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TITLE OVERVIEW OF TRITIUM SYSTEMS FOR THE COMPACT IGNITION TOKAMAK

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Abstract: The Compact Ignition Tokamak (CIT) is being designed at several laboratories to produce and study fully ignited plasma discharges. The tritium systems which will be needed for CIT include fueling systems and radiation monitoring and safety systems. Design of the tritium systems is the responsibility of the Tritium Systems Test Assembly (TSTA) at Los Alamos National Laboratory. Major new tritium systems for CIT include a pellet injector, an air detritiation system and a glovebox atmosphere detritiation system. The pellet injector is being developed at Oak Ridge National Laboratory.

Introduction

The Compact Ignition Tokamak (CIT) is a next-generation tokamak being designed for installation at the Princeton Plasma Physics Laboratory. The goal is to create and study ignited plasmas, with the use of high magnetic fields, high plasma currents, RF heating, and deuterium-tritium fuel. CIT is expected to provide physics and engineering data for the next major phase in the development of fusion energy.

The machine and its supporting systems are being designed by a team of physicists and engineers from a number of national laboratories, universities, and industrial firms. These organizations are also participating in research and development efforts, and they will take part in CIT fabrication, installation, and testing.

Because cost was a major consideration, it was decided to locate the machine at the Tokamak Fusion Reactor (TFTR) facility in Princeton, New Jersey, so that the many supporting systems now being used for TFTR could be applied to CIT. Many of the TFTR buildings will be used for CIT, and in addition, the TFTR electrical power system, the central computer system, the tritium system, some of the diagnostics, and the water cooling system will be utilized by CIT.

Tritium will be supplied for injection as a gas and also as frozen pellets. Because CIT will use tritium at a rate higher than used by any tokamak built so far, the tritium systems will be a vital part of the facility. The entire TFTR tritium system, with minor modifications, will be utilized for CIT. A newly-designed Air Detritiation System (ADS) will be built both for routine maintenance and for emergency detrition of air in the CIT test cell and other areas that may contain tritium. In addition, a new Glove Box Atmosphere Detritiation System (GBADS) will be provided for continuous removal of tritium from CIT glove boxes. The existing TFTR systems, as well as the new CIT systems will be described in this paper.

The organization responsible for design, construction, and test of the CIT tritium system is the Tritium Systems Test Assembly (TSTA) group at the Los Alamos National Laboratory. TSTA has constructed and is now testing a tritium facility that handles tritium in quantities suitable for a fusion reactor. Experience gained by TSTA is being applied to the CIT design.

The CIT tritium pellet injector, which is being designed at the Oak Ridge National Laboratory, is covered briefly in this paper.

Tritium systems for the Compact Ignition Tokamak are being designed in accordance with underlying philosophy as follows:

i) releases to the environment and doses to personnel will be maintained as low as reasonably achievable;
ii) no reprocessing of fuel will be done on-site;
iii) a maximum on-site inventory will be maintained which is as low as practicable considering the holdup in the vacuum vessel;
iv) tritium accounting will be done by difference of input and output from the facility.

Fueling System

The fueling system supplies hydrogen isotopes to the torus to increase and maintain the plasma density. In addition the system supplies non-hydrogen gases, such as argon or nitrogen, for discharge cleaning, wall conditioning, bringing the torus up to atmospheric pressure, and minority heating (plasma heating by means of rf interaction with a minority species, such as helium-three). As shown in Figure 1, fueling system equipment includes hydrogen isotope gas injection systems, tritium storage and supply systems, and non-tritium gas delivery systems. The turbomolecular pumps and the pellet injector, shown in the figure for clarity, are part of the vacuum pumping system and the pellet injection system, respectively. The vacuum pumping system is currently being designed at the Fusion Engineering Design Center and is described elsewhere.[1]

Pellet Injector: The principal tritium fueling system will be a pellet injector. The pellet injector for CIT will be designed by Oak Ridge National Laboratory to meet the following pellet fueling requirements:[2]

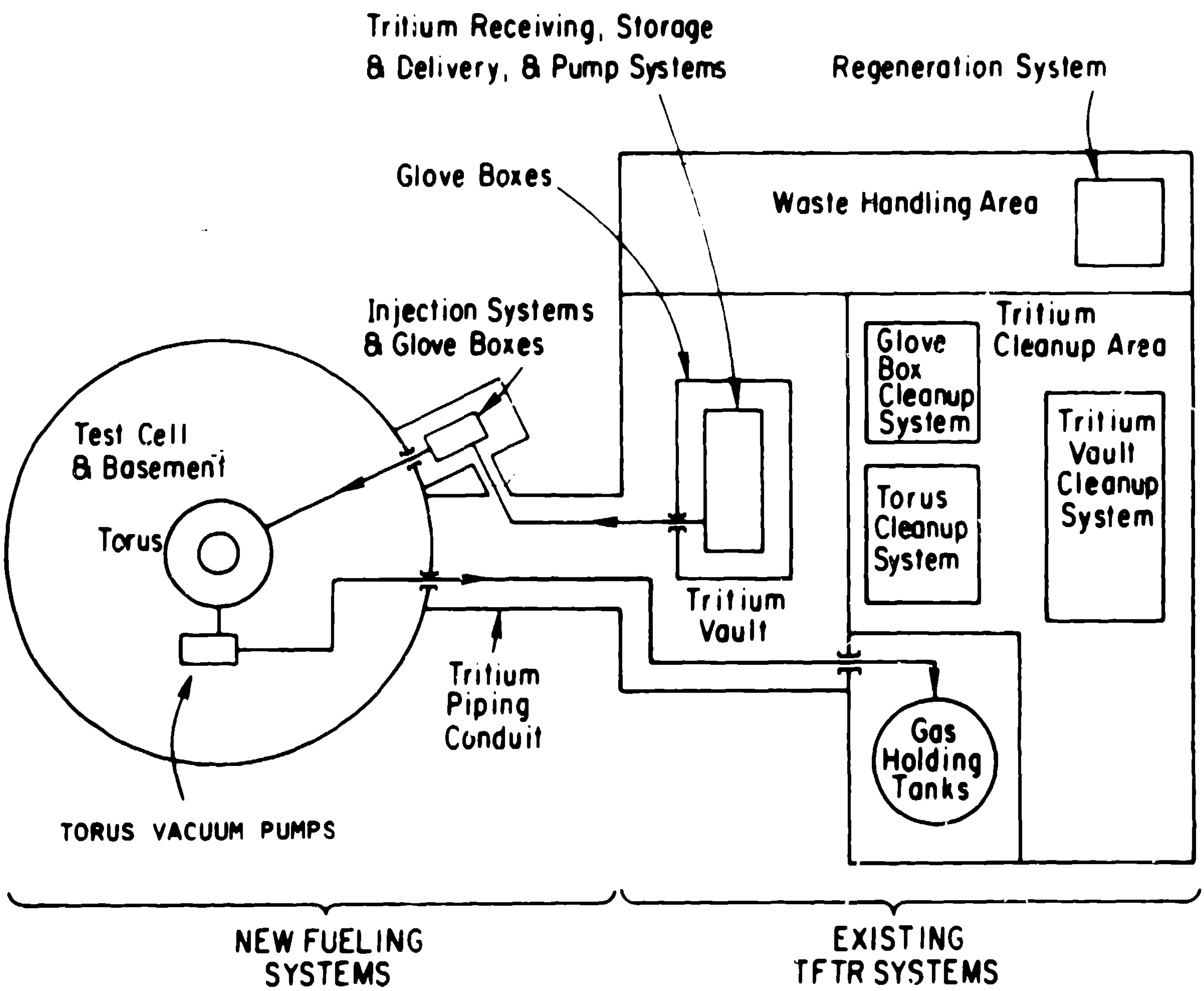
- a pellet velocity of at least 2 km/s
- a pellet radius of 2 mm
- H_2, D_2, T_2 species pellets
- delivery rate of at least 10/s for 4 s

The specific injector concepts to be used for the CIT pellet injector (e.g., pneumatic or centrifugal) have not yet been determined. A proof of principle tritium pellet injector will be tested at the Tritium Systems Test Assembly in the fall of 1987.

Tritium Gas Injection: In addition to the pellet injector, gas injection ("puffer") valves will be required for fueling. These will be small piezoelectric-type valves that provide rapid and accurate control of small flows, using automatic feedback from measured plasma parameters to provide proper control of the plasma density. TFTR uses this type of gas injection system with three injection points for non-tritium gas.[3] Three separate injection points for tritium gas using piezoelectric valves are currently being installed. A double-walled pipe (about 1/4-inch inner diameter) will be needed to bring tritium from storage in existing TFTR facilities to both the pellet injector and gas injection valves.

Tritium Storage and Supply System: This system stores the tritium required for the project in low-grade (depleted) uranium powder contained in compartmentalized metal structures called uranium beds. These are secondarily contained in a glove box with an Argon gas atmosphere. The system automatically delivers measured quantities of tritium to the pellet injector and to the gas injection valves on demand from the computer system. Sufficient capacity to store approximately 50 kCi (about 5 grams) of tritium is needed for a tritium shipment schedule of twice a month. Good practice requires designing the usable capacity for 40% of the full stoichiometric loading to UT_3. The needed capacity should be incorporated in more than one bed, so one bed can be maintained at room temperature while another bed is heated, which is the method for releasing the tritium gas for delivery to the fueling systems.

Associated facilities required include a tritium receiving area (for receiving a few 12-liter double-walled shipping containers) and a storage vault for housing the uranium-bed glove boxes. In addition, Gas analysis instruments will be needed for verifying tritium quantities as received and to meet DOE regulatory requirements for tritium accountability. A quadrupole mass spectrometer or laser Raman spectrometer are suitable instruments.



TRITIUM SYSTEM

Figure 1 Fueling Systems

The existing TFTR tritium storage and delivery system will be used for the CIT tritium system. This system contains three uranium beds with sufficient capacity to meet the requirements described above. In this system, the tritium is placed initially in the nitrogen atmosphere Tritium Receiving Glove Box (TRGB) where it is assayed by using a mass spectrometer and PVT (pressure, volume, temperature) measurements.[4] After the chemical and isotopic purities are verified, the tritium is pumped to the tritium generators (uranium beds) that are contained in the adjacent argon atmosphere glove box. The tritium concentration, in both of these glove box atmospheres, is continuously monitored. If high tritium concentration is detected in the TRGB, the atmosphere of this glove box will be cleaned up by the TFTR Torus Cleanup System.

The tritium gas is pumped into a holding volume until the required pressure for filling the gas injection volumes or the pellet injector holding volume is reached. Control of the amount of gas generated can be achieved by regulation of the tritide temperature. When two tritium generators are used for storing tritium, the third generator is available for pumping or scavenging tritium. This generator is also used for pumping back the unused tritium from the injection volumes and the connecting tubing. This is an important safety feature under abnormal or emergency conditions when power is lost and tritium must be returned to the storage system.

Non-Tritium Gas Delivery System: Non-tritium systems are conventional gas supply systems, consisting of pressurized cylinders or tube trailers to deliver nitrogen or argon gas. Deuterium gas is supplied from one or more conventional laboratory H-size cylinders. Except for conventional pipes to carry gases to the new CIT test cell and perhaps a separate non-tritium gas injection system for the torus, the existing TFTR systems will meet this need.

Radiation Monitoring and Safety Systems

The Radiation Monitoring and Safety Systems include the safety systems for radiation and tritium monitoring, protection of the public and employees against exposure to radiation, and preparation of waste tritium for shipment off-site for reprocessing or safe disposal. Systems for both normal operation and emergency situations are discussed in the following paragraphs.

Radiation Monitoring System: The radiation monitoring system involves monitoring for safety as well as for diagnostic purposes. The instruments to be used include gamma and neutron monitors as well as tritium monitors. Many are environmental (i.e., room, stack, or duct) monitors, whereas others are for monitoring glove box atmospheres or processes for tritium concentrations.

At present, there are some 60 to 70 fixed, active monitors planned or in place at the TFTR facility. Tritium instruments are of the flow-through ionization chamber type and are capable of measuring tritium concentrations from a few micro-Ci/m^3; the actual range depends on the application. All of these instruments will be available for use at the CIT facility, some with no change in location or purpose because they are involved in systems to be used with CIT.

Additional monitors, however, will be needed for the new glove boxes, new handling rooms for activated and/or contaminated equipment (i.e. hot cell, warm cell), and for the Glove Box Atmosphere Detritiation System and Air Detritiation System and their rooms. It is estimated that an additional 30 tritium process, glove box, and room monitors, and 6 gamma monitors, will be needed for the additional rooms and glove boxes at the CIT facility. All of these projected instruments are fixed or transportable and do not include portable instruments and passive monitoring devices such as thermoluminescent dosimeters, neutron or gamma sensitive film, etc.

Detritiation Systems: Tritium may be accidentally released into glove box or room atmospheres. In either case, the tritium will be purged from the atmosphere and solidified on a matrix as an oxide for eventual recovery or disposal. Two new detritiation subsystems are planned to supplement the existing systems at the TFTR: a smaller system with a capacity of 50 cfm for continuously processing glove box atmospheres, and a larger system for maintenance and emergency use having a maximum capacity of 1800 cfm for processing room atmospheres. The three existing detritiation systems at the TFTR, the cleanup system for the TSDS (Tritium Storage and Delivery System), the Torus Cleanup System, and the Tritium Vault Cleanup System, will continue operating as before. The description of new systems that follows is based largely on experience gained at the Tritium Systems Test Assembly.

The smaller Glove Box Atmosphere Detritiation System (GBADS) will be a batch system consisting of redundant blowers, oxidation catalysts with preheaters and heat exchangers, and desiccant beds. This redundancy may be achieved by a single subsystem with parallel components or by two separate and independent units, each with a capacity of 25 cfm. In either case the maximum capacity of 50 cfm can be achieved with both blowers in operation. Common to the system will be two large receiving tanks kept normally below atmospheric pressure. Four desiccant beds are to be used, two for each of the units if the separate unit configuration is adopted. A separate regeneration unit will be available for drying the desiccant beds as needed. A possible alternative to the above described method for removing tritium from inert glove box atmospheres is the adsorption through chemical bonding of elemental tritium by metal "getters". This technology, under current development, is not available at the present time.

The larger Atmosphere Detritiation System (ADS) will provide air detritiation both for maintenance operations (e.g., in association with a flexible ventilation duct) and for emergency room cleanup. It will consist of four separate and independent units that can operate individually or in parallel, depending on the capacity needed for a maintenance operation or the size of the room to be cleaned up and the number of such rooms involved (Figure 2). The rooms to be ducted to the ADS include the test cell, test cell basement, decontamination cell, pellet injector cell, hot cell, warm cell, and GBADS and ADS rooms. The current tritium handling area at TFTR will be handled by the existing Tritium Vault Cleanup System

The ADS capacity was determined by the requirement that it be capable of reducing the tritium concentration in the CIT test cell (8800 m^3) following a maximum credible release of 15 kCi to the Derived Air Concentration (for HTO in air) of 20 micro-Ci/m^3 in 48 hours, which is satisfactory for worker exposure with no protection. The capacity required for this operation is 1200 cfm. Two units of 600 cfm each meet this requirement. Two units of 300 cfm each will be used as a redundant 600 cfm capacity and either separately or in parallel for maintenance operations. Each unit will consist of a blower. a catalyst with heater and heat exchanger, and two redundant desiccant beds. A cooler/refrigerator dryer may be incorporated to reduce the size of the desiccant beds. The components of the four units may be linked together so as to provide component redundancy as opposed to unit redundancy. Regeneration of the desiccant beds will be done by unloading and replacing with dry desiccant. Once removed, regeneration of the moist desiccant may be accomplished by the GBADS regeneration unit, or alternatively, it may be treated as waste.

Tritium Waste System: The primary purpose of this system (TFTR Torus Cleanup System) is to receive and process the effluent gas from the torus after a fusion burn. This gas will contain tritium, deuterium, helium, and impurities that may be tritiated. In addition, other gaseous effluent generated throughout the facility (such as vacuum pump exhausts) that could possibly contain tritium will be processed by this system. Tritium removal may be based on the catalytic oxidation of tritium-containing compounds and the subsequent removal of the tritiated water by adsorbtion on molecular sieve beds. The decontamination factor (tritium input/tritium exhausted to environment) will be better than 10^5. The system includes holding tanks, blowers, catalyst bed, and molecular sieve beds. The tritiated water is recovered from the molecular sieve beds by regeneration with a heated purge gas. The water is collected and packaged for shipment to an external disposal or reprocessing facility. The existing TFTR gas holding tanks and Torus Cleanup System will be used for this system. An alternative to catalytic oxidation and removal of tritiated water under consideration is to getter the gaseous effluent on uranium beds and ship the beds off-site for reprocessing.

Breathing Air System: The test cell and tritium handling areas will be equipped with a supplied breathing air system. Personnel will use breathing air for emergency access to areas where tritium has been accidentally released and for maintenance operations where there is the possibility that significant tritium may be released into the room. The major components of the system are supplied air suits (approximately seven suits) and connecting air hoses, breathing air stations located throughout the facility, a pressure regulation and distribution system, and a source of breathing air. As a source for breathing air, either a compressor and a holding tank or a tube trailer filled with breathing air (approximate capacity 45,000 scf) will be used. One or more portable breathing air stations (on carts) may also be employed either as an alternative or a supplement to the fixed system.

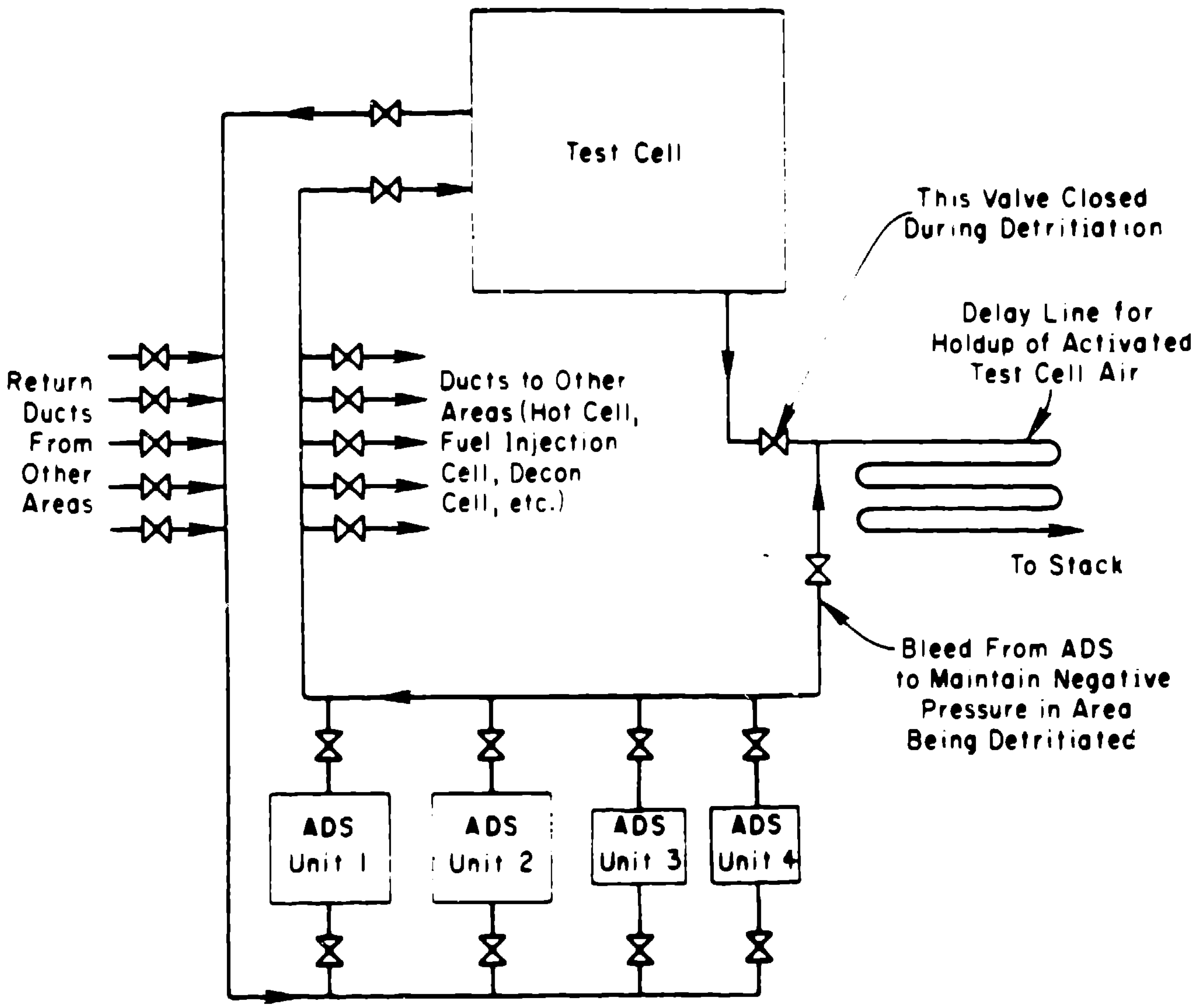


Figure 2 Air Detritiation System

Liquid Radioactive Waste System: This system includes all the piping, drains, pumps, and storage vessels necessary to collect liquid radioactive wastes, and to prepare them for shipment off-site for disposal. These wastes may be generated as a result of normal operations (washing, decontamination, etc.) or accident conditions which may, for example, produce water used for extinguishing a fire. The waste may be tritiated or may contain other radioactive materials. The system will normally handle only water. Other radioactive liquids will be packaged separately. The existing waste storage tanks at TFTR will be used for this system.

House Vacuum System: This system will provide service vacuum used to evacuate tritium-contaminated or potentially contaminated lines located throughout the newly-built CIT tritium areas. Components will include an oil-free vacuum pump (with an approximate size of 100-300 scfm), and piping and outlets distributed in areas in which tritium will be handled. The pump will discharge to one of the tritium waste cleanup systems.

Flexible Ventilation Duct System: The flexible ventilation duct system will be used to provide local ventilation to areas where tritium has been or may be released into the room air because of an accident or a planned maintenance operation. Examples of uses are maintenance on the torus through an open torus port, or removal of a glove box window. The exhaust of the flexible ventilation duct can be either routed to the stack or to one of the tritium cleanup systems, if the tritium concentration in the exhaust is higher than desirable release levels.

Problems, Issues

Tritium Inventory: One of the more difficult problems in dealing with tritium in a fusion device is determining where and in what amounts tritium is held up within the system. In the Compact Ignition Tokamak, tritium accounting will normally be done by difference of input and output from the facility. During operation, tritium will be held up in the graphite tiles of the torus, deposited on the torus walls, held in different amounts at different times in the gas holding volumes of the pellet injector and the tritium gas injection system, held in the molecular sieve beds or gas holding tanks of the cleanup systems, held in the LP-12 shipping containers prior to putting the gas on the uranium storage beds, held in the storage beds in varying amounts, held in disposal containers prior to shipment off-site, and of course, held in piping and diagnostic equipment. For purposes of estimating the distribution of tritium in the facility at various times, several methods can be employed.

Tritium holdup in the graphite tiles of the torus and deposition on the torus walls is expected to be the largest component of tritium inventory. Predicting the amount of tritium inside the torus is subject to a good deal of uncertainty. This is because the bulk retention in the graphite is a function of several different parameters, including the type of graphite used, the temperature the graphite reaches, and the tritium flux. Likewise, the amount of redeposited carbon film and the tritium content of the redeposited layer are uncertain and dependent on such things as vessel geometry. The amount of redeposited tritium can only be estimated at this time from measurements made in TFTR, JET and laboratory scale "plasma simulators." The latest estimate from Sandia National Laboratories, Livermore indicates that the tritium inside the vacuum vessel may be on the order of 13 grams (3 grams bulk retention in the graphite and 10 grams of deposited carbon films on all plasma facing surfaces).[5] Further experiments are planned to make a more precise determination of the amount of tritium in the vacuum vessel.

Determining the amount of tritium shipped off-site presents another difficulty. Molecular sieve beds or product containers (PC's) may be used to ship tritium off-site for reprocessing or disposal. The tritiated water put onto molecular sieve beds is generally of varying concentration and the water is not distributed evenly over the bed, so any method of sampling the contents of a bed is inherently uncertain. At the Tritium Systems Test Assembly, plans are being made to inventory disposal molecular sieve beds filled by regeneration of the Tritium Waste Treatment System (TWT). The method proposed for the TWT involves determining the tritium content of vapor at the point of departure from the TWT. In the case of the CIT disposal molecular sieve beds, a better scheme would be to sample all of the tritiated water just before putting it onto the bed. This could be done fairly easily if the accounting capability is included in the system design. The composition of tritiated gas sent off-site in PC's can be easily determined by sampling the gas.

The amount of tritium held on uranium beds and any other metal getters which may be used in the system can be adequately determined by putting the gas into a holding volume, sampling it and returning it to the getter.

The amount of tritium held up in process piping and diagnostic equipment is expected to be very small compared to the amount held up in the torus, molecular sieve beds and metal getters. Tritium gas which is in holding volumes can be quantified by sampling and pressure and temperature measurements.

Capacity of the Tritium Storage and Delivery Glove Box: The TFTR Tritium Storage and Delivery Glove Box contains three uranium beds. The capacity of two beds at 50% loading is 5 grams of tritium. The third bed is used to facilitate transfer of the inventory. The original plan for CIT involved 12 tritium shipments per year. This would have involved some redesign of the TFTR uranium storage system to accommodate a larger tritium inventory. If a tritium shipping schedule of two shipments per month is used, it is anticipated that the current storage capacity of the TFTR system will be adequate for CIT. While this doubling of the shipping schedule may mean more operational, shipping or production delays, it alleviates the problems associated with redesigning or reconfiguring the existing TFTR system.

Using Metal Hydrides Other Than Uranium for Tritium Storage: One of the options suggested for tritium storage beds for CIT with the original shipment schedule of twelve tritium shipments per year was to design new storage beds with materials other than uranium. This option is still being pursued to some extent. Two materials suggested for storage were ZrCo and $LaNi_{5-x}Al_x$ alloys. Two ZrCo beds designed and built at the Japan Atomic Energy Research Institute are currently being used in non-loop experiments at the Tritium Systems Test Assembly. $LaNi_{5-x}Al_x$ alloys are currently being used successfully at Savannah River Laboratory for tritium handling and processing, including storage.[6] Experiments comparing the pyrophoricity of these three metal getters are currently under way at the Idaho National Engineering Laboratory.

Maintenance Mask: A maintenance mask concept for controlling tritium during torus maintenance is being proposed for use in conjunction with the flexible ventilation duct. When the torus is opened for maintenance, the opening is quickly plugged with a flexible plastic piece (a "maintenance mask") that has the following characteristics:

- a good, but not hermetic, seal with the torus wall
- sufficient rigidity to be easily handled and capable of sealing
- lightweight
- containing numerous sliding doors, openable portholes, etc. of various sizes, shapes, locations and functions

The overall purpose of the mask is to minimize at all times the area of torus open to the room. Outgassing of tritium to the room is controlled by maintaining a slightly negative pressure in the torus with respect to the room. One way to maintain this negative pressure is to use the flexible ventilation duct attached to one of the portholes to provide the necessary draft for operations at another opening. This type of ventilation is used on open glovebox operations at the Tritium Systems Test Assembly[7] and good results have been achieved (no tritium levels detectable outside the face of the open glovebox window).

Conclusion

Conceptual designs have been described for the tritium handling and safety systems planned for the CIT. The designs draw heavily on existing hardware used at the Tokamak Fusion Test Reactor, and on designs developed and tested at the Tritium Systems Test Assembly at Los Alamos National Laboratory. Although several system improvements are being pursued, the currently well-tested systems are adequate to meet the requirements of CIT.

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