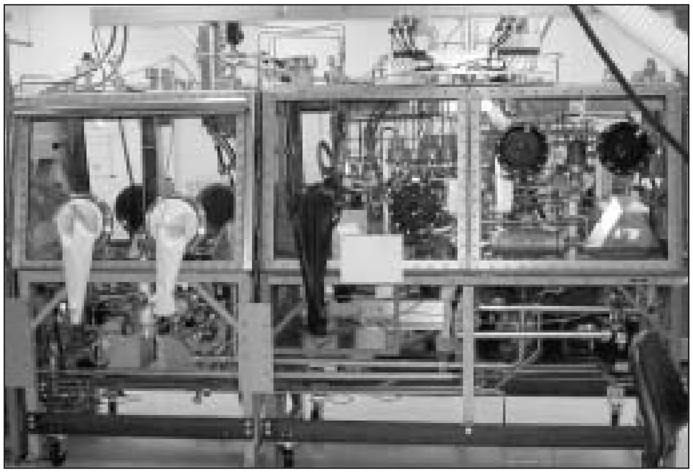
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Figure 5.0-1
The Tritium Fill Station process equipment can be seen through the three panels. The panel on the right houses the U-beds and pumps; the middle panel contains the contact tube and condensation cell. The left panel is used as a pass box to bring equipment or targets in and out of the TFS. The panel on the left also provides cold storage for room-temperature, low-pressure-filled targets.

5.0.1 Equipment Overview

The major components in the Tritium Fill Station are shown schematically in Fig. 5.0-1. A brief description of these components follows:

1. **Uranium beds:** The uranium beds absorb tritium at ambient temperatures. The tritium is released when the U-bed is heated to 430°C.
2. **Calibrated volume:** This 7.2-liter vessel is used to expand the tritium inventory. The vessel has pressure and temperature gauges so accurate assays can be performed.
3. **Condensation cell:** The condensation cell is a vacuum-jacketed vessel that has a cold head to bring a cold finger to cryogenic temperatures. The tritium is condensed on the cold finger.
4. **Contact tube:** This tube contains the targets and is where the target filling takes place when the TFS is used to fill ambient pressure targets.
5. **Normetex pump:** This pump is used for circulation and evacuation procedures.
6. **Metal bellows pump:** This pump serves as the backing pump for the Normetex pump. It exhausts into the glovebox purification system.
7. **Glovebox purification system:** This system removes impurities, moisture, and tritium from the glovebox and process loop.
8. **TFS glovebox:** The glovebox is filled with He and is a barrier to outside moisture. It is also designed to contain any tritium that may be accidentally released. The glovebox contains several glove ports that are used to maintain the equipment and transfer targets in and out of the TFS.

5.0.2 Overview of Room-Temperature Fill

The maximum permissible tritium inventory at LLE is 1 gram of tritium (10,000 Ci). This tritium is reversibly stored in one of two uranium beds. At room temperature, the U-beds absorb deuterium/tritium (by converting DT to uranium hydride), and the tritium is released when the U-bed is heated to 430°C. To improve the efficiency of DT removal, it is condensed in the condensation cell to minimize back pressure.

The DT is transferred from the U-bed to the condensing cell and then to the assay volume. The assay volume is a 7.2-liter volume that has two pressure gauges and temperature gauges that are used to assay the contents. A portion of the DT is then recondensed in the condensation cell. The DT that is not condensed is returned to the cold U-bed.

The condensation cell temperature is then raised to evaporate the DT and increase the pressure. The DT is then transferred to the contact cell where the targets reside. After the fill has been completed, the DT is transferred to the second U-bed (referred to as the “cold U-bed”). The residual DT left in the process line is removed by circulating the residual DT over the cold U-bed using the Normetex pump. The system is then evacuated.

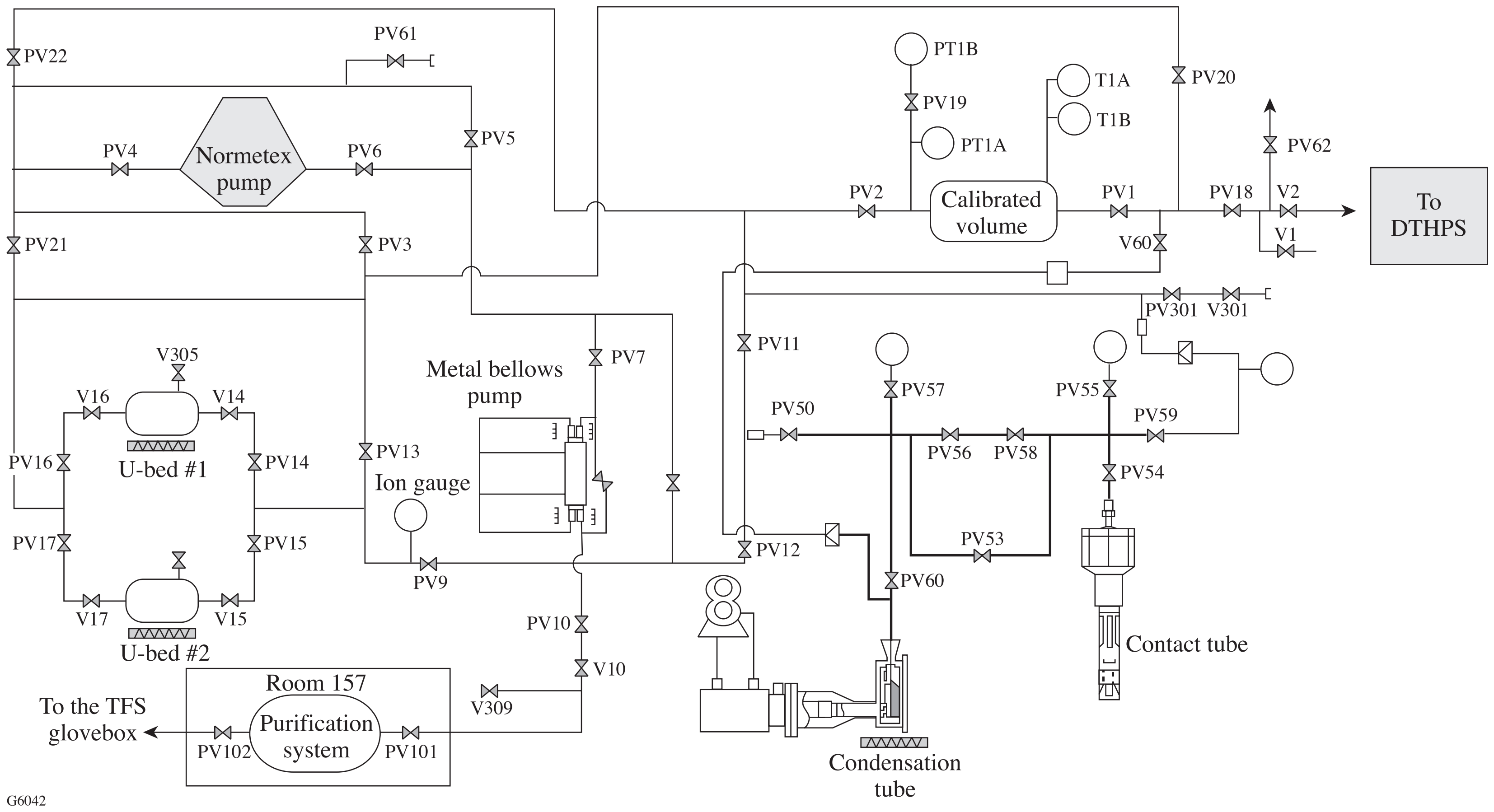

Figure 5.0-1
The process and instrument diagram for the Tritium Fill Station.

5.0.3 Overview of Cryogenic, High-Pressure Fill

The TFS supplies DT for the cryogenic, high-pressure fills. The DT is first transferred to the condensation cell by heating the U-bed and condensing the DT in the condensation cell. The pressure remains very low at the end of the heating cycle because the DT gas is condensed. This allows all of the DT to be driven off the hot U-bed in one heating.

The DT is then expanded to the assay volume, and an assay is taken. After the assay, the DT is transferred to the DTHPS (condensed in DTHPS condensation tube). The DTHPS will return portions of the inventory during the high-pressure fill cycle. Each time DT is returned, the DT is assayed and then transferred to the cold U-bed. The residual DT is then circulated over the cold U-bed and the TFS is evacuated. The high-pressure fill cycle is described in more detail in another chapter.

5.0.4 Tritium Fill Station Summary

The following is an overview of the TFS:

- The TFS can simultaneously fill 18 capsules with up to 60 atm of DT at room temperature.
- The TFS can contain up to 1 g (10,000 Ci) of tritium mixed with an equimolar ratio of deuterium.
- A typical 1-mm target filled to 20 atm contains about 10 mCi of DT.
- Filling operations are accomplished in gloveboxes to meet environmental, health, and safety regulations.

5.1 EQUIPMENT OVERVIEW

As originally constructed, the Tritium Fill Station (TFS) consisted of the receiving and inventory loop, pumping system, DT storage loop, capsule-charging loop, piping and valving, glovebox, ancillary systems, glovebox purification system, electrical and instrumentation systems, glovebox atmosphere monitors, control system, and the supporting facility. In 1995 the TFS was modified with the addition of a glovebox annex to allow for the handling and coating of filled targets, modification of the process loop to allow for additional cryogenic filling capabilities, replacement of the contact tube to allow filling of mounted targets, and installation of a cryogenic cooler. The TFS is a very sophisticated piece of equipment and will be discussed in more detail in subsequent sections.

5.1.1 Uranium Bed

Long-term storage of DT in the TFS is provided by a pair of uranium storage beds (U-beds shown in Fig. 5.1-1) to limit leaks and outgassing, as well as reduce the possibility of accidental releases. At ambient temperature, hydrogen isotopes form uranium hydrides within the beds.

One storage bed provides adequate storage capacity for the entire TFS inventory, but a second bed has been provided to serve as a backup. The prime function of the uranium storage bed is to store tritium and deuterium in a stable form to minimize the possibility of releases from the system. A secondary function of the bed is to act as a helium filter. Hydrogen isotopes and impurities such as O_2, N_2, H_2O, and hydrocarbons form chemical compounds with uranium, but helium is left in a gaseous form. After the hydrogen isotopes have been absorbed, residual helium can be evacuated from the process systems.

The beds are enclosed in a rechargeable vacuum jacket to maximize thermal efficiency and reduce outer-skin temperature to 50°C. Heating the U-bed to 400°C desorbs the elemental D and T that are chemically bonded to the uranium.

Figure 5.1-1
Tritium is stored in uranium beds. The U-beds absorb tritium at room temperatures and releases the tritium at ~400°C.

5.1.2 Assay Volume

The major component of the receiving and inventory loop is a 7.13-liter calibrated volume. Tritium and deuterium are loaded into the loop through the calibrated volume, where they are assayed using high-accuracy temperature- and pressure-sensing equipment.

5.1.3 Target Filling System

The target filling system is comprised of four major components:

1. A closed-cycle cryogenic refrigeration system,
2. A condensation tube,
3. A pressure-reducing mechanism, and
4. A contact tube.

5.1.3.1 Closed-Cycle Cryogenic Refrigeration System

The closed-cycle refrigeration system is used to cool a condensation tube to 10 K and (by cryopumping action) to evacuate DT from the uranium getters or calibrated volume to the condensation tube. The refrigeration system consists of

- A helium compressor located outside the glovebox,
- A cryo-refrigerator (cold head) located inside glovebox A,
- A vacuum shroud, and
- A helium-transfer line between the compressor and the cryo-refrigerator.

The refrigeration system is a closed-cycle helium refrigeration system that utilizes the Gifford–McMahon refrigeration cycle. The cold head achieves the Gifford–McMahon cycle by expanding high-pressure helium to low pressure. This is accomplished through a reciprocating expansion device that allows the helium to expand in two stages: first to approximately 50 K and then to 10 K. Helium is then returned to the compressor through a second transfer line. The cold head is enclosed in a vacuum jacket to permit the system to achieve cryogenic temperatures by minimizing heat absorbtion from the surrounding areas. The system requires a vacuum of 60 mtorr to provide adequate insulation.

5.1.3.2 Condensation Tube

Deuterium and tritium are transferred from the uranium getters or assay volume to the condensation tube (shown in Fig. 5.1-2). The tube is isolated from the other TFS loops, and the DT is cryogenically pumped to the condensation tube, where it is condensed in solid form. When the transfer is complete, the tube is heated to room temperature, generating DT pressures up to 23,800 kPa.

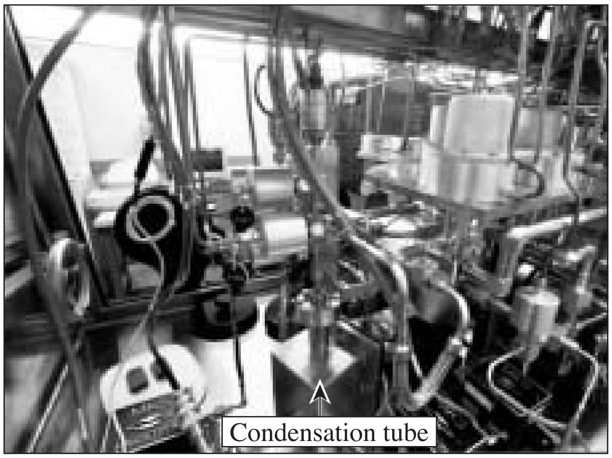

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Figure 5.1-2
The condensation tube is encased in a vacuum jacket that provides thermal isolation. The cold-finger temperature is lowered to 10 K, and tritium is condensed on the cold finger.

5.1.3.3 Contact Tube

The targets are charged in the contact tube—a long tube sealed at one end with a welded end cap. The other end is fitted with a male VCR gland for connection to the charging loop by a VCR connector. Eighteen targets can be filled at one time (six per rack × three racks).

5.1.4 Vacuum Pumps

The vacuum-pumping loop consists of a Normetex scroll vacuum pump for generating vacuums in the 5-mtorr range. This is backed by a two-stage metal bellows, single containment pump. The pumps (shown in Fig. 5.1-3) are used to evacuate the various process loops prior to transfer of DT. The Normetex pump is also used to circulate hydrogen back to the U-beds to enhance gettering.

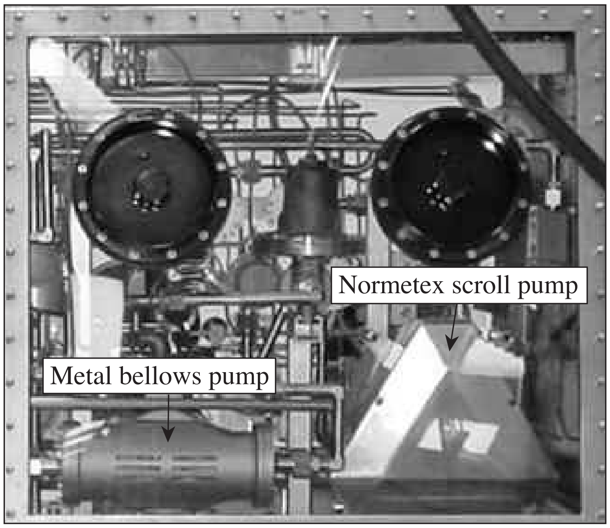

Figure 5.1-3
The Normetex pump is used to evacuate the process lines. The metal bellows pump is the backing pump.

5.2 TFS GLOVEBOX CONTROL SYSTEM

The inert helium atmosphere within the TFS glovebox is maintained by a glovebox control system. The purpose of this system is as follows:

1. To control the glovebox pressure,
2. To monitor and trap residual tritium in the glovebox,
3. To monitor and reduce moisture,
4. To reduce organic impurities,
5. To monitor and reduce TFS process line tritium discharge, and
6. To monitor tritium discharged to the stack.

There are six subsystems (illustrated in Fig. 5.2-1) required to achieve the objectives listed above:

1. **Glovebox Purification System (GPS):** This system takes effluent from the TFS glovebox, reduces the moisture, removes impurities, and reduces the tritium content. The effluent is then returned to the TFS glovebox system.
2. **Process Loop Getters:** This system takes effluent from the process line evacuation pumps, removes impurities, and reduces the tritium content. The process effluent is sent to the GPS system for additional processing and is finally discharged to the TFS glovebox.

3. **Glovebox Primary Pressure Control System**: This system controls the glovebox pressure +1/2 in. of H_2O. This system requires He pressure and power to operate.
4. **Glovebox Bubbler Pressure Control:** This system passively controls the glovebox pressure to +8 in. of H_2O of setpoint. This can operate without power or He pressure and serves as overpressure protection of the glovebox.
5. **Overhoff Tritium Air Sampler:** This system samples the exhaust stack stream to verify compliance with environmental release limits.
6. **TFS Glovebox:** A plexiglass enclosure pressurized with He.

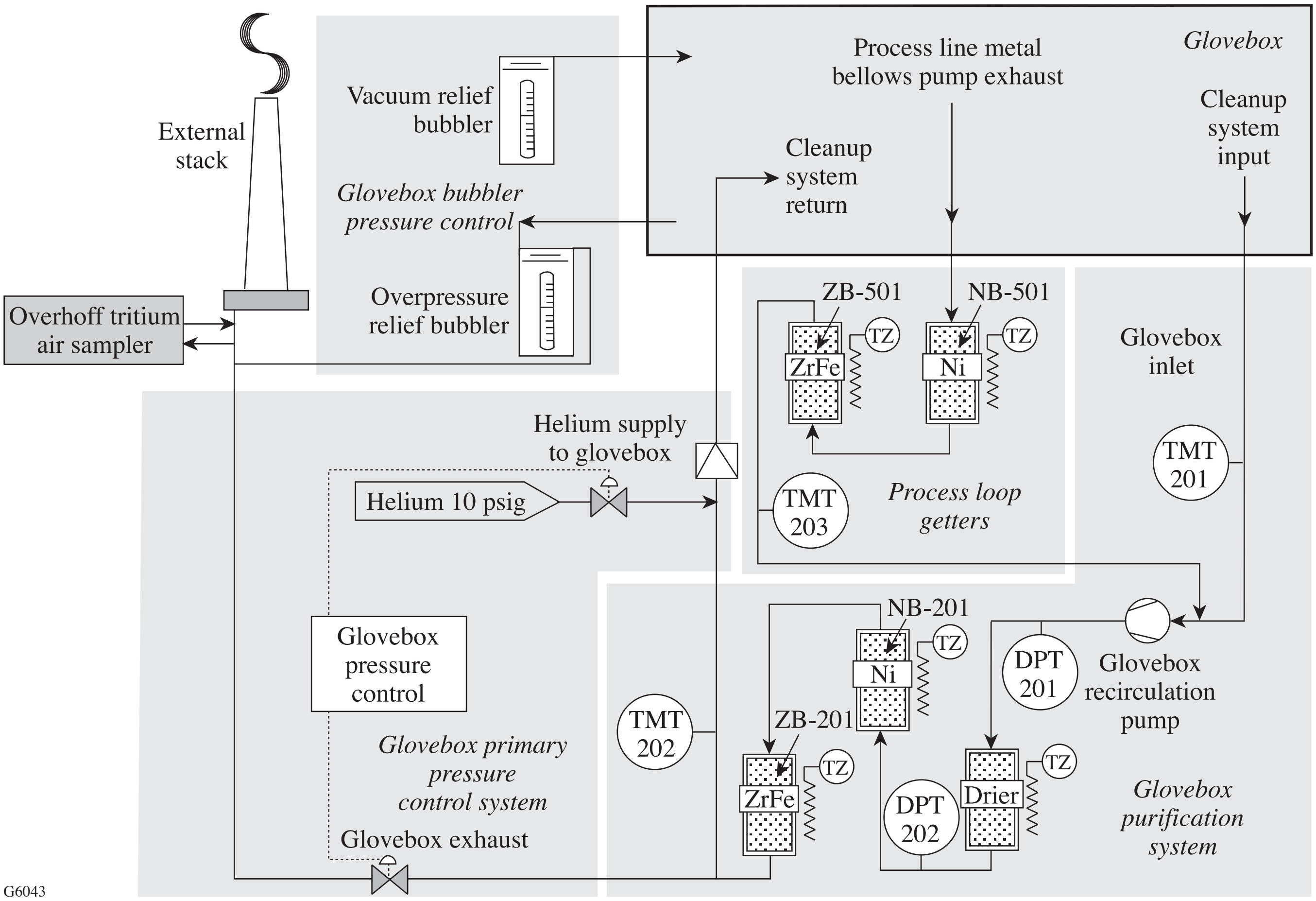

Figure 5.2-1
The TFS glovebox control system is comprised of six subsystems: (1) glovebox bubbler pressure control, (2) glovebox, (3) process loop getters, (4) glovebox purification system, (5) glovebox primary pressure control system, and (6) Overhoff Tritium Air Sampler.

5.2.1 Glovebox Purification System (GPS)

The inert helium atmosphere is maintained by a Glovebox Purification System (GPS). The glovebox helium is continuously circulated through the reactor to extract impurities, including hydrogen oxides, nitrogen, hydrogen, oxygen, hydrocarbons, and moisture. Separate moisture and tritium monitoring systems are provided to monitor the glovebox atmosphere. The basic components of the GPS are summarized below and shown in Fig. 5.2-2:

1. Molecular sieve: removes moisture
2. Nickle catalyst: cracks hydrogen oxides and hydrocarbons
3. SAES (ZrFe) metal getter: removes gaseous tritium, nitrogen, and hydrogen
4. Tritium monitors
5. Glovebox recirculation pump

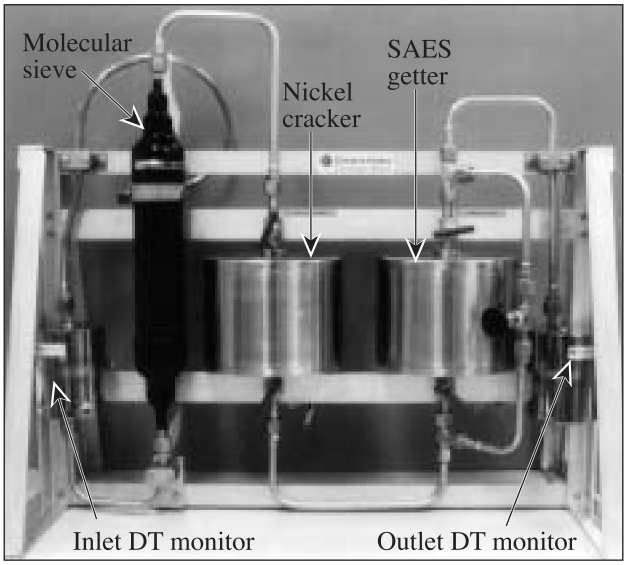

Figure 5.2-2
The Glovebox Purification System's main components include the DT monitors, the SAES (ZrFe) getter, the nickel cracker, and the molecular sieve bed.

5.2.2 Process Loop Getters

The process loop getters are used only when the process lines are being evacuated. The process effluent is directed through the reactors to extract impurities, including hydrogen oxides, hydrogen, oxygen, and hydrocarbons. The basic components of the Process Loop Getter are summarized below and shown in Fig. 5.2-2:

1. Nickle catalyst: cracks hydrogen oxides and hydrocarbons.
2. SAES (ZrFe) metal getter: removes tritium and hydrogen
3. Tritium monitor

5.2.3 Glovebox Pressure Control System

Glovebox pressure is maintained 1/2 in. of H_2O of atmospheric pressure by a system that exhausts helium to the stack from the glovebox on overpressure conditions, or supplies fresh helium when the pressure is too low (see Fig. 5.2-1). A check valve on the cleanup system return line ensures that glovebox He does not backflow to the stack in an overpressure condition.

5.2.4 Glovebox Bubbler Pressure Control

The bubbler pressure control system is used to protect against extreme pressure conditions such as a failure of the primary pressure control system. This system will limit the pressures when the glovebox pressure deviates 8 in. of H_2O from setpoint.

5.2.5 Overhoff Tritium Air Sampler

An Overhoff Tritium Air Sampler (see Fig. 5.2-3) collects liquid scintillation counter samples from the exhaust stack stream to verify compliance with release limits. To date, the average tritium concentration released to the environment is below the DEC permit limit (2.2 Ci/year) established by the NYS Department of Environmental Conservation.

Figure 5.2-3
The Overhoff Tritium Air Sampler collects tritium samples from the exhaust stack stream. The four liquid sample vials can be seen.

A pump controlled by an adjustable constant flow controller draws a representative sample from the exhaust line and passes it through liquid bubbler scintillation vials separated by a high-efficiency (typically 99%) catalytic oxidizer. The first two vials in the process stream collect the oxide form of tritium, and the second two vials collect elemental tritium after it is converted to the oxide form by the catalytic oxidizer. Each vial has a >95% collection efficiency. The vials are located on the front panel of the sampler for ready detachment and counting by the liquid scintillation counter.

The system is calibrated to determine the percentage of tritium collected by the vials to allow accurate measurements of tritium. Typically, a collection time of 8 h will yield detection thresholds to $<10^{-9}$ Ci/ml. Increasing the collection time results in even-lower detection thresholds.

5.2.6 Glovebox

The glovebox is fabricated of stainless steel with plexiglass windows on the front and back. Materials are transferred into or out of the glovebox through an airlock. Glove ports are provided on the front and back of the glovebox to permit access for operation and maintenance (as can be seen in Fig. 5.2-4).

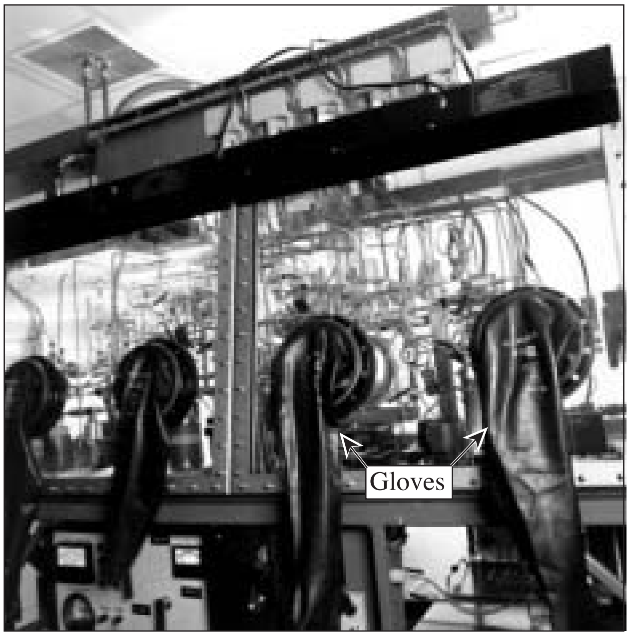

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Figure 5.2-4
The gloves allow the operator to load or unload targets and perform maintenance on the process equipment.

5.2.7 Glovebox Cleanup System Instrumentation

The instrumentation rack for the glovebox cleanup system is shown in Fig. 5.2-5. All of these instruments can be located on the process diagram shown in Fig. 5.2-1.

1. **Cleanup System Inlet Monitor (TMT-201):** This monitor measures the tritium activity of the Glovebox Cleanup System inlet. This is the tritium activity level of the TFS glovebox. A high activity level will initiate an emergency stop.

2. **Process Loop Outlet Monitor (TMT-203):** This monitor measures the tritium activity of the TFS process loop outlet (after the process loop getters). This shows the tritium activity level of the TFS process loop before it enters the Glovebox Cleanup System.

3. **Cleanup System Outlet Monitor (TMT-202):** This monitor measures the tritium activity of the Glovebox Cleanup System outlet before it is returned to the TFS glovebox.

4. **Glovebox Getter Heater Controllers (ZB-201 and NB-203):** These units control the temperature of the glovebox getters.

5. **Glovebox Getter Over Temperature Controllers:** These units monitor the temperature of the glovebox getters and disrupt the power to the heaters.

6. **Process Loop Getter Heater Controllers (ZB-501 and NB-501):** These units control the temperature of the process loop getters.

7. **Moisture Sensors (DPT-201 and DPT-202):** There are two moisture sensors in the glovebox cleanup system; one sensor measures the moisture level at the drier inlet and the other sensor measures the dryer outlet moisture level. A high moisture level will initiate a emergency stop.

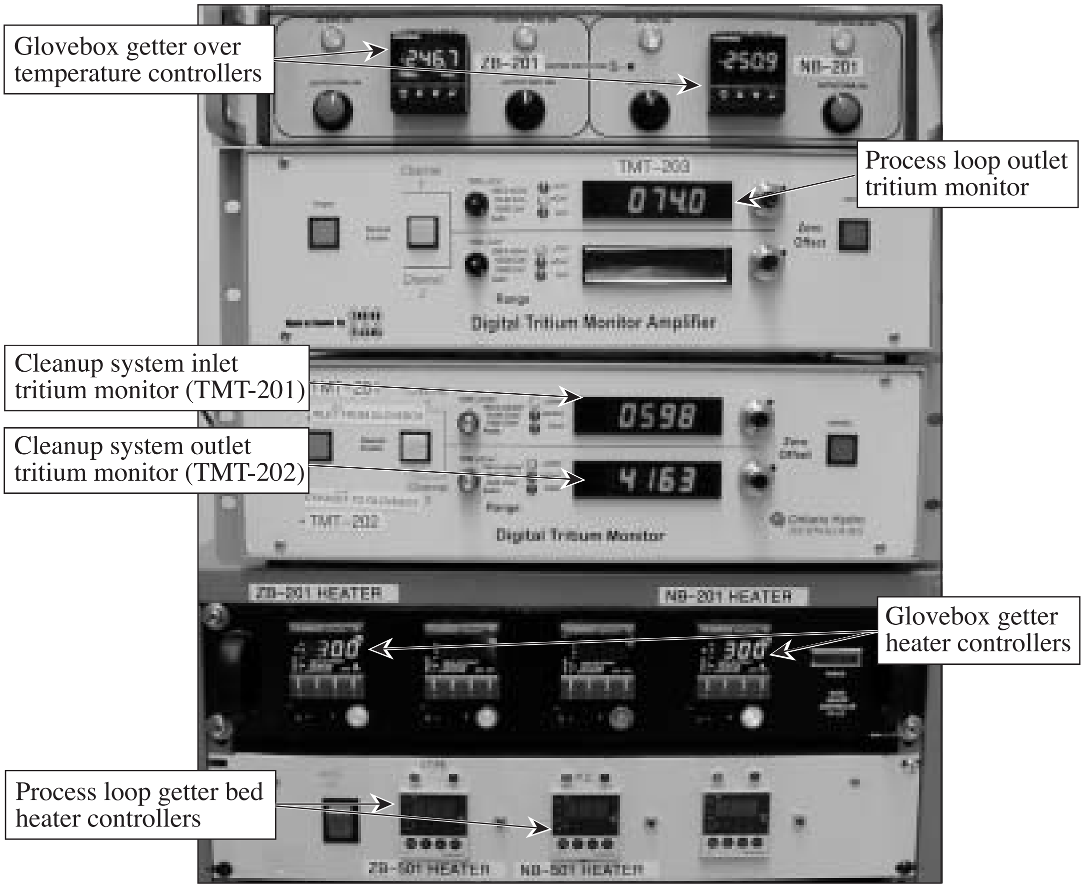

Figure 5.2-5
The Glovebox Cleanup System instrumentation rack.

5.3 PROCESS OVERVIEW

During the loading operation, up to 10,000 Ci of tritium are retrieved from the uranium bed, assayed, and transferred to the high-pressure loop of the system where actual loading takes place. The different modes of operation during a typical loading cycle are described below.

5.3.1 Initialization and Preparation

The system is evacuated ~5 mtorr, venting the effluent to the glovebox purification system to remove any DT. The contact cell containing the mounted capsules is connected to the TFS, and the system is evacuated. The high-pressure loop is then isolated.

5.3.2 Driving DT from the U-Bed to the Condensation Tube

The contact cell containing the mounted capsules is connected to the TFS and the system is evacuated. The condensation tube (at 10 K) is connected to the U-beds. The DT inventory is driven off the U-bed by energizing the bed heaters and condensed into the condensation tube. The DT pressure is kept to a minimum since the gas is condensed as it is driven off the U-bed (see Fig. 5.3-1).

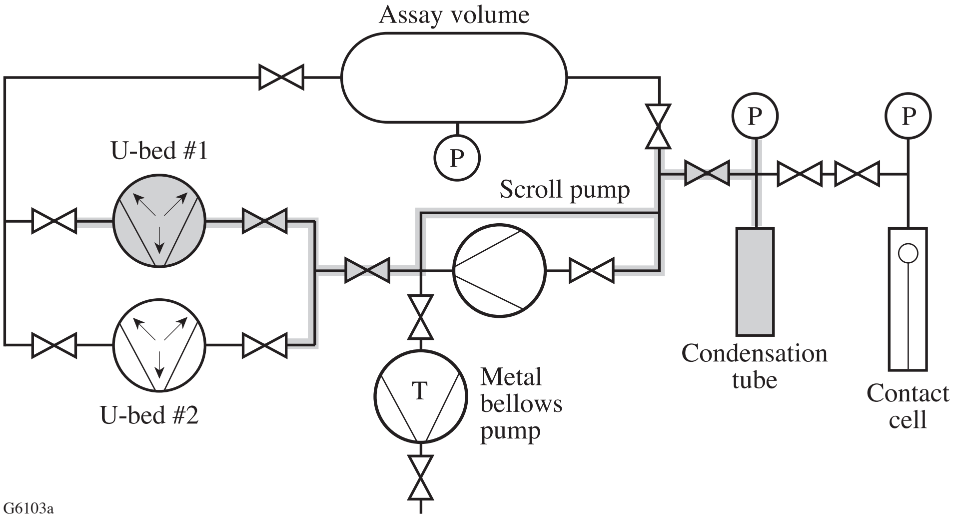

Figure 5.3-1
The uranium bed is heated to condense the DT into the condensation tube.

5.3.3 Expanding the DT into the Assay Volume

The assay volume is connected to the condensation tube. The DT is then expanded into the assay volume by heating the condensation tube to ~40 K (see Fig. 5.3-2).

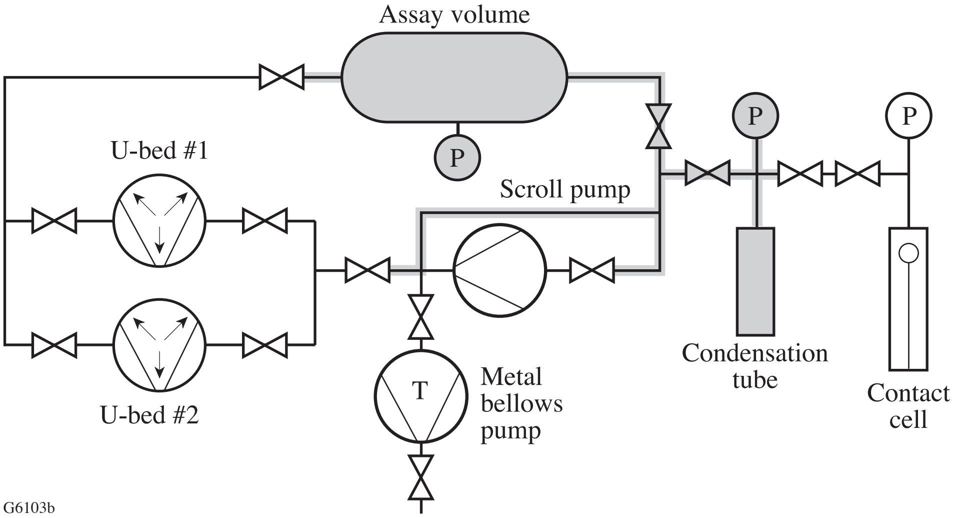

Figure 5.3-2
The DT is expanded into the assay volume by heating the condensation tube.

5.3.4 Condensing the DT Inventory Required for a Room-Temperature Fill

The room-temperature fills require only a fraction of the DT inventory. The required amount is condensed back to the cold finger by cooling the condensation tube to ~10 K (see Fig. 5.3-3).

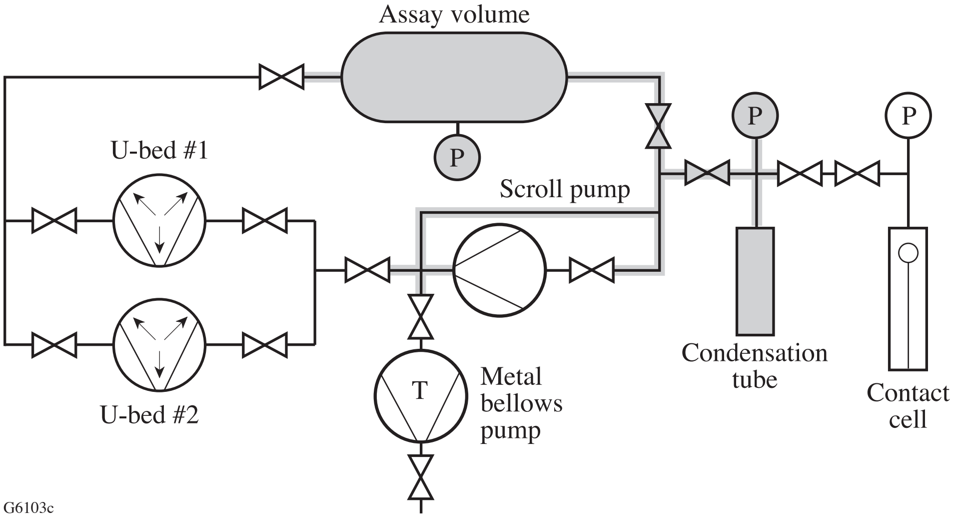

Figure 5.3-3
The pressure of the DT is increased by first condensing it, confining it, and then reheating it.

5.3.5 Returning the Unused DT to the Cold U-Bed

The cold U-bed is connected to the assay volume and the unused DT is pumped to the cold U-bed (see Fig. 5.3-4).

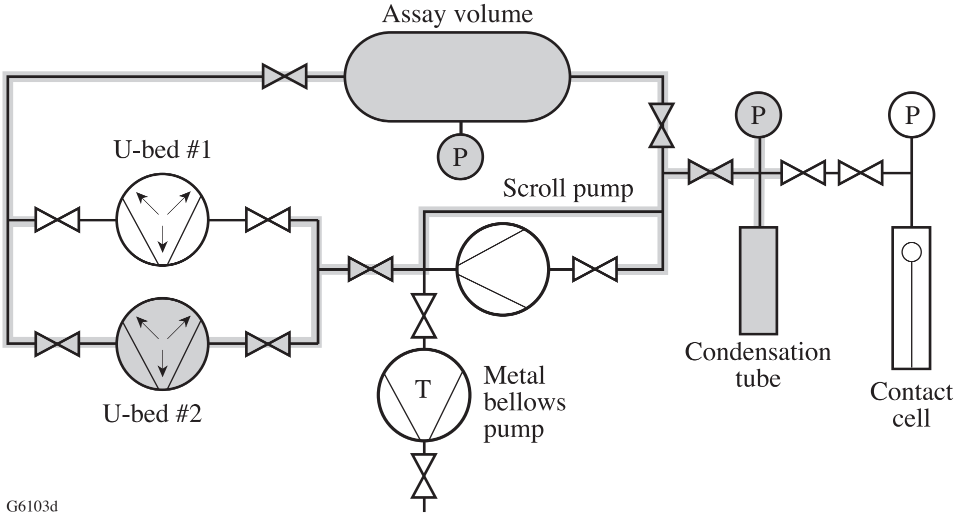

Figure 5.3-4
The DT not required for the fill is absorbed by the cold U-bed.

5.3.6 Target Filling

The condensation tube is heated to return it to room temperature, thereby increasing the pressure of the DT. The DT is transferred to the contact cell by sequentially opening and closing valves at each end of a trapped volume. The capsules are therefore subject to a gradual increase in pressure until the desired pressure in the capsules is attained (see Fig. 5.3-5).

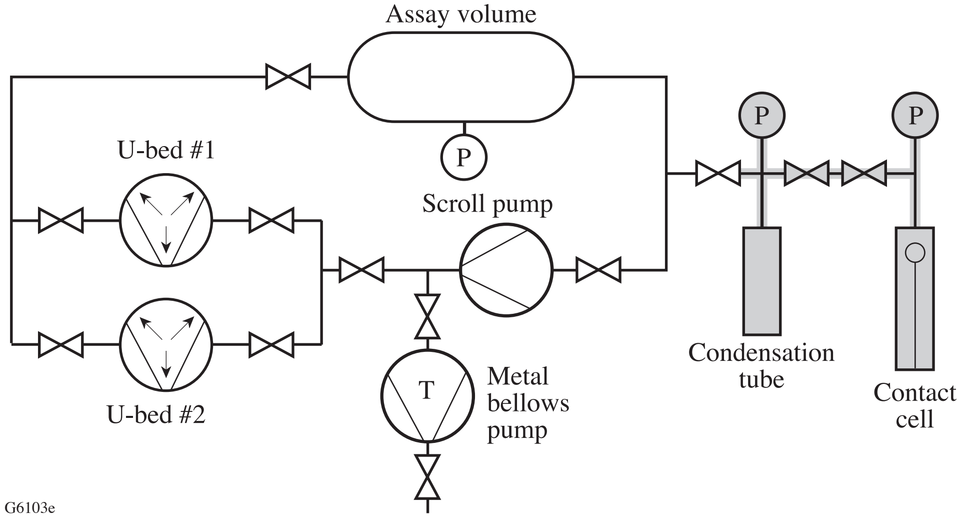

Figure 5.3-5
The condensation cell is brought up to room temperature, which releases and pressurizes the DT. The DT is then transferred to the contact cell, where the targets reside.

5.3.7 Returning DT to the Uranium Bed

After charging, the DT is transferred from the high-pressure loop to the uranium storage beds, where the remainder of the DT inventory is stored. The high-pressure loop is evacuated and backfilled with helium, and the contact cell and capsules are removed from the TFS for post-filling processing (see Fig. 5.3-6).

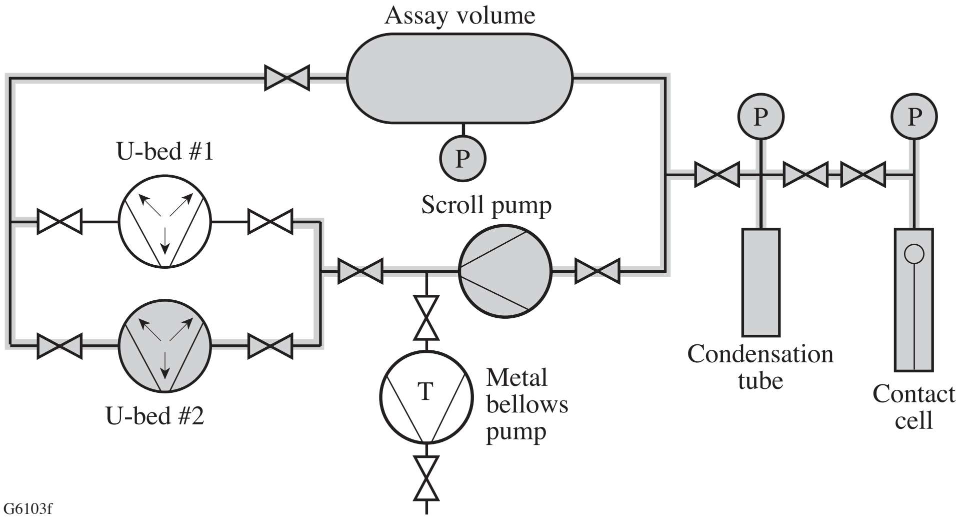

Figure 5.3-6
After the fill has been completed, the DT is "pumped" back to the "cold" U-bed.

5.4 TRITIUM MANAGEMENT AND MONITORING

Under normal operation, the TFS completes up to one loading cycle every 3 days. The actual tritium content of each polymer capsule will be variable dependent upon the experimental program. A reference value of 12.5 mCi is assumed for gaseous targets, and a reference value of 0.35 Ci is assumed for cryogenic targets.

The TFS was designed to achieve practically zero leakage of tritium from system components located in the glovebox. The glovebox serves as a second barrier to prevent tritium leakage into the atmosphere. Any tritium that enters the glovebox will be collected in the Glovebox Purification System. As a third barrier to people within the UR/LLE building, the room housing the TFS is kept at a negative pressure to ensure zero leakage to adjacent spaces.

To ensure safety, accidents that could affect either the general environment and population or individual UR/LLE employees were analyzed. The analysis concluded that there was no accident that would put either the general population or environment at risk. An accident that releases the entire inventory of tritium to the TFS room and then from there to the environment in one hour is the worst-possible accident. This accident would result in a 6-μrem exposure to the general public and <60-mrem exposure to an operator. The TFS Radiological Safety Assessment evaluates the probability of this accident to be very remote since it would require at least dual failures (i.e., failure of the TFS system resulting in release to the glovebox and the simultaneous failure of the glovebox).

5.4.1 Tritium Monitors

Tritium levels are monitored continuously inside the glovebox by a tritium monitor integral to the TFS. If this monitor detects excessive tritium, the TFS is automatically shut down and the tritium is returned to the uranium beds.

5.4.2 Tritium Activity

Normal glovebox concentrations typically remain <5 mCi/m^3. Stack effluent concentrations average <0.05 $\mu Ci/m^3$ for each year. Tritium activity trended against process operations can be seen in Fig. 5.4-1.

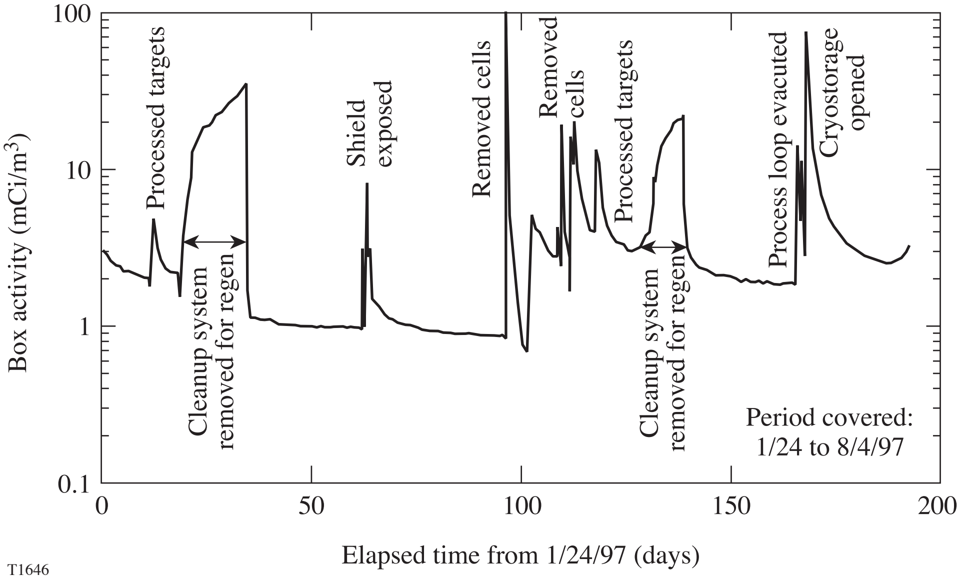

Figure 5.4-1
The process operation impacts the tritium activity within the glovebox.

The getter system has proven to be very effective. In one incident where 450 Ci was released into the glovebox, the concentration was reduced to about 100 mCi/m^3 after 1 day. Tritium in the stack effluent was measured for weeks following the incident. This can be seen in Fig. 5.4-2.

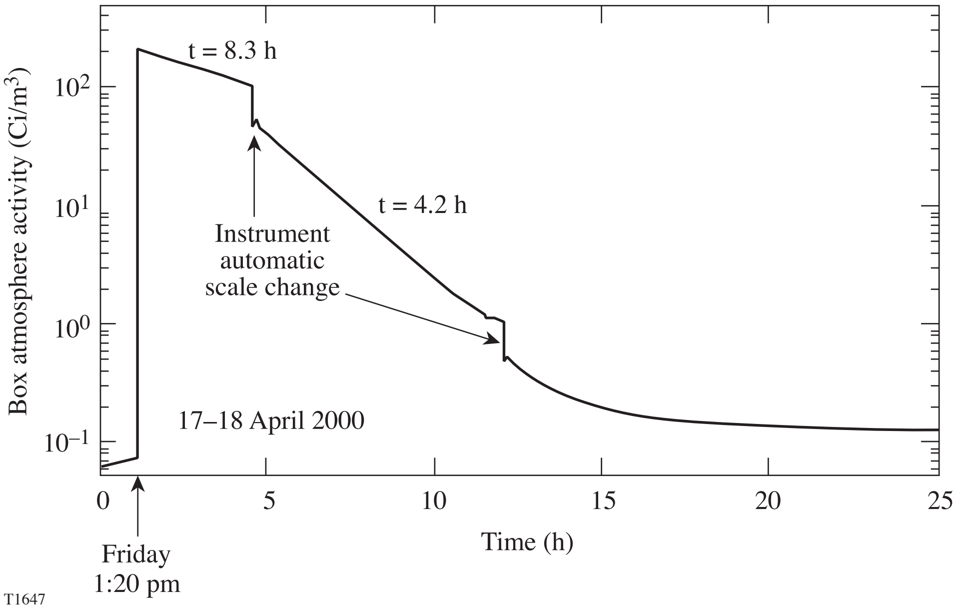

Figure 5.4-2
The glovebox purification control system was very effective in processing a 450-Ci release in the glovebox.

5.5 CONTROLS

All operations in the TFS are manually controlled and initiated, with the exception of the emergency stop and the target-filling sequence, which is manually initiated, but automatically controlled by a programmable logic controller located in a control console adjacent to the glovebox. In addition to the PLC, the panel contains an LCD touch panel for control of the valves, instrumentation readouts, alarms, etc. Most process-related instrumentation readouts are located on the controls console.