TRITIUM-HANDLING CONSIDERATIONS FOR ETF AND STARFIRE

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by

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TRITIUM HANDLING CONSIDERATIONS FOR ETF AND STARFIRE*

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Summary

The tritium handling requirements for both the ETF and the STARFIRE fusion reactor designs are analyzed. The use of a limiter/vacuum system for STARFIRE produced a high fractional burnup (0.42) which resulted in a low tritium inventory in the fueling system. The importance of a fast process flow rate in achieving a rapid cleanup after a tritium release is demonstrated; another important factor is the rate at which HTO is released from building surfaces. A complete fusion reactor tritium facility is described.

Introduction

The tritium containment and handling strategies developed both for the ETF and the STARFIRE fusion reactor designs are presented. Major objectives adopted for both designs are that: 1) a minimum tritium inventory is to be maintained in the entire plant, 2) the tritium impact on the environment is to be minimized, 3) worker exposure is to be reduced to levels as low as practical, 4) tritiated waste generation is to be minimized, 5) the tritium systems are to be operated in areas free of gamma or neutron radiation, where possible and 6) the tritium systems are designed to have maximum reliability and availability. To implement these objectives, information accumulated in previous studies[1-4] and being developed at the Tritium Systems Test Assembly[5] (TSTA) have been incorporated into the tritium system designs.

The ETF,[6] the first fusion reactor to incorporate a complete deuterium/tritium fuel cycle, is at present a pulsed-burn, non-breeding device which is ignited by neutral beams. The latter require relatively tritium-free deuterium ($\geq$ 99%). Plasma impurity control is achieved through the use of a divertor system which incorporates deuterium gas puffing at the plasma edge. The recycled particles are enriched in deuterium which reduces the tritium inventory by 30 - 50%.

The STARFIRE[7] design, a continuous-burn device driven by rf heating, represents a mature tokamak fusion power reactor with a fully integrated deuterium/tritium/lithium fuel cycle. Plasma impurity control is achieved with a limiter/vacuum system; the high fractional burnup (0.42) which results significantly reduces the tritium fuel inventory. The protium-free tritium and deuterium fuel streams require ~ 90% isotopic purity; this simplifies the fuel reprocessing system. The STARFIRE plant when operational is independent of any off-site tritium sources because of its tritium breeding/processing system which is directly interfaced with the main fuel reprocessing system.

Tritium Scoping Studies

Previous studies have scoped the effect of fusion operating parameters on tritium inventory[3,4,8] and have demonstrated the negative impact of a low fractional burnup[4,8]. In Figure 1,
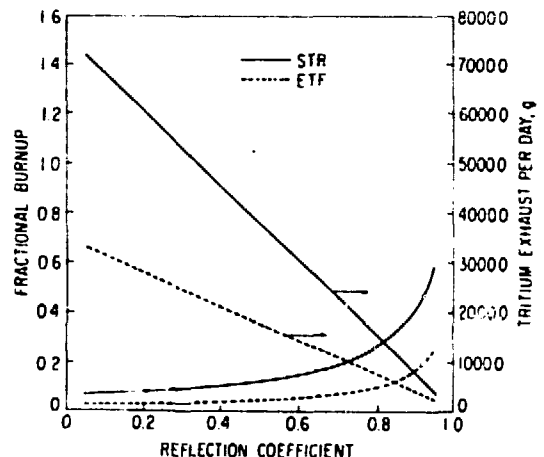

Fig. 1. Dependence of the fractional burnup and the tritium exhaust per day on the tritium reflection coefficient, R.

the dependence of the fractional burnup and the tritium exhaust per day on the reflection coefficient, R, (the probability that a particle will return to the plasma after escaping the plasma edge) is shown. The fractional burnup decreases as R decreases while the tritium exhaust is proportional to 1/R. To minimize the tritium fuel inventory which is directly related to the tritium mass flow rate, a large R is required. The limiter/vacuum system in STARFIRE(STR) has an R of 0.9; the tritium exhaust is 750 g/d. The tritium inventory in the vacuum pump equals 60 g when a pump residence time of 2 h is used. (This is the shortest time interval which will assure reasonable valve reliability). If R equals 0.2, the tritium exhaust is > 6000 g/d; the associated pump inventory is 500 g. In this latter case, a single pump failure would result in a ten-fold increase in the amount of tritium released. In the reference ETF design, R equals 0.6. (The divertor impurity control system is a more efficient tritium trap than is the limiter). The tritium exhaust is 1500 g/d which is twice that of the STARFIRE reactor which is designed to produce five times as much power. The pump inventory is 130 g.

Fuel Cycle

The tritium fuel cycle for STARFIRE is shown in Figure 2. The tritium handling systems; (1) reprocess tritium for fueling; (2) process tritium produced in the blanket; (3) control the amount and location of tritium in the plant; and (4) process tritiated wastes. The first function includes units which chemically purify and isotopically enrich the fuel. The tritium generated in the blanket as $T_2O(HTO)$ is electrolyzed and then passed to the main fuel cycle to be processed. The location of tritium in the plant is handled by a storage and disposition system. Several treatment systems maintain low tritium levels in the secondary enclosures (controlled-atmosphere glove boxes and double-walled pipes) and in the coolant systems. The atmospheric tritium recovery systems are designed to scrub the atmosphere of a tritium handling area in the event of a tritium release. The tritiated wastes (solids, liquids, gases) which accrue as by-products from various tritium handling systems are detritiated and/or consolidated by several different units. The fuel cycle for ETF differs in that a fueling and processing system for the neutral beams is added and the tritium recovery system for the blanket is eliminated.

The main fuel pathway as shown in Figure 2 begins at the plasma chamber, proceeds to the compound cryopumps and thence to the fuel cleanup unit (FCU). (The effluent from the neutral beams follows this same pathway). The purified fuel is passed to the isotopic separation system (ISS) after which the D_2 and the T_2 fuel streams are either stored until needed or are passed directly to the fuel blenders (FBU). There the
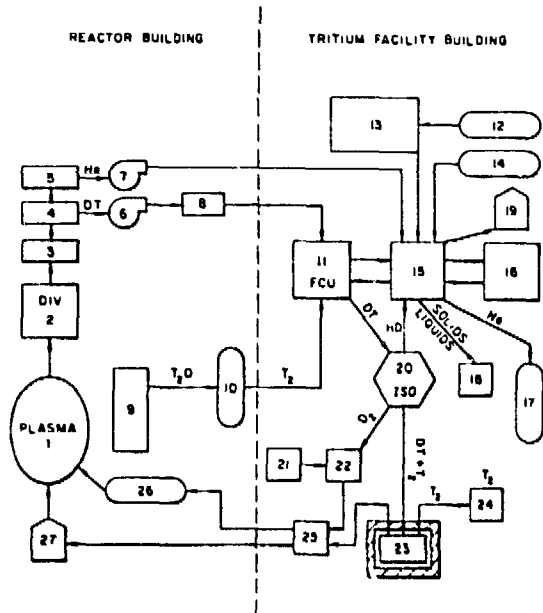
1. Plasma Chamber
2. Limiter Plates
3. Debris Separator
4. D-T Cryocondensation Pump
5. Helium Pump
6,7. Regeneration Pumps
8. Metal Bellows Pumps
9. Breeder Blanket
10. Electrolysis Unit
11. Fuel Cleanup Unit
12. Tertiary Enclosures
13. Emergency Air Detritiation Systems
14. Secondary Enclosures, Purge Streams
15. Tritiated Waste Treatment
16. Water/Tritium Recovery Unit
17. Helium (tritium-free)
18. Tritiated Waste -- Liquids and Solids
19. Detritiated Gases: N_2, O_2, CO_2, Ar
20. Isotopic Separation Unit
21. D_2 Supply
22. D_2 Storage
23. DT and T_2 Storage
24. T_2 Shipment/Receiving
25. Fuel Blender
26. Gas Fueling
27. Pellet Fueler

Fig. 2. Fuel Cycle Scenario for STARFIRE

needed fuel mixtures are prepared for use in the reactor fueling devices. A tritium feed stream from the breeder blanket joins the main stream at the fuel cleanup unit. A smaller tritium feed stream from the tritiated waste treatment system (TWT) also joins the main stream at the FCU. The TWT processes tritium from various streams in-

cluding small amounts which accrue from secondary enclosures, the coolant, and atmospheric processing systems. Within the main fuel feedstream, the transfer of fuel between different components as well as the maintenance of uniform flow is handled by transfer pump units (TPU) which are composed of surge tanks, bellows pumps and appropriate valving systems. These are presently designed as separate units but could be incorporated into the larger systems. The advantage of having a separate TPU system is that since most component failures will occur in these units they are easily accessible and easily removable for maintenance and repair.

The removal of condensible impurities, molecules containing I, N, O, C, etc, from the unburned fuel (DT) and the helium is the first operation performed at the fuel cleanup unit. The helium is then removed from the DT by means of a cryogenic stripping column. To minimize tritiated waste, the condensible impurities are processed. (The technology for this step is still under development. TSTA will incorporate getter beds into their design. The presence of iodine in the process stream (STARFIRE) may create problems which will be dealt with by modification of the FCU).

The basis of the isotopic separation system is cryogenic distillation. To fulfill STARFIRE requirements ($\geq 90\% D_2$, $\geq 90\% T_2$; < 1% H_2 in either stream), the system consists of five distillation columns and two equilibrators. The three product streams consist of a 97% pure T_2 stream (3% D_2), 91% pure D_2 stream (9% T_2) and a waste protium/deuterium stream (57% H_2) containing a residual amount of tritium (0.2%). For ETF, six distillation columns and two equilibrators are required. The three product streams consist of a 97% pure T_2 stream (3% D_2), 99.4% pure D_2 stream (0.6% T_2), and a waste protium/deuterium stream (99% H_2) containing a residual amount of tritium ($3.6 \times 10^{-4}\%$).

Tritium is removed from the STARFIRE blanket as T_2O by means of a helium purge stream and recovered by collection on molecular sieves. The T_2O is passed through ion exchange columns to remove radioactive species other than tritium and then electrolyzed. The T_2/H_2 is passed through a palladium/silver diffuser in the hot cell before joining the main tritium processing stream at the fuel cleanup unit in the tritium facility.

The tritium parameters for ETF and STARFIRE are listed in Table 1. The tritium inventory (location and amount) for both designs is listed in Table 2. For ETF, a 30 day burn storage inventory is assumed while for STARFIRE which produces its own fuel, a 2 day burn storage inventory is assumed. For both designs, a two hour residence time in the pumps is assumed. The fuel recycle time has been minimized to less than an hour. Redunancy and reliability of fuel process-

ing and tritium recovery subsystems are implicity required.

The designation "vulnerable" or "non-vulnerable" refers to the degree of control which can be enforced on the associated system. The ~ 10 kg of tritium sited in the STARFIRE blanket is relatively immobile since it is in the oxide form and tenaciously retained by the solid breeding material. The tritium in storage, ~ 1 kg (STARFIRE) and ~ 3 kg (ETF) in the form of small units of UT$_x$ (each containing ~ 12 g of tritium), is located in a barricaded vault with an inert cover gas for fire protection; thus making it relatively "non-vulnerable" to accident. The fuel processing systems in the STARFIRE tritium facility contain ~ 154 g of tritium in the unoxidized form (T_2, DT, HT) distributed as follows: 50g in each of two ISS units, 15 g in each of two FCU units and ~ 3 g in four different surge tanks used to ensure uniform flow throughout the plant. (ETF's processing inventory would be similarly distributed). Each tritium processing unit is doubly contained and under monitor control to ensure maximum accident protection. Vacuum or an inert cover gas is present to reduce the fire hazard. The ISS units which contain the highest tritium inventory (~ 50 g as T_2) have high reliability with no vessel failure being experienced in prototype units. The tritium in the fuel handling systems (vacuum pumps, fueling units, breeder tritium recovery units in the reactor building) is considered to be "vulnerable" since the reactor area is subjected to severe thermal, magnetic and radiation loads which may interfere with a unit's function or may accelerate its aging.

At STARFIRE plant startup, ~ 10 kg of tritium will be supplied from off-site. This tritium will later be recovered from the breeder blanket. For ETF, ~ 3 kg of tritium will be supplied at startup; the yearly consumption which presently has to be supplied from off-site is ~ 9 kg.

Coolant

Tritium can potentially migrate into the primary coolant from the plasma through the first wall or from the blanket through coolant tubes, or it can be produced in the water from neutron reactions. Tritium can pass from the primary coolant to the secondary coolant by permeation or leakage. Because of "blow-downs", tritium in the secondary coolant is considered not recoverable and is assumed to be lost to the environment. Tritium transport in coolant circuits is discussed below.

The permeation of hydrogen isotopes through structural materials has been extensively studied at Argonne National Laboratory,[9,11] Oak Ridge National Laboratory,[12,13] and elsewhere.[14,16] At a given temperature, the permeation rate per unit area is proportional to the square root of pressure and inversely proportional to the square root of the atomic mass. Thus, the permeation

Table 1. Tritium Parameters for the ETF and STARFIRE Designs

	Plasma Parameters	
	ETF	STARFIRE
Thermal Power (MW)	750	4000
Plant Availability	0.25	0.75
Ion Density (ions/m^3)	18×10^{19}	8×10^{19}
Plasma Volume (m^3)	289	783
Particle Confinement Time (s)	2.3	1.8
Reflection Coefficient	0.6	0.9
Fractional Burnup	0.05	0.42
Burntime (s)	100	———
	Tritium Mass Flow Rates	
Tritium Burnup (g/d)	85	536
Tritium Fueled (g/d)	1600	1296
Tritium Exhausted (g/d)	1500	760
Tritium Bred (g/d)	——	562
Tritium Consumed (kg/y)	+8	-7
Deuterium Exhausted (g/d)	3000	506
Deuterium Burned (g/d)	60	360
	Neutral Beams	
Deuterium Pumped (g/d)	260	——
Deuterium Injected (g/d)	30	——
Tritium Pumped (g/d)	1.2	——

rate, ϕ, of T_2 through a membrane of area A, thickness t is given by:

$$\phi = \frac{1}{\sqrt{3}} K \left(\frac{A}{t}\right) (P_1^{1/2} - P_1^{1/2}) \qquad (1)$$

where P_1 = upstream pressure, and P_2 = downstream pressure. In general, the units of K are given as standard cc's of H_2 per unit time, per unit length, per square root of pressure, e.g., cc(STP)/m·s·(kPa)$^{1/2}$. For fusion application it is convenient to use units of Ci/d·m·(Pa)$^{1/2}$. The conversion factor from cc(STP)/m·s·(kPa)$^{1/2}$ for H_2 to Ci/d·m·(Pa)$^{1/2}$ for T_2 is 4056. Selected data[9,16] for structural materials of interest are shown using the more convenient units in Fig. 3. Permeation rates into the primary coolant were calculated and are listed in Table 3. It was found that anticipated permeation rates are very small; all are less than 10 Ci/d both for STARFIRE and ETF if tritium barriers are used.

For STARFIRE another loss mechanism i.e., "insertion" may be more important than permeation

for producing tritium migration into the coolant. Tritons striking the first wall implant to a certain depth. Assuming that permeation in any direction is inversely proportional to thickness, the fraction of tritons that enter the coolant is directly dependent on the depth of penetration via "insertion". Two important factors may reduce the "insertion" effect. First, the outer surface is likely to be highly damaged and therefore will have a high porosity. Thus, inserted tritons are more likely to return to the plasma. Second, the inside surface of the coolant tubes will be covered by an oxide film which acts as a permeation barrier reducing the permeation . . typically by a least two orders of magnitude. The "barrier effectiveness" for STARFIRE is therefore assumed to be 500. Experimental results are required to verify the mitigating effect of both of these factors. For STARFIRE, "insertion" calculations for beryllium indicate that tritium levels will increase at rates of $\sim$ 10 Ci/d. A minor source of tritium in the primary coolant ($\sim$ 1 Ci/d) is the lithium

Table 2. Tritium Inventory in the ETF and STARFIRE Designs

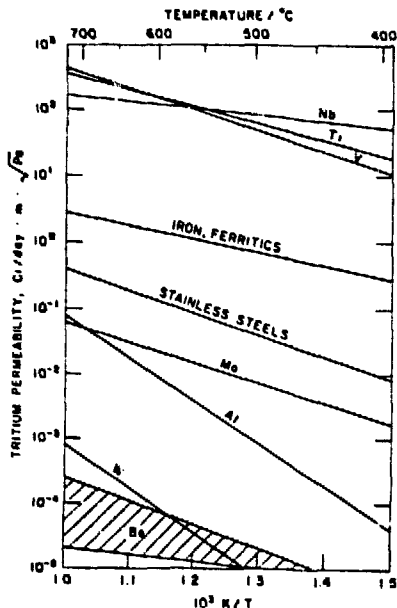| "Vulnerable" Tritium Inventory (g)		
	ETF	STARFIRE
Vacuum Pumps	130	63
Fuelers	20	54
Blanket Purge	——	0.2
Blanket Tritium Recovery	——	281
Total	150	398
"Non-vulnerable" Tritium Inventory (g)		
Breeder Blanket	——	∿ 10,000
Storage	2550	1071
Fuel Processing	120	154
Total	2670	11,225
Initial Tritium Inventory (kg)		
	3	10

Fig. 3. Tritium permeability of several materials as a function of temperature.

activation of the lithium hydroxide (LiOH) present as a corrosion inhibitor. The total tritium accumulation in the primary coolant for STARFIRE and ETF is estimated at ∿ 10 Ci/d. The main tritium loss mechanism between the primary and secondary coolant is not permeation (< 10^{-4} Ci/d – Table 3) but rather leakage across the steam generator. At tritium levels of ∿ 0.3 Ci/ℓ (steady state level in STARFIRE) in the primary coolant, leakage rates < 30 ℓ/d are required to minimize the tritium release to the environment to < 10 Ci/d. Similar leakage rates are required for ETF.

To ensure that tritium levels in the primary coolant are maintained at < 1 Ci/ℓ, a tritiated water recovery unit (TWRU) based on combined electrolysis/catalytic exchange (CECE) has been included in the tritium system design. Approximately 1% of the primary coolant, from which activated materials have been removed by means of ion-exchange units, is directed to the main tritium processing area (the tritium facility). There the HTO is converted to HT in the TWRU. The gas stream is then routed to the main fuel stream via the fuel cleanup unit.

Atmospheric Tritium Recovery (ATR) Scenarios

To minimize the tritium impact on the environment, both the STARFIRE and the ETF designs have attempted to contain all tritium releases, whether due to normal leakage or to accidental

Table 3. Tritium Permeation Calculations

Source	Material	Temp. (K)	Press. (Pa)	Area (m^2)	Thickness (mm)	Barrier	Permeation (Ci/d)
STARFIRE							
First Wall	Be	773	1.3×10^{-3}	780	1.0	———	0.3
Limiter	Be	573	1.3×10^{-1}	100	1.0	———	0.03
Limiter	Ta	573	1.3×10^{-2}	100	2.0	1000-X	5.5
Blanket	316SS	773	1.3×10^{-7}	5760	1.5	150-X	0.09
Steam Gen.	Inconel	573	1.3×10^{-12}	5000	2.0	150-X	$< 10^{-4}$
ETF							
First Wall	316SS	513	1.3×10^{-1}	400	2.0	100-X	0.07
Divertor	W	643	1.3×10^{-1}	400	10.0	———	10^{-4}

releases within the confines of the plant. Several tools have been utilized to accomplish this goal. The outer walls of potential tritium containing areas are lined with a tritium barrier (stainless steel or aluminum). The materials and equipment used in a tritium area are selected to minimize surface adsorption. Tritium areas are operated at reduced atmospheric pressure to minimize tritium out-leakage. The atmospheric tritium level (HTO) in all areas is maintained at < 5 $\mu Ci/m^3$. Tritium systems utilize triple containment where reasonable and practical; double containment is used throughout. The number and length of lines used to transport tritium between different buildings are minimized. The impact of a tritium release from the coolant system is minimized by: (1) maintaining the tritium inventory in the coolant at < 1 Ci/ℓ; (2) minimizing leaks in the primary coolant system; and (3) recovering all tritiated water and recycling it into the main fuel stream. Timely decontamination of potential tritium spills within containment is provided by: (1) dicating an appropriately sized atmospheric tritium recovery unit (ATR) to each tritium containing area; and (2) interfacing the HVAC systems with the ATR systems to prevent a tritium release to the outside environment. Multiple, discrete flow paths between units are used to partition the tritium inventory and thus reduce the magnitude of a tritium release. The tritium waste generated is minimized by (1) processing tritiated water, (2) minimizing use of organica, (3) minimizing the contamination of organics where they are functionally necessary, (4) using all metal seals in valves, pumps, etc., and (5) reprocessing tritiated waste. Any waste generated within the plant is packaged in as small as a volume as possible.

The effect of a possible tritium release within the plant was modeled by postulating the failure of a component of any of the "vulnerable" systems. For STARFIRE the following scenarios were identified: 1) the blanket purge stream ruptures and flows for 10 minutes releasing 2 g of tritium; 2) malfunction of one of the 24 blanket tritium recovery units would release $\sim$ 12 g of tritium; 3) a pump fails releasing all its inventory (2.6 g); 4) failure of one of the fuelers would release $\sim$ 13 g of tritium. The tritium is in the form HTO (T_2O) in the first two cases; it is present as DT in the later two. For ETF which lacks a blanket only two scenarios are postulated: 1) 13 g of DT is released if a pump fails; 2) failure of a fueler would release $\sim$ 10 g of DT (T_2). For modeling purposes therefore, the maximum release in the reactor building or hot cell area is assumed to be 10 g ($\sim 10^5$ Ci) of tritium in the form T_2O. During actual reactor operation when remote handling is used no worker hazard would result; however, the atmosphere after a release will be detritiated to ensure that the tritium does not enter the environment and that the tritium adsorption on exposed surfaces is minimized. To effect this, atmospheric tritium recovery systems based on a prototype at TSTA are installed in all tritium areas. The basic operation consists of the processing of the atmosphere by catalytic oxidation of tritium gas to T_2O followed by its absorption on molecular sieves. (The presence of a CO_2 environment in the STARFIRE design will require a slight increase in the number of sieves used).[17]

To study the effect of tritium "soaking"[18] on the cleanup time, a parametric analysis was performed using the computer code TSOAK-M1[19] to determine the dependence of the cleanup time required after a tritium release on the following variables: 1) the rate of formation of HTO from T_2 or HT (RR); 2) the ratio between the rate of release of HTO from the surfaces within a building to the rate of adsorption onto the surfaces

(REL/ADS); 3) the relative flow rate (F = percent of building volume per minute); 4) the building volume (V) and 5) the total surface area (S' or S) taken as two or four times the surface area of volume V. Reported values for the rate of formation of HTO from T_2 or HT varies from 10^{-5} to 10^{-15} $m^3/\mu Ci \cdot s$.[18,20,21]. When RR is $\leq 10^{-13} m^3/\mu Ci \cdot s$, the time required to scrub the tritium from the building (i.e., to other tritium levels ≤ 10 $\mu Ci/m^3$) is identical to that for the ideal case[18] (less than four days when the process flow rate, F, = 0.2 Vol %/min and REL/ADS = 1). If RR is $\geq 10^{-9} m^3/\mu Ci \cdot s$, the cleanup time increases to > 15 d due to the adsorption of the HTO formed on the surfaces within the building. Thus, it is advantageous to design all tritium handling areas to minimize the rate of formation of HTO, i.e., to ensure small values of RR. However, additional experiments are needed to define the values of RR for materials which might be exposed to tritium in the fusion environment.

In the event of a tritium release involving HTO, the most important variable is the ratio between the rate of release and the rate of adsorption of HTO on the surfaces. The dependence of the residual tritium concentration on this ratio 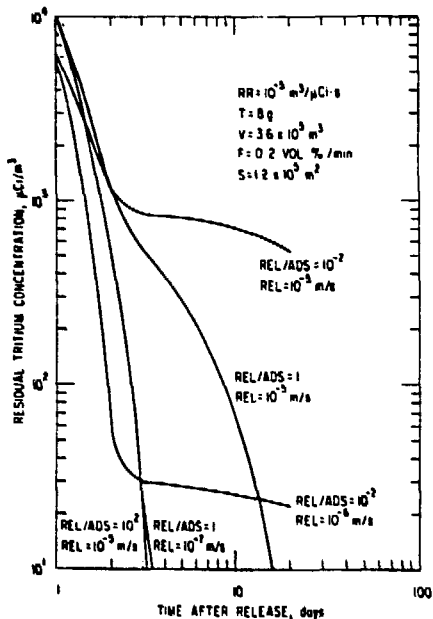is shown in Fig. 4. When the ratio is < 1, the atmospheric tritium level remains elevated due to the large amounts of tritium adsorbed on the surfaces of HTO. Even when REL/ADS = 1, the time required to attain levels < 10 $\mu Ci/m^3$ may be excessive. If the REL/ADS ratio is one and the HTO release rate is < 10^{-5} m/s the surfaces become a permanent sink for the adsorbed tritium. To ensure the removal of tritium with the atmospheric recovery system, the tritium handling areas are designed with REL/ADS ≥ 1 and REL $\geq 10^{-4}$ m/s. This is achieved by using materials and equipment designed to minimize surface adsorption.

The effect of increasing the volume on the required cleanup time is minimal. Doubling the surface area (S'→S) (Fig. 5 also has a minimal impact on the tritium concentration after a release. A more important parameter is the process flow rate (F) as shown in Fig. 5. With F = 0.5 Vol %/min; tritium levels are reduced below 100 $\mu Ci/m^3$ in ~ 1 day; 3 - 5 days are required if F = 0.2 Vol %/min; and 10 days if F = 0.1 Vol %/min. For areas where personnel access in not required (reactor building, hot cell), process flow rates can be less than those where access is required (tritium facility). For STARFIRE, the ATR systems for the remotely operated hot cell and the reactor building are designed with F = 0.2 Vol %/min; in the tritium facility the ATR is designed with F = 0.5 Vol %/min. In the latter area, workers wearing bubble suits can enter

Fig. 4. Dependence of tritium concentration after release on ratio between the rates of releasing HTO from surfaces and the rate of adsorbing HTO.
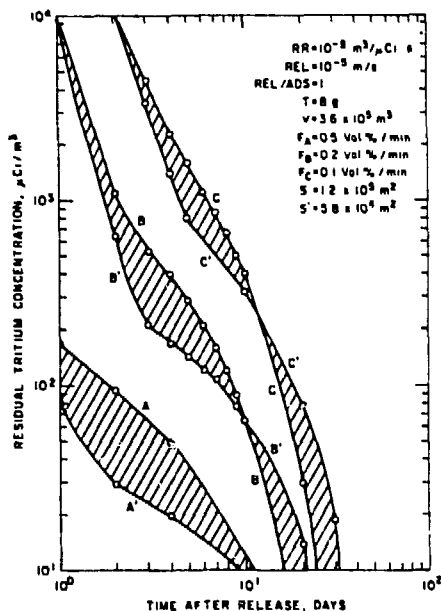

Fig. 5. Dependence of tritium concentration after release on processing rates and surface areas exposed.

-7-

immediately after a tritium release. For ETF, ATRs with P = 0.5 Vol %/min are provided for all areas where worker access is required.

The tritium released to the environment during the release scenarios postulated is minimal (< 12 Ci) because the cleanup is handled within the containment buildings. In the event of a simultaneous loss of coolant (LOCA) in the primary system and a rupture of a tritium processing line, the following procedure is followed to prevent swamping of the ATR: 1) shutdown of the ventilation system; 2) collection of the condensed coolant in a flow tank; and 3) startup of the ATR ∿ 1 hour after the tritium release.

The maximum tritium released in a single failure of a "non-vulnerable" component is the 50 g in the ISS unit. Because the tritium is in the unoxidized form (a factor of 40 less toxic than the oxidized form) and because no worker is permitted in the vicinity of the operating ISS units without a bubble suit, the average dose received in the tritium facility (2×10^4 m^3 – building volume) by an unprotected worker would be 1.9 rem/min after a 50 g release of T_2. With a suit (permeation rate of 1.2×10^{-4} m^3/h),[22] the dose would be 0.008 rem/h. With prompt response to tritium release alarms, no worker will be subjected to an excessive radiation dose (the present recommended yearly dose is 5 rem). The fire hazard from a 50 g release (0.2 m^3 at STP) is minimal; conversion to HTO under non-fire conditions will require more than an hour.

Tritium Release Design Goals

The design goal for tritium release for both STARFIRE and ETF is less than 5000 Curies per year in all forms (gas, liquid and solid waste) averaged over operating, standing and maintenance phases and including in-plant releases. The sources of all releases are shown in Table 4. The coolant is the primary source of tritium release from either plant. The tritium loss due to building leakage will be < 1 Ci/d assuming a leakage rate of 3×10^{-5} Vol %/d with a tritium concentration of 5 μCi/m^3. Five atmospheric turnovers per day in the tritium building (STARFIRE) and in all tritium units (ETF) will account for 1 and 6 Ci/d respectively. The packaged solid waste is assumed to contribute ∿ 1 Ci/d. To reduce the projected tritium releases, the most productive method will be to reduce leakage across the steam generators into the secondary coolant loop.

Routine replacement of the STARFIRE blanket modules will release some tritium into the reactor building which will be processed by the ATR units. An estimate of the magnitude of this release was obtained using the permeation data in Fig. 3. At an average temperature of 673 K

(arising from the afterheat) < 10 Ci/d will be lost from the beryllium surfaces and < 30 Ci/d from the stainless steel surfaces to the reactor building atmosphere. Maintenance operations which will be more frequent for the ETF reactor release comparable levels of tritium to the reactor hall.

Tritium Facility

The tritium facility is a completely separate building from the reactor building but is located nearby to minimize the length of the tritium feedlines and thus to reduce the tritium accident potential. The building is designed for contact maintenance, having an air environment and being free of gamma and neutron radiation. All tritium handling units are under remote, independent (hard-wire) computer control; the computer is equipped with an uninterruptible power supply to ensure that all tritium systems can be shutdown in the event of a power failure. The tritium storage area is sited in the tritium facility. It consists of a shielded barricaded vault in which an inert cover gas is used for fire protection. Because of space and safety benefits, the majority of the tritium is stored as UT_x, but some low-pressure gaseous storage in tanks is also provided. The tritium processing units are based on prototypes being tested at TSTA[5] and they are of modular design to facilitate replacement. Multiple units are provided and full redundancy is built into the tritium facility to ensure maximum reliability and availability. The primary containment systems are metal (no elastomers). An inerted, dry atmosphere glove box is the secondary containment for most components. Double wall piping is used between units. The dimensions of individual components are found in Table 5.

The layout of the two levels of the tritium facility is shown in Fig. 6. The building is divided into two main sections. The tritium processing section is 30 m x 40 m; within it a slightly negative pressure is maintained by a self-contained HVAC system interfaced to the ATR system to minimize tritium out-leakage. The first level in this section is 6 m high, the second level is 12 m high (6 m of which is dedicated to crane operation.) The control section is 30 m x 10 m x ∿ 8 m high; a slightly positive pressure is maintained by a separate HVAC system to prevent tritium in-leakage. Within this latter section are found the tritium facility control room, offices for the supervisory personnel, the locker/shower area, the radiation safety office, tritium bubble suits not yet in use and the main entrance to the building. The control room contains the control units for all tritium processing systems and the tritium monitor readouts for the tritium facility, the reactor building and the hot cell. The latter are used to detect small leaks in any of the tritium systems. There are several personnel airlocks into the tritium processing section; the one designed for

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Table 4. Tritium Releases in the ETF and STARFIRE Designs

Source		ETF	STARFIRE
Coolant			
Steady State Concentration (Ci/ℓ)		0.001-1	0.3
Leak Rate	(ℓ/d)	1000-10	$\sim$ 30
Tritium Release	(Ci/d)	1-10	$\sim$ 10
Buildings			
Volume	(m^3)	3 x 10^5	4 x 10^5
Tritium Level	(μCi/m^3)	5	5
Leak Rate	(Vol %/d)	3 x 10^{-5}	3 x 10^{-5}
Tritium Release	(Ci/d)	$\sim$ 1	$\sim$ 1
Ventilation			
Volume	(m^3)	2 x 10^5	2 x 10^4
Tritium Level	(μCi/m^3)	5	5
Number of Releases		5	5
Tritium Release	(Ci/d)	6	$\sim$ 1
Solid Waste			
Tritium Release	(Ci/d)	1	1
Total			
Tritium Release	(Ci/d)	9 - 18	$\sim$ 13

routine use connects the locker/shower area and the tritium section. The others are intended for emergency use. Within the tritium processing area, 25% of the available volume is occupied by the ATR and the interfaced HVAC system. The placement of all units is designed to provide good accessibility with a remotely operated crane. The TWRU, TWT and SWD units which generate and/or process tritiated waste are located near the dock to provide easy waste removal. The dock itself is located outside the building to ensure that the tritium liner within the tritium facility is completely sealed. Four ISS and four TCU units are provided for redundancy, only two sets are on-stream at any one time. The ISS units are 6 m high; the 6 m high vacuum shell around each unit is removed vertically. (Space on the second level is provided). The TPU units which regulate the gas flow through the tritium facility are stacked in two tiers per level. Piping joining all units is not shown. Storage space is provided for non-tritiated gaseous deuterium and hydrogen as well as helium and nitrogen. Within the tritium area are three service areas. The first is an analytical laboratory for doing routine

analyses on catalysts, molecular sieves, etc; the second is an electronics laboratory in which non-activated tritium monitors are serviced and tested; the third is a maintenance area where tritium units are repaired. A storage/cleaning area for used bubble suits is also provided.

To minimize worker contact with tritium in the tritium facility, which is designed for contact maintenance, the following procedures are followed. Atmospheric levels are maintained at < 5 μCi/m^3. An ATR with F = 0.5 Vol %/min is dedicated to the facility. Normal hydrogen fire prevention practices are exercised.

Conclusions

The tritium systems have been designed to achieve a minimum inventory in the plant, minimum tritium release to the environment, minimum worker exposure, minimum solid waste, and maximum availability and reliability. The tritium facility based on TSTA prototypes is a full-scale processing plant with high reliability. The effects of a tritium release have been modeled

Table 5. Tritium Facility Components

Component	Abbreviation	Dimensions(m)	Volume(m^3)
Atmospheric Tritium Recovery Unit	ATR	6.25 x 8 x 5 (1 unit)	2500 (10 units)
Isotope Separation System	ISS	3 x 3 x 12	108
Fuel Cleanup Unit	FCU	6 x 2 x 2	24
Tritium Waste Treatment	TWT	5 x 5 x 5	125
Solid Waste Disposal	SWD	5 x 5 x 4	100
Transfer Pump Unit	TPU	4 x 1 x 2	8
Tritium Storage		8 x 4 x 2	64
Tritiated Water Recovery Unit	TWRU	6 x 9 x 3 3 x 4 x 3	162 36
Fuel Blender Unit	FBU	4 x 1 x 2	8

and indicate the importance of different parameters, the most significant being the flow velocity and the ratio of the rate of HTO adsorption to the rate of its release. The coolant is the primary source of release from the plant.

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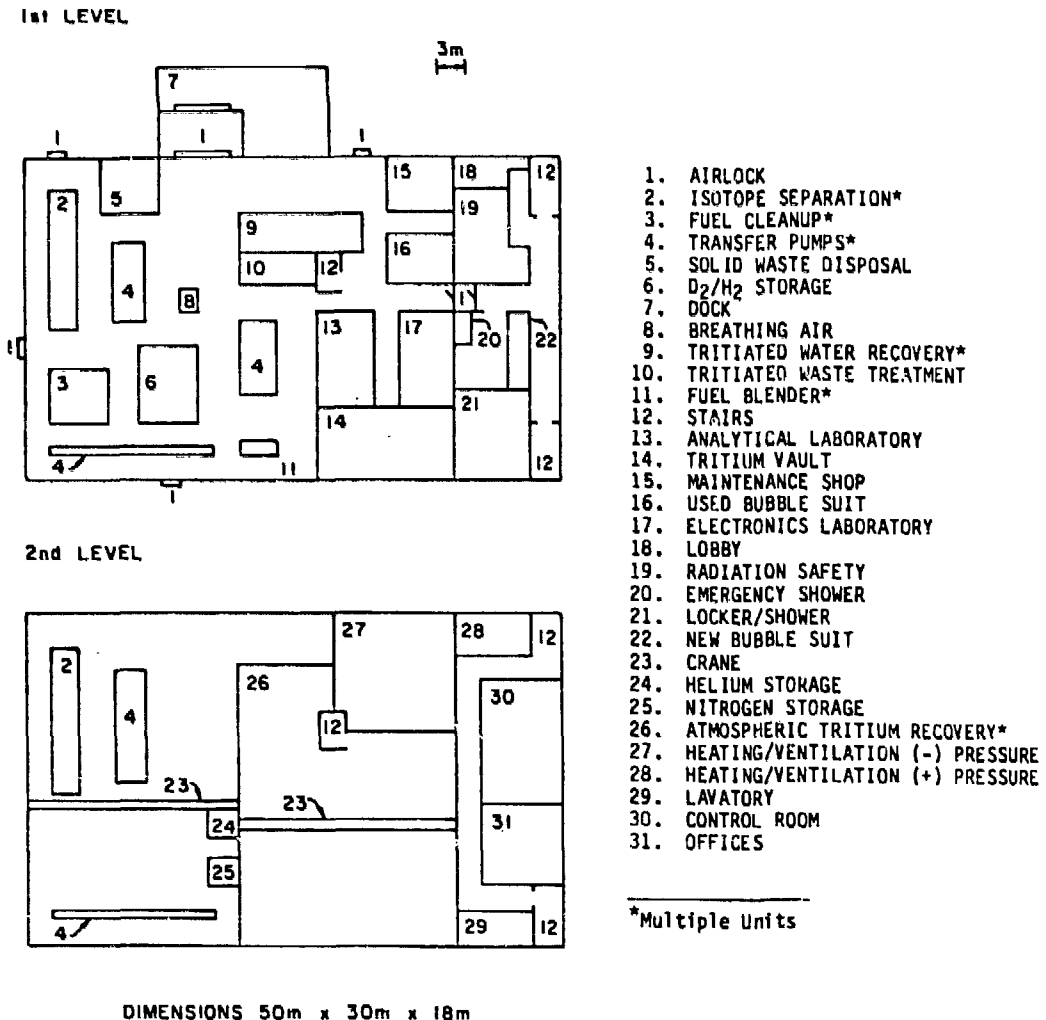
3m

No.	Description
1.	AIRLOCK
2.	ISOTOPE SEPARATION*
3.	FUEL CLEANUP*
4.	TRANSFER PUMPS*
5.	SOLID WASTE DISPOSAL
6.	D2/H2 STORAGE
7.	DOCK
8.	BREATHING AIR
9.	TRITIATED WATER RECOVERY*
10.	TRITIATED WASTE TREATMENT
11.	FUEL BLENDER*
12.	STAIRS
13.	ANALYTICAL LABORATORY
14.	TRITIUM VAULT
15.	MAINTENANCE SHOP
16.	USED BUBBLE SUIT
17.	ELECTRONICS LABORATORY
18.	LOBBY
19.	RADIATION SAFETY
20.	EMERGENCY SHOWER
21.	LOCKER/SHOWER
22.	NEW BUBBLE SUIT
23.	CRANE
24.	HELIUM STORAGE
25.	NITROGEN STORAGE
26.	ATMOSPHERIC TRITIUM RECOVERY*
27.	HEATING/VENTILATION (-) PRESSURE
28.	HEATING/VENTILATION (+) PRESSURE
29.	LAVATORY
30.	CONTROL ROOM
31.	OFFICES

2nd LEVEL

*Multiple Units

DIMENSIONS 50m x 30m x 18m

Fig. 6.   Fusion Reactor Tritium Facility

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