Radiation Safety at the University of Rochester's Laser Fusion Research Facility

P. Andrew Karam[1] and Gregory Pien[2]
[1]University of Rochester Medical Center, 601 Elmwood Avenue, Box HPH, Rochester, NY 14642 USA
[2]Laboratory for Laser Energetics, 250 East River Road, Rochester, NY 14623 USA

INTRODUCTION

The University of Rochester operates the Laboratory for Laser Energetics (LLE) which conducts research in the area of inertial confinement fusion. Unique radiological concerns include working with large quantities (up to 370 TBq) of tritium, decontamination of tritium-contaminated components, high neutron fluxes (up to $3x10^{15}$ neutrons per shot) neutron activation of Target Chamber (TC) materials, and minimizing environmental releases of tritium from the tritium fill station and the TC. Some of these concerns will be heightened later this year (2000) when research commences using cryogenic targets, each containing up to 28 GBq of tritium. In addition, all "routine" radiological concerns remain.

These problems were addressed through a series of engineering and administrative controls, chiefly developed by LLE staff. The result is a high-quality radiation safety program with low radiation exposure to personnel, low environmental releases, and constant awareness of radiological concerns. Specific measures taken include:

1. Use of specially engineered containment systems to minimize the potential for leakage while filling targets
2. Use of uranium "getters", each capable of holding the entire tritium inventory
3. Use of tritium scavenging and effluent monitoring systems to minimize tritium release to the environment
4. Modifications to these systems to allow the use of high-activity cryogenic targets beginning in the year 2000
5. Personnel monitoring systems to track exposure to neutron radiation from neutron-producing shots, gamma exposure from neutron-activated components, and possible uptake of tritium during operations
6. Development of a comprehensive site-specific training program
7. Development of detailed Standard Operating Procedures for all aspects of LLE operations

This paper describes the systems in use to achieve an exemplary record of radiation safety at the LLE over many years while simultaneously maintaining a higher tempo of operations than any similar facility in the world (in excess of 10 shots on a typical day).

Description of the LLE

The LLE contains several major areas, of which the last three will be described in some detail:

- Technical support
- Administrative
- Tritium fill station
- Laser bay
- Target bay and chamber

The mission of the LLE is to investigate the interactions between high-intensity radiation with matter. An ultraviolet laser is used to illuminate tiny (about 1 mm diameter) polymer "microspheres" or other targets. Targets containing tritium and/or deuterium, will undergo some degree of hydrogen fusion while others are vaporized.

Microspheres are filled at the tritium fill station (TFS) and are transferred to the target chamber (TC). The TC, a 3.3 meter evacuated sphere, has 60 beam ports, allowing the laser light to enter the TC. The laser beam, generated in the laser bay, is split into 60 beams, each nearly 20 cm in diameter when they enter the target bay (the room containing the TC). They are focused so that they can strike the target simultaneously from all directions.

When a DT target is shot, about 0.1% or less of the tritium present will fuse and the rest is released into the TC. Most is exhausted into the tritium recovery system via cryogenic vacuum pumps while the remainder contaminates the TC interior and any equipment contained within. During the shot, tritium and deuterium fusion release neutrons with maximum credible calculated neutron fluxes of about $3x10^{15}$, released in about 10^{-9} seconds. This, plus the gamma radiation emitted gives calculated radiation doses of up to about 5 Sv (500 rem) per shot in parts of the target bay. No personnel are allowed in the target bay during a shot and dosimeters are kept in a variety

of locations around the exterior of the target bay to ensure shielding adequacy.

Tritium Fill Station (TFS) Containment Systems

Target microspheres are filled with an equal molar mixture of deuterium and tritium by immersion in a tritium atmosphere pressurized to as much as 40 atmospheres from an inventory as large as 370 TBq (10,000 Ci) of tritium. The deuterium-tritium gas diffuses through the polymer skin of the microsphere, charging the microsphere with about 0.7 GBq (20 mCi) of tritium. The TFS is contained within a sealed glovebox which allows manual or pneumatic operation of valves and instruments and, if necessary, manipulation of the microspheres. After filling, the microsphere is placed into a clean transport bottle. This transport bottle is then removed from the TFS and taken to the TC. Future plans are to add the capability to use cryogenic targets, pressurized to 1500 atmospheres and cooled to form tritium ice about 350 microns thick at ~18K. These targets will hold up to about 30 GBq (0.8 Ci) of tritium each. This operation raises the following radiological concerns:

1. Potential tritium contamination outside the glovebox
2. Potential release of large amounts of tritium to the room surrounding the TFS
3. Ensuring the complete removal of tritium gas from the TFS prior to removing the transport container
4. Tritium permeation of gloves

The interior of the TFS is contaminated because of its immersion in a tritium atmosphere during filling operations. The potential exists for this contamination to escape, exposing workers to tritium. The actual tritium filling system is a relatively small volume that is designed for virtually zero leakage. This is the primary containment and the glovebox is the secondary containment.

Periodic contamination surveys are performed both within and on the outside of the glovebox to monitor for tritium contamination and decontamination is performed as necessary. In addition, tritium levels within the glovebox are continuously monitored and the system is shut down if excessive levels of tritium are noted. The “clean” side of the gloves are surveyed periodically for contamination and the gloves are replaced as necessary.

The worst possible accident would be the simultaneous failure of both barriers while filling a target, resulting in the release of 370 TBq to the room. Since the room is approximately 10 meters square and 3 meters in height, this would result in tritium concentrations of about 1.23 MBq ml^{-1}, which is about $6.2x10^9$ times the Derived Air Concentration (DAC) noted in Federal Guidance Report Number 11 (1) for elemental tritium. Obviously, this level of exposure is potentially dangerous. In the event of such a release, tritium monitors would alarm, the system would shut down, gettering the tritium, and personnel would leave the room immediately. Assuming that one minute elapsed from the time of the release until complete evacuation of the room it is calculated that the most-exposed individual would receive a whole-body dose of about 0.42 mSv (42 mrem).

The ventilation half-life of this room is about 11.5 minutes (the ventilation flow rate is about 75 m^3 $min^{-1)}$, so it would take about 1 hour to remove the majority of tritium and discharge it to the atmosphere. This would result in a calculated dose of 0.065 μSv to the maximally-exposed individually under the worst-case assumptions (no rain, Pasquill Stability Class F, low-altitude temperature inversion) (2).

In addition to the factors noted above, the use of cryogenic targets will pose the additional risk of rupturing the targets if they are allowed to warm and pressurize excessively before implosion. This is avoided by transporting the targets in a cryostat and maintaining it at cryogenic temperatures at all times prior to implosion. In this case, the cryostat is lifted into place in the TC, the cover removed, and the target hit, all within a few milliseconds. This system is expected to be operational in 2000.

Tritium Storage on uranium getter beds

In keeping with the philosophy of maximizing safety and serviceability, the 370 TBq of tritium (which is part of an equimolar mixture of deuterium and tritium) inventory is stored on one of two depleted uranium (^{238}U) getter beds as uranium tri-hydride (3). The depleted uranium in a conditioned getter bed reacts with hydrogen, deuterium, or tritium, to form UH_3 (or in this case UD_3 and UT_3) at temperatures approaching room temperature. The hydrogen isotopes are released by heating the getter beds (4).

At room temperature, the partial pressure of tritium outside the uranium hydride surface is reported below $2x10^{-3}$ Torr, and does not exceed 760 Torr until heated above 400° C (5). In this scheme, the tritium inventory is stored in a solid state at room temperature. Additionally, at room temperature the uranium bed functions as a pump, evacuating the system of tritium.

The uranium getter bed scheme allows for the storage of the 370 TBq (10 kCi) of tritium inventory at sub-atmospheric pressure and room temperature in a package occupying an approximate volume of 1500cc. Each getter bed is composed of 100 g of ^{238}U in a double walled stainless steel vessel fitted with electrical heating elements and thermocouple temperature sensors. The volume between the inner and outer shells of the vessel is evacuated to provide a secondary containment wall as well as thermal isolation. Each of these units is rated at 925 TBq (50 kCi) capacity, providing a reasonable safety factor.

During the target loading operations, up to 300 TBq (8 kCi) is released by heating the loaded uranium getter bed to a temperature of 425° C. One bed is maintained at room temperature to recover the DT gas that is not loaded into the target and to serve as a getter in the event of a system emergency shutdown.

Tritium scavenging and effluent monitoring systems

Significant tritium activity is routinely encountered in two process streams at LLE. These are the TFS process area and the TC vacuum system. To comply with radiological control and environmental regulations, both commercially available and custom designed equipment is employed to monitor and recover tritium in potentially contaminated exhaust streams. For reliability and cost reasons, identical, commercially available technology was selected for use in both the TFS and TC areas whenever possible.

Emissions compliance monitor

Representative samples of exhaust stream activity are collected by Overhoff TASC bubbler-type tritium collection systems. These units employ a 100 sccm air pump to draw a sample of the exhaust stack air through four glycol filled vials. Each vial collects roughly 90% of the HTO in the incoming air stream **(6)**, and the vials are arranged in pairs with a heated copper reactor between the pairs. This delivers >95% collection of HTO in the first vial pair, and then converts the HT in the stream to HTO for >95% collection in the second vial pair.

These samples are then assayed using a commercial Liquid Scintillator Counter (LSC). The sample flow rate and elapsed time of sampling is reported by the Overhoff TASC, and the stack flow rate is monitored by a flow meter installed in the exhaust stack. This information is fed to a uniform report using an MS Excel spreadsheet that details the total release and average effluent activity over each week to assure compliance with NY regulatory release limits.

The total activity for the samples is calculated using the following formula:

$$A_{total} = \frac{\sum_{x=1-4} DPM_x * Vol_x}{2.22 \cdot 10^6 \, DPM / \mu Ci}$$

The average effluent activity for the process stream for the sample period is calculated using the following formula:

$$A_{average} = \frac{A_{total}}{Flow_{sample} \cdot Time \cdot 60(\text{min}/hour)} \mu Ci/ml$$

Finally, the total release for the process stream for the sample period is calculated using the following formula:

$$A_{released} = A_{average} \cdot Flow_{stack} \mu Ci$$

Calibration of this monitor system consists of weekly preparation of a control glycol sample, used for background subtraction for the LSC assay, and bi-annual calibration of the flow meters.

Liquid Scintillation Counter

An EG&G Wallac 1409 LSC is employed to assay the liquid samples generated by the Overhoff TASC compliance monitor. This unit is fitted with an 444 kBq (12μCi) ^{152}Eu external source for quench correction. Its features include chemilumenescence correction and employs a digital signal processing to report activity directly in DPM per sample (7).

This computer controlled LSC uses bar-coded racks to combine multiple samples from a single survey. Each rack is prepared with one control, or background sample. The bar-code on each rack indicates the type of sample being assayed. The 1409 has a capability to store up to 100 different assay protocols. This LSC is used for many different types of tritium surveys, including surface and liquid samples. Specific protocols have been developed for each of these sample classes commonly used at LLE, each one tailored, for example, to the liquid type (e.g. water, glycol, pump oils, etc.).

Each survey is documented on a survey sheet which is filed by date with a copy of the Wallac 1409 data file. Electronic data files from the Wallac 1409 LSC are stored on a file server.

This unit uses an internal LED array to self-calibrate prior to each assay. This unit is equipped with a self-diagnostic capability to ensure system performance. Annual preventative maintenance is performed by an EG&G representative.

Inline process ionization chamber monitors

At key locations in the process streams, particularly at the inlets and outlets of tritium scavengers, inline ionization monitors are employed. These Ontario Power Generating Incorporated units are custom devices that have typical wet volumes of less than one liter. These units are not gamma compensated, and have electronics that are integrated into the tritium scavenger system. The data from these units are recorded on PCs and analyzed using MS Excel based spread sheets.

Description of scavenging hardware

High level activity is removed from process streams at LLE using Ontario Power Generating Incorporated Tritium Scavenger Units. Three of these custom built units are installed at LLE. Two of these units service the TFS, while the remaining unit services the Target Bay area.

The tritium scavengers employed at LLE are designed to provide reliable performance under conditions

typically encountered in LLE process streams. The process stream for the TFS is largely HT with residual HTO and tritiated CH_2 and CH_3.

The source of the process stream for the TC vacuum system is the cryopump regeneration exhaust. This stream is composed of the gas collected by the cryopumps during high vacuum operations. The estimated typical composition of each regeneration cycle is shown in Table 1.

Component	Volume in Torr Liters
N_2	2216
H_2O (from outgassing)	0.000146
DT	6.86
CH_2/CH_3 (from stalk/shell)	5.5
O_2	585.9
H_2	0.001
He	0.015
CH_4	0.006
Ar	26.01
O_3	0.000196
CO_2	0.923

Table 1: Estimated typical composition of cryopump regeneration process stream

Ontario Power Generating Incorporated Tritium Scavenger unit

This scavenger unit, designed and constructed by Ontario Power Generating Incorporated, consists of a molecular sieve as a pre-filter, a heated (350°C) nickel bed to crack hydrocarbons, and a zirconium-iron getter bed to collect HT. The zirconium-iron getter collects HT in the form of zirconium hydride at a temperature of 350°C. Ionization chambers are located at the inlet and exhaust of this unit to assess decontamination factor (DF), the ratio of inlet activity to outlet activity for the scavenger unit.

During normal operations, the molecular sieve and getter beds become saturated. In this situation the scavenger output activity may exceed the inlet activity. The inline ionization chamber monitors report this situation. If encountered, the getter beds are removed and returned to the manufacturer for regeneration. Regeneration of the beds is performed by heating the beds to 700°C and collecting the released gas.

The functional layout of the Tritium Scavenger Unit is shown in Figure 1.

Although these units have a theoretical DF of exceeding 20,000:1 (9) , in practice at LLE they typically operate at DFs or 10:1 to 100:1.

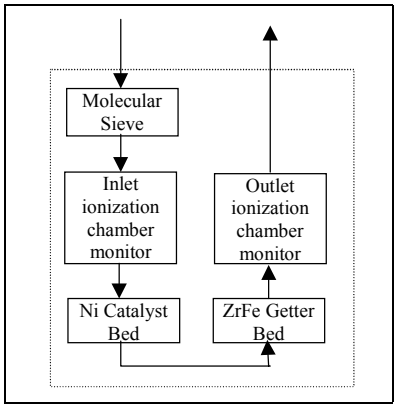

Figure 1: Functional layout of Tritium Scavenger Unit

Target Area use of effluent monitoring / scavenging systems

Tritium in the target area is primarily contained within the Omega TC (TC), a 550 cubic foot spherical vacuum chamber, and is associated vacuum systems. Tritium is introduced into this system in the form of Deuterium/Tritium (DT) gas filled microsphere targets, typically at an activity of 740 MBq – 1.85GBq (20 – 50 mCi) per target. During a typical target shot, a burn ratio of 0.1% is achieved, leaving 740 MBq – 1.85GBq per shot inside the TC. A significant fraction of this gas is trapped on the cryogenic pumps servicing the TC.

Tritium trapped on the cryopumps is released during the cryopump regeneration operation. During this operation the cold arrays in the pump are warmed using heated argon gas at a flow rate approaching 0.5 SCFM. This gas stream is processed by one of the Ontario Hydro Tritium Scavenger units. The output of this unit feeds into the main Experimental Area Exhaust Stack, as does the exhaust from the four Edwards EH1200/GV160 boosted dry vacuum pumps.

During manned access of the TC, room air is drawn through the TC and sent via the main vacuum roughing line directly up the Experimental Area Exhaust Stack. Air is driven from the Target Bay, through the TC and main vacuum roughing line by the pressure gradient resulting from the clean room HVAC requirements of the TB.

The Experimental Area Exhaust Stack draws air from outside the building at a flow rate of approximately 1500 scfm. Gas discharge from the sources within the experimental area is mixed into this air stream, which is then monitored on a weekly basis using the Overhoff TASC EPA 40.CFR.61.102 compliance monitor.

Effluent streams of potentially high tritium activity in the Target Bay systems are confined to the vacuum system exhaust and TC purge streams. Operational protocol limits activity in the mechanical pump exhaust feeds, and the TC atmospheric purge is typically of relatively low activity (<<7.4Bq/ml typical peak activity). These streams discharge directly to the Target Area Exhaust Stack without additional clean up. Any activity discharged is monitored by the Overhoff TASC EPA 40CFR61.102 compliance monitor. The schematic layout of tritium monitoring / recovery hardware and flow of tritium for Omega's experimental systems is shown in Figure 2.

The stream of highest activity is the cryopump regeneration exhaust streams. These effluent streams are only active during the cryopump regeneration cycle, which typically occurs at a 4-6 week interval. The duration is 120 minutes for each of the three pumps. This effluent is processed by one Ontario Hydro Tritium Scavenger unit. Inlet and outlet ionization chamber monitors on the Tritium Scavenger monitor the process in real time. The exhaust from the Tritium Scavenger is routed to the Target Area Exhaust Stack. Any residual activity discharged is monitored by the Overhoff TASC EPA 40CFR60.102 compliance monitor.

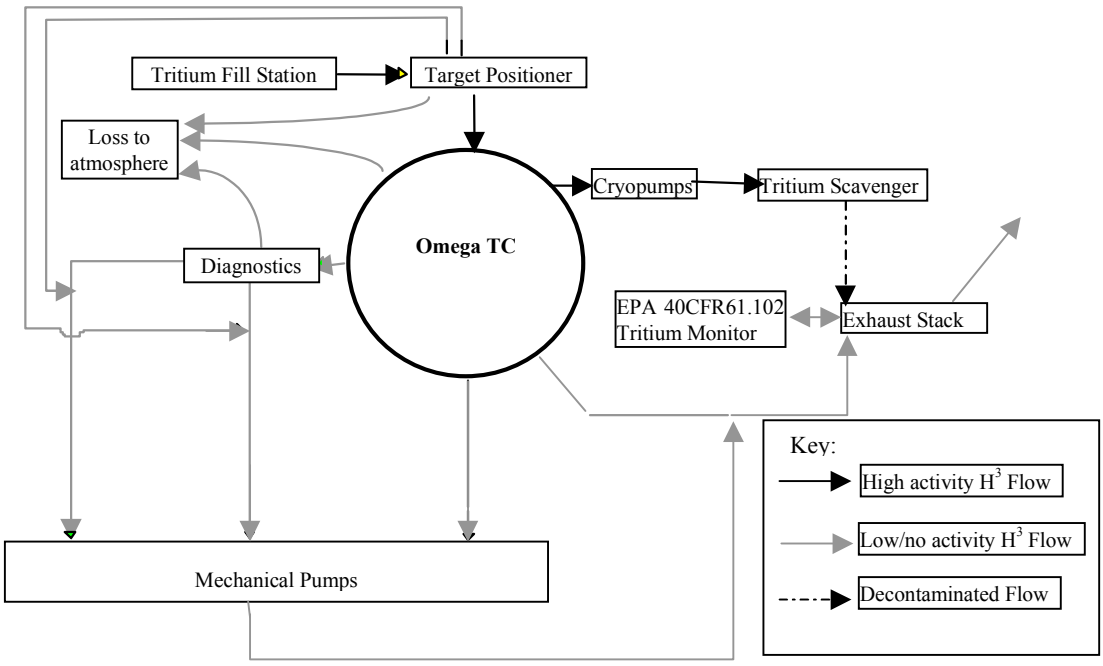

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Figure 2: Tritium flow in the Omega Target Chamber vacuum system

TFS use of effluent monitoring / scavenging systems

Tritium in the TFS is normally contained within the piping system of the TFS. The uranium beds source and recover the tritium in the piping. Prior to filling the piping of the TFS is evacuated using a dry vacuum pump. Piping and vacuum pumps are located within a glovebox that serves as a secondary containment vessel.

Tritium is contained primarily with the process lines of the TFS. These lines are themselves contained with a glove box. Up to 300 TBq of tritium is used during a target fill operation, and this is recovered onto a uranium getter bed after that operation, using the uranium bed as a pump. Prior to the next target fill operation the process lines are evacuated using a dry vacuum pump. One of the Ontario Power Generating Incorporated Tritium Scavengers processes the exhaust stream from the dry vacuum pumps, with its exhaust fed to the second scavenger for polishing. Additionally, the second scavenger unit processes the atmosphere from the glovebox in a multipass mode. The TFS Exhaust Stack draws air from the TFS room at a flow rate of approaching 2000 scfm.

The second scavenger unit is fed from both the first (process output) scavenger and the glovebox atmosphere. Its output is returned to the glovebox, providing multi-pass decontamination of the glovebox atmosphere. The overpressure vent from the glovebox directly feeds the TFS Exhaust Stack. Any residual activity discharged is monitored by the Overhoff TASC EPA 40CFR60.102 compliance monitor and the EG&G Berthold LB110 Proportional monitor. The tritium flow path for the TFS is shown in Figure 3.

Systems modifications for high-activity cryogenic targets

To accommodate the higher levels of tritium present in target handling systems, new Tritium Recovery Systems (TRSs) are being developed for both the TFS and the TC. Two units will be installed, one in the TFS and one on the TC vacuum systems. These systems will employ an oxidize-and-adsorb scheme. In this scheme HT is oxidized to HTO and adsorbed on a molecular sieve. Palladium will be used as the oxidation catalyst and synthetic zeolite will adsorb the resultant HTO. HTO already in the process stream and hydrocarbons will also be adsorbed

by the molecular sieve.

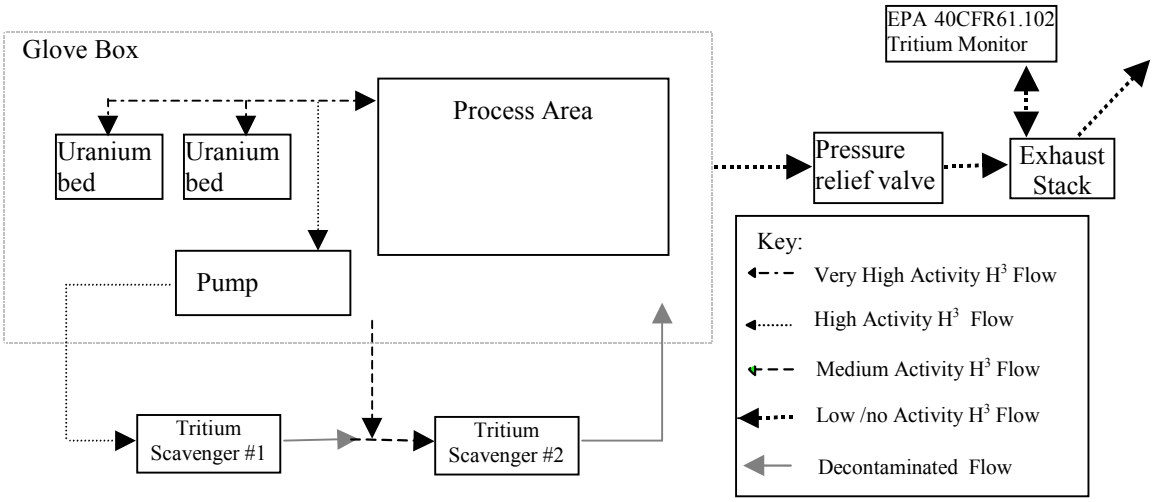

Figure 3: Tritium Flow Path in TFS

Each TRS will include a receiver tank and pump to permit multi-pass operation. Each TRS will include inlet and outlet ionization chambers and an outlet hygrometer to track performance and predict regeneration requirements. This process will in a finite period of time consume the adsorption capability of the molecular sieve. The molecular sieves will be regenerated on-site before the dewpoint of the outlet gas exceeds –40°C using a 60 CFM N_2 stream heated to 300°C. The moisture removed from the bed under regeneration is then removed by an aftercooler/condenser and is stored in transport containers for disposal. The remaining gas is sent through a second molecular sieve column prior to entering the exhaust stack.

Common components will be used at all locations, however the TC system is being designed for higher gas flow to accommodate the unique operational requirements of the experimental system. Additionally, the TC TRS will include the regeneration system. In keeping with a policy of redundant critical components, each TFS TRS will be fitted with two molecular sieve columns, while the TC TRS system will be fitted with three molecular sieve columns. The functional layout of a typical TRS unit is shown in Figure 4.

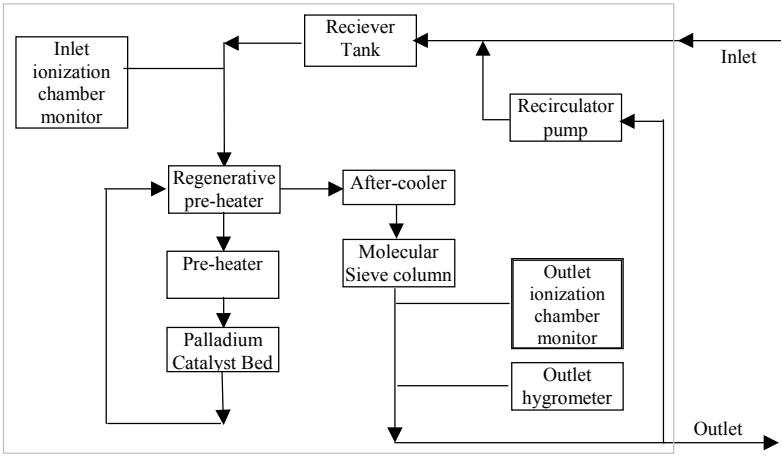

Figure 4: Functional layout of TRS unit

The TC installation will use the receiver tank and circulation pump to permit optional multi-pass operation. The new TRS system will essentially be added between the present vacuum system (including the Tritium Scavenger) and the exhaust stack. This configuration is shown in Figure 5.

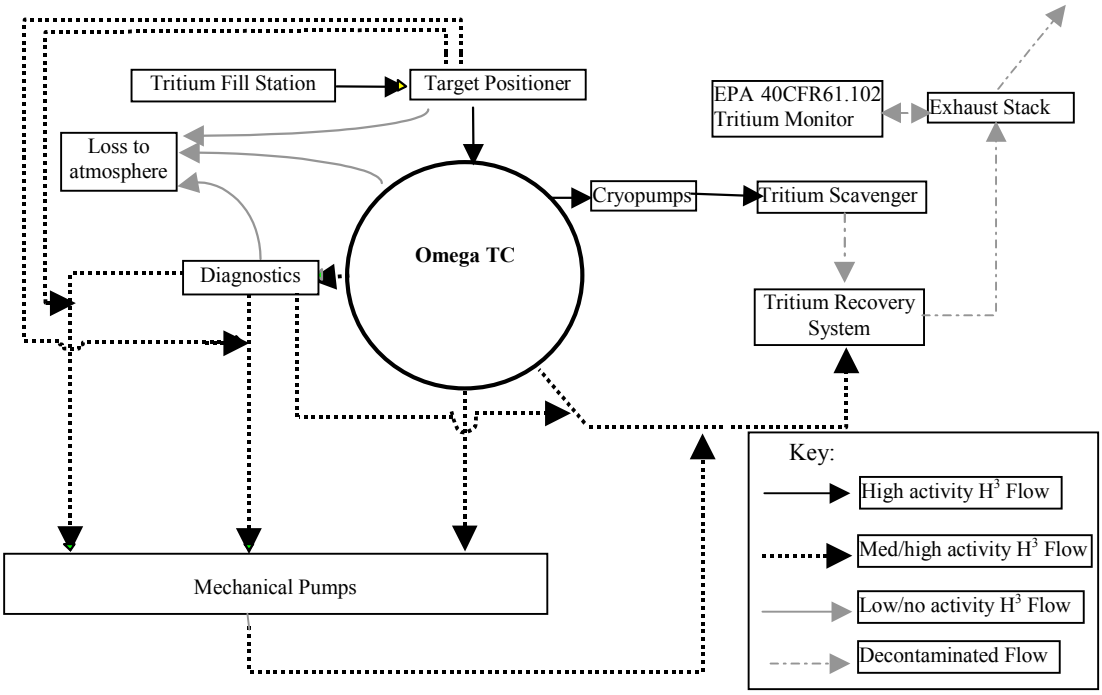

Figure 5: TC tritium flow path with TRS upgrade

In the TFS installation, the TRS units will replace the Tritium Scavenger units. The TRS servicing the process circuit will be exhaust directly to the exhaust stack, while the TRS servicing the glove box will operate in multi-pass mode, with its exhaust directed back into the glovebox. This configuration is shown in Figure 6.

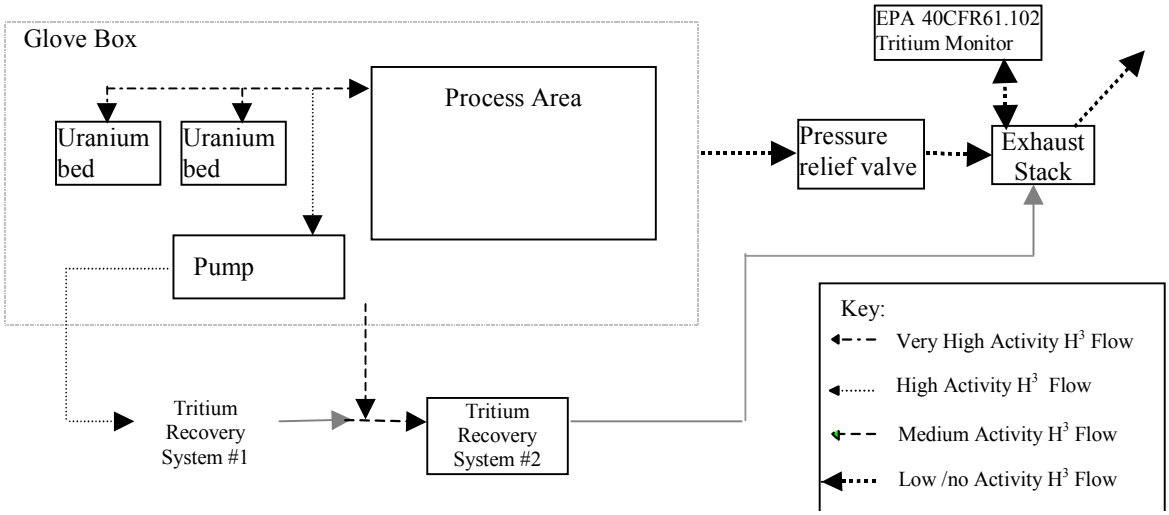

Figure 6: TFS tritium flow with TRS upgrade

Internal and external radiation monitoring systems

In spite of the stringent radiological controls noted later in this paper, the possibility for radiation exposure exists. Primary sources of exposure include tritium uptake, gamma and neutron exposure during a deuterium-tritium (DT) shot, and beta/gamma exposure from neutron-activated components in the TC. In addition, the possibility of an accident, however unlikely, must be considered and methods available to determine radiation exposure after the fact. To accomplish these, the LLE maintains personal and area dosimetry, conducts periodic bioassay measurements of those workers with the potential for tritium uptake, and has a thorough radiological survey program. Gamma and neutron shielding is provided by about 75 cm (30 inches) of concrete shielding.

Bioassay program

Personnel using more than 3.7 GBq (100 mCi) of tritium must submit a urine sample for bioassay measurement within one week of use. Personnel who use tritium on a recurring basis submit weekly samples. These samples are collected weekly by the Radiation Safety Unit and a 1 ml aliquot is analyzed for tritium. These are personnel who work at the tritium fill station, within the TC, and personnel engaged in decontamination activities.

All bioassay results are maintained in a spreadsheet. Body burden is calculated based on the number of dpm present in the 1 ml sample, assuming that the tritium is equally distributed in all body water. Radiation dose is calculated by comparing calculated body burden to the allowable limit on intake (ALI) (1) and assuming that tritium is in equilibrium throughout the body.

There has been only one indication of a significant uptake (calculated to be about 518 MBq) of tritium. This was investigated and determined to be erroneous due to the presence of chemical luminescence in the sample. A more detailed description of this incident and the lessons learned will be published in Operational Radiation Safety in early 2000 (10).

External monitoring

Regulations require radiation dosimetry for all persons who may be exposed to more than 1.25 mSv (125 mrem) of radiation in a calendar quarter. As noted above, the target bay is shielded by 75 cm of concrete with a considerable reduction in radiation dose from a DT shot, of which there are from 100-200 annually (the other shots involve other target materials or, in some cases, no targets at all). Shield wall performance is assessed through the use of both neutron and beta/gamma dosimetry badges placed outside the target bay.

Personnel working in any area containing neutron-activated components where the general radiation levels exceed 0.05 mSv (5 mrem) per hour at a distance of 30 cm from any radiation source are required to wear appropriate dosimetry. In addition, any personnel working around x-ray generating equipment are badged.

Continuous air monitoring for tritium occurs in the TFS, and effluent stacks. The target bay is sampled using portable monitors as necessary during operations and maintenance. This monitoring is accomplished using a variety of instruments. Limits for tritium concentrations in air are:

Area	**Tritium concentration limit**	
Radiological work area	0.8 MBq m^{-3}	($2x10^{-5}$ μCi ml^{-1})
Monitored gaseous effluent (with regulatory permit)	4 KBq m^{-3}	(10^{-7} μCi ml^{-1})
Effluent without regulatory permit	0.4 KBq m^{-3}	(10^{-8} μCi ml^{-1})

Other monitoring methods used are radiological surveys. Radiation surveys are performed in the target bay every six months or after an integral neutron production of 10^{16} neutrons, whichever occurs first. The TC is

surveyed for radiation levels annually. In both cases, radiological monitoring is required and stay times are calculated if radiation levels are in excess of 0.05 mSv (5 mrem) per hour.

Contamination surveys are performed, as well, in the TC, around the TFS, and in decontamination areas. These surveys are performed as indicated below:

Location	Contamination survey periodicity
Target chamber	Prior to entry, semi-annually
Tritium filling station	Weekly
Micro assembly facility	Weekly
Decontamination controlled contamination area	Every 4 hours when in use

Personnel Training

State and federal regulations require training for all radiation workers prior to commencing work with radiation or radioactive materials. The LLE provides "in-house" training for its radiation workers because its program needs are unique. This training is then audited annually by the Radiation Safety Unit.

Training is a combination of classroom and practical factors. The classroom portion of training includes four lectures of two hours length, at the end of which students are given a written examination. Students must then complete practical factors in which they are trained and, later, demonstrate good radiological work practices. At the completion of both classroom and practical training, students must pass an oral examination. All LLE radiation workers must complete annual refresher training. Topics covered during training are listed below:

Classroom training

- Hazards of neutron, gamma, and beta radiation
- Control of radiation, high radiation, contamination areas
- Basis for Target Bay radiation shielding design
- Limits for airborne, surface, water-borne, and oil-borne tritium contamination and their basis
- Personnel exposure limits and monitoring
- Anti-contamination clothing requirements
- Emergency procedures
- Radiation detectors and their operation
- Radioactive materials disposal procedures

Practical factors

- Establish controlled surface contamination area
- Perform a tritium smear wipe survey, including counting wipes and logging results
- Perform and log results of gamma radiation survey in Target Chamber
- Decontaminate a tritiated piece of equipment
- Calculate expected neutron radiation level from a target shot expected to produce 10^{13} neutrons

Standard Operating Procedures

Implementation of radiological controls is facilitated through training and procedures. These operating procedures include all tasks performed on Omega that are impacted by radiological concerns. These procedures are uniform in layout and are contained in the LLE Radiation Control Manual (8). Specific procedures include:

- Shielding effectiveness monitoring
- Target Chamber activation survey
- Target Bay general radiation survey
- Airborne radiation survey
- Surface contamination survey
- Liquid activity survey
- Anti-contamination clothing use
- Establishment of controlled surface contamination areas
- Decontamination procedures
- Radioactive material accountability and disposal
- Personnel monitoring
- Internal transfer of tritium targets
- Cryopump regeneration / tritium scavenger operation
- TFS operating procedures

Additionally, procedures for the operation and maintenance of subsystems include measures to limit and mitigate radiation exposure and contamination spread where appropriate. These detailed procedures are available to operations and maintenance crews in the OMEGA System Operation Manual Volume II (S-AA-M-13) and Volume III(S-AA-M-14) in print and online at the LLE web site (http://www.lle.rochester.edu/).

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