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ENVIRONMENTAL CONTROL OF TRITIUM USE AT THE TOKAMAK FUSION TEST REACTOR (TFTR)

BY

H. J. HOWE, JR. AND K. E. LIND

PLASMA PHYSICS LABORATORY

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PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

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H. J. Howe, Jr. and K. E. Lind

Princeton Plasma Physics Laboratory
and
Ebasco Services, Inc.

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ABSTRACT

A primary objective of the Tokamak Fusion Test Reactor Project (TFTR) is to demonstrate the production of fusion energy using the deuterium-tritium fusion reaction in a magnetically confined plasma system. This paper will discuss the various tritium control methods employed to minimize the release of tritium to the environment. The methods to be described include the containment and ALAP philosophy, engineered safety features, redundant tritium cleanup systems, redundant instrumentation and control systems, interlocks, monitoring systems, management controls, and waste handling systems. Estimates will be included concerning the impact of routine and accidental tritium releases with these control systems in place.

I. INTRODUCTION

The established goal of the magnetic fusion program is to develop and demonstrate the practical application of fusion to the production of central station electrical power. TFTR will be the first magnetic fusion system in this country to produce fusion energy in any significant quantity. While no electrical power will be generated, TFTR will provide an essential link between the scientific machines currently being operated or under construction and the first power producing fusion reactor. The purposes of the TFTR project are to demonstrate fusion energy production from the pulsed burning of deuterium and tritium in a magnetically confined toroidal plasma system, to study the plasma physics of large tokamaks, and to gain experience in the solution of engineering problems associated with large fusion systems approaching the size of presently planned experimental power reactors and to do so in a manner such that the impact on the environment is as low as is practicable.

The TFTR will be a device in which a fully ionized gas, a plasma, is created within a toroidal vacuum vessel maintained at high vacuum. The plasma will be constrained to move inside the vacuum vessel by means of a strong toroidal magnetic field (TF) generated by passing a changing electric current through large copper coils. The position of the plasma within the torus will be refined and controlled by poloidally directed magnetic fields generated in copper coils referred to as equilibrium field (EF) coils and vertical correction (VC) coils. A current will be produced in the plasma by means of a changing magnetic field induced by coils referred to as ohmic heating (OH) coils. This induced current will heat the plasma to the high temperatures necessary for fusion reactions to occur. Further heating will be provided by the injection of beams of neutral particles (deuterons) from three neutral beam injectors (NBI). (See Fig. 1.) The fusion reactions that will occur in the high temperature plasma (D-D, D-^{3}He, D-T) will result in the emission of energy in the form of charged particles and neutrons, the properties of which will be studied by various diagnostic systems.

The TFTR will be housed within a test cell (TC) approximately 115 feet by 150 feet by 60 feet supported on a structure tied to the TC floor bearing on a foundation designed to satisfy the appropriate safety-related criteria. Attenuation of the neutron and gamma radiation resulting from fusion interactions will be provided by a shield close to the device, by movable blocks at the TC wall and by the TC wall itself. This shield will reduce radiation levels to below the DOE ALAP criteria. Handling of activated components, primarily those components inside of the igloo shield and close to the vacuum vessel, will be accomplished remotely by specially designed apparatus and devices.

The eventual operation of TFTR at a scientific break-even power level will involve the generation and containment of a tritium (^3H, T) plasma. The TFTR systems are being designed to minimize the potential release of tritium under both routine operation and accidental conditions. Analyses show that potential effects due to credible tritium releases are minimal. The design philosophy that has been adopted and will be described here is that of containment, minimum dilution, and as low as practicable releases. This will be accomplished by using engineered safety features, redundant cleanup systems, extensive monitoring and control systems and by applying rigorous management controls to the device operation.

II. TRITIUM CONTROL PHILOSOPHY

In order to minimize the release of tritium to the environment surrounding the TFTR the following control philosophy has been established and is being followed:

A. Containment - as much of the tritium inventory as is practicable will be contained in a basement area designed to withstand major accidents (including most intense natural phenomena such as earthquakes, tornadoes and floods). This area will be carefully controlled and interlocked and will have ventilation systems designed to keep its pressure negative relative to other spaces. The tritium generators and gas delivery system will be housed in a glovebox with an inert atmosphere. In order to minimize releases this glovebox will be connected to and exhausted through a cleanup system.

B. ALAP - tritium releases will be reduced to levels that are "as low as practicable" (ALAP) and in all cases will be less than the appropriate DOE guidelines. (See Table I.) The primary approach will be to engineer all components to high standards of reliability in order to minimize the probability of accidental releases.

C. Minimum Dilution - system design techniques will emphasize the prevention of tritium releases to large volumes in order that cleanup systems can operate on high tritium concentrations for which they are most effective. Dilution in air before release will be employed only if absolutely necessary to minimize exposure to on-site personnel.

The achievement of these objectives will result in the minimization of potential releases of tritium to the atmosphere and to other effluent pathways and will reduce exposures to humans and to the environment to levels that are small when compared to natural background.

III. ENGINEERED SAFETY FEATURES

After being introduced into the torus by the gas delivery system, tritium will, to some extent, dissolve in and permeate components such as the measuring volume, valves and pipes, the torus, neutral beams, cryogenic traps, vacuum pumps and lines, getters, cleanup systems, etc. Diffusion of tritium out of the system during routine operation will be inconsequential. The presence of tritium in the components will, however, present the possibility of accidental release to the test cell and subsequent release to the atmosphere, hence each component will be engineered to emphasize tritium containment.

Tritium will be received in a doubly contained shipping container inside of a Department of Transportation (DOT) tested and approved outer pack. Source transfer operations will take place inside of the tritium vault which in the event of a tritium release will be exhausted through a cleanup system. The vault area will be maintained at a ventilation pressure negative to other spaces. The complete loss of one tritium transport container (24,000 curies) would be cleaned up and a release to the environment of only 24 curies would result. The probability of such an event is estimated at 5×10^{-2} (0.05) per year.

Tritium will be stored as uranium tritide (UT_3) on a solid bed inside of a heavy double-walled stainless steel container housed in an inert atmosphere glovebox located in the vault. Releases from this system would be reduced by the tritium storage and delivery cleanup system.

It is estimated that about 1000 curies of tritium could be present for short times in valves and pipes. Those pipes normally expected to contain high tritium concentrations will be double-walled with pumping on the annulus. The quantity will be minimized by vacuum pumping systems wherever possible with the exhaust being directed to the torus cleanup system.

Up to 400 curies of tritium will be magnetically contained in the torus during a pulse with an estimated 4000 curies being adsorbed on surfaces of the vacuum vessel, bellows, diagnostic pipes, etc. The bellows are backed up with a cooling system the exhaust of which is directed to a cleanup system. This inventory will be periodically reduced by bakeout and/or discharge cleaning techniques with the dislodged tritium being directed to a cleanup system designed to handle the torus and neutral beam systems.

It is estimated that up to 3 curies per pulse per beamline could be collected on the neutral beam cryopanels. These cryopanels will be regenerated under tight administrative controls in order to limit the accumulation of tritium in all beamlines to less than 2200 curies. The vacuum exhaust during regeneration will be processed by the torus cleanup system with a cleanup efficiency of 99.9%, hence maximum potential accidental releases to the environment will be below 2 curies.

During routine tritium operation the tritium used in the torus will be physically adsorbed on Zr-Al getters located in the basement area. A maximum of 20,000 curies could accumulate after 100 pulses of operation. The getters will be packaged and sent to a sister laboratory for regeneration and/or waste disposal. Accidental releases from the getters are highly unlikely (10^{-5}, 0.00001 per year), however, should an accident occur, the tritium would be cleaned up by the vault cleanup system restricting any release to the atmosphere to about 20 curies.

During regular tritium operation the torus vacuum pumping system will exhaust to Zr-Al getters as described above. In some cases, however, such as D-D operation or during the last stages of bakeout cleaning, etc., the resulting low level concentration of tritium will be handled by exhausting the torus vacuum pumping system to gas holding tanks and subsequently to a cleanup system. Similarly, the regeneration of the neutral beam cryopanels will release not only 1200-1800 curies of tritium but large quantities of deuterium from the beam sources and neutralizers as well. The neutral beam vacuum pumping system will also exhaust to the collecting tanks. The tanks will be located in the tritium area and any accidental release of tritium from the tanks would be cleaned up by the vault cleanup system.

To summarize, while tritium will appear in many areas, those areas are being designed with high tritium containment in mind. (See Fig. 2.) All systems are protected by cleanup systems and have backup systems available in order to mitigate potential releases.

IV. REDUNDANT CLEANUP SYSTEMS

Supplementing the containment of tritium by tight vacuum system design and engineering there will be several cleanup systems designed to mitigate and reduce potential releases to environmentally acceptable levels. Four such systems will be employed and are summarized below:

A. Tritium Storage and Delivery Cleanup System (see Fig. 3) - the inert atmosphere of the glovebox containing the tritium generator and delivery equipment will be processed by this cleanup system with a cleanup efficiency of 99.9%. After preheating, the tritium containing gas will pass into a hydrogen removal catalyst which will combine the tritium with oxygen, forming tritiated water vapor. After passing through the recombiner, the gas will enter an oxygen getter. The removal of oxygen from the stream will be necessary to obviate formation of tritiated water in the glovebox. The oxygen free gas stream will then be cooled and passed through adsorbent beds where the triated water vapor will be removed and the dry gas recycled to the glovebox. The adsorbent beds will be of a disposable type and when one of the beds is saturated with moisture/tritium it will be sent off-site for disposal and a second bed introduced to the process system. In case of a failure of the tritium storage and delivery cleanup system, the glovebox atmosphere will be purged with an inert gas and routed to the gas holding tanks of the Torus Cleanup System.

B. Torus Cleanup System - vacuum system exhaust gases from the torus and neutral beam pumping systems will be processed by this cleanup system with a tritium removal efficiency of 99.9%. The torus cleanup system will have two main modes of operation, namely a holdup-process mode (HPM) and a direct-process mode (DPM). Each mode will utilize the same treatment components for preheating, tritium oxidation, and water vapor removal from the process stream.

The holdup-process mode will utilize holding tanks for collection of system inputs and as surge capacity for the system. These tanks will receive inputs from the following sources:

1. The torus and neutral beam pumping system.

2. Purge of the tritium supply and delivery system glovebox after a tritium release to the glovebox.

3. The vacuum vessel bellows heating and cooling system during discharge cleaning and bakeout.

Inputs will be directed to one holding tank until the tank pressure reaches approximately 750 torr at which time the tank inlet will be isolated and the second tank "valved in". The tanks will be continuously monitored for explosive mixture conditions and for tritium concentration.

Gas will be pumped from the holding tank at a constant rate of 2SCFM by a compressor into a 50SCFM recirculating nitrogen stream. This dilution approach negates the possibility of an explosive mixture being present in the process stream by maintaining the hydrogen isotope concentration below 4% by volume (lower explosive limit). The gas will then flow to a preheater to initiate the recombination reaction. The process stream will then be processed through a catalytic recombiner where hydrogen isotope gases will be converted to water vapor. In addition, the recombiner will operate at high enough temperatures to oxidize any hydrocarbons that may be present in the gas stream. The gases from the recombiner will then be passed through a cooler where stream temperatures will be reduced to the operating range of the desiccant bed. From the cooler, the gas containing tritiated water vapor will enter a regenerable desiccant bed where moisture will be removed. The purified stream will then be recycled.

The direct-process mode will utilize recycle blowers to take direct suction on the source requiring processing. Inputs to the system which will be handled in this operating mode are as follows.

1. The torus and neutral beam pumping system.

2. The utility glovebox atmosphere.

3. The tritium receiving glovebox atmosphere.

In this mode the gases will be pumped directly into the preheater for subsequent cleanup thus bypassing the holding tanks.

C. Tritium Vault Cleanup System - this system will serve as a third level of protection for the tritium source and would be activated by monitors sensing the tritium concentration in the vault area. The system will also be capable of backing up the torus cleanup system. Should large vacuum leaks occur in the torus or neutral beam systems this cleanup system would maintain a negative pressure thus preventing a tritium release into the test cell. The cleanup process is essentially as described above, i.e., preheat, recombine, catalytic oxidation, cooling, adsorbing on desiccant beds.

D. Test Cell Cleanup System - should tritium be released to the test cell the ventilating (HVAC) system would be switched to a recirculation mode in which water vapor is introduced to humidify the air. The resulting water vapor (containing HTO from the release) will then be condensed on the coils of the HVAC system. The resultant HTO-containing condensate will be collected in the radioactive liquid holding tanks for sampling and subsequent release or solidification and disposal. A conservative estimate of the efficiency of this process for removing HTO is 90%.

While the primary method of minimizing tritium releases to the atmosphere is by containment and subsequent cleanup and disposal as solid waste, adequate systems are being designed to provide backup to mitigate accidental releases.

V. MONITORING, INSTRUMENTATION AND CONTROL

In order to assure the proper operation of systems involved in the control of tritium it will be necessary to employ monitors at various locations in the facility and at various points in the process streams.

Tritium monitoring instruments capable of sensing concentrations of about 10% of the appropriate DOE guidelines will be located in the Test Cell, the basement area, the tritium area, the ventilation equipment room, the pump room; at selected areas in occupied spaces such as the power buildings, the mockup building, and the access tunnel as well as at the exclusion zone boundary fence. Information will be collected in the safety computer and continuously displayed with appropriate trigger levels to the operations staff.

Monitoring of tritium levels in the cleanup process streams will take place and will determine the system operation. Signals from these process monitors will be displayed in a hardwired manner in a local tritium control room as well as in the main control computer by way of an optical data link. All systems are required to "fail safe", i.e., valves close, power supplies go on emergency power, cleanup systems go into emergency priority modes, etc. In this way the major sources of potential tritium release become physically contained behind redundant valves in a physically protected area in the basement of the facility.

Emergency power will be provided to all safety related systems by a diesel generator backed up by a battery/inverter system, thus assuring power for control and monitoring under even the most serious credible accident.

VI. MANAGEMENT CONTROLS ON OPERATION

In order to minimize potential releases of tritium to the environment TFTR management has established the following major restrictions on tritium use and accumulation (see Table II):

A. There will be no more than 50,000 curies on the TFTR site at any one time, and no more than 25,000 curies of this amount will be "in process", i.e., in an on-line generator at temperature feeding the torus.

B. Neutral beamlines will be regenerated on or before the accumulation of 2200 curies of tritium is reached.

C. There will be no more than 96 full power D-T pulses in any single day and no more than 1000 full power D-T pulses in a year.

D. Every attempt will be made to restrict releases of tritium to below 100 curies/year.

With these controls being applied from design through the operation of the TFTR, releases to the environment will be minimized.

VII. WASTE HANDLING SYSTEMS

The use of tritium in TFTR will lead to the generation of tritiated waste materials which will require careful collection and disposal.

The gaseous wastes from the spent plasma will be adsorbed on zirconium-aluminum "getters" which will be housed in a hood in the tritium area. These getters will be packaged for transportation to a sister laboratory for tritium regeneration or disposal. It is expected that 99.99% of the tritium will be collected in this manner. That quantity of gaseous waste not "gettered" will be processed by the previously described torus cleanup system thus minimizing the gaseous release of tritium to the environment.

A small quantity of tritiated oil will be collected periodically from the vacuum pumps, polymerized in concrete and disposed of off-site in double metal containers. Any tritiated water escaping the various systems will be collected in radiation waste tanks by way of the radiation liquid waste drain system designed into the facility. The water will be monitored for radioactivity and either released or solidified for controlled burial depending upon its level relative to DOE guidelines.

Solid components no longer needed for operation will be monitored for tritium contamination and, if necessary, compacted remotely in the hot cell (if high level) or compacted in the mock-up area. Eventual methods of off-site disposal by controlled burial will depend upon the levels encountered.

VIII. RELEASE ESTIMATES/DOSE EQUIVALENTS

Proposed operational scenarios have been analyzed in order to estimate the potential maximum tritium releases during routine operations. The most significant releases will result from diffusion through components of the tokamak, primarily the bellows of the vacuum vessel. It has been estimated that about 300 curies will diffuse through these bellows during one year of routine operation. If released directly to the atmosphere this quantity would represent a dose equivalent at the exclusion boundary of about 0.72 mrem, well below our design objectives. The TFTR design will include the capability to direct most of this potential release (~90%) to a cleanup system by using a relatively tight, closed system around each bellows. The release to the atmosphere under routine conditions from this source will be kept to about 40 curies.

In addition to the diffusion through the bellows, it was necessary to consider various additional sources from which very small releases could occur as modifications are made on the device – for example, the removal or modification of a diagnostic component. Administrative controls will require a bakeout to drive off to cleanup systems any absorbed tritium that is not tightly bound to the metal. The resulting small accumulated releases will not exceed 20-30 curies per year.

The cleanup systems associated with routine operations (excepting the Zr-Al getters used for torus pumping with an efficiency of 99.99%) are expected to have an efficiency of 99.9%. The major source of routine cleanup will be the regeneration of the neutral beam cryopanels and cleanup will reduce the routine release to about 18 curies per year.

The total annual release of tritium due to routine operations, assuming 90% cleanup of the amount permeating the bellows, will be in the 100 curie range. Assuming all releases to be HTO at ground level, the resulting dose equivalent at the nearest residence by all exposure pathways (inhalation, diffusion, ingestion) is about 0.2 mrem, less than 1/400 of natural background.

Those areas where tritium inventories are the largest have been identified and worst case accidents have been analyzed in terms of potential tritium release. Probabilities have been estimated for these potential releases, the magnitudes of each potential release before and after mitigation have been estimated, and maximum potential dose equivalents have been calculated and compared to the appropriate guidelines. (See Table III.) It is seen that in no case, even in the case of massive destruction of the test cell accompanied by fire, does the dose equivalent associated with a release exceed the appropriate design objective. For credible releases (probabilities $>10^{-3}$ per year) the resulting maximum dose equivalent (0.44 mrem) is a small fraction of the normal radiation background for this area.

IX. SUMMARY

To summarize, in order to properly mitigate potential tritium releases, present TFTR designs include provisions for various cleanup systems (storage and gas delivery, torus, vault, test cell) to maintain a negative pressure during vacuum system failures in order that the tritium in the torus and neutral beams be directed to a cleanup system for 99.9% removal. In addition, the test cell heating, ventilating and air conditioning system is being designed to capture the tritiated water vapor on the HVAC coils and to direct this tritium-containing water to the liquid radiation waste holding tanks. Monitoring and instrumentation will be employed to properly control the systems containing tritium. Management controls on operation are designed to minimize the quantity of tritium at risk and all wastes generated will be properly handled. Releases to the environment will be minimal and the dose equivalents associated with these releases will be well below DOE guidelines.

Table 1

TFTR RADIATION EXPOSURE CRITERIA

The research facility radiation exposure criteria itemized in this table shall be invoked for the TFTR only and shall not be construed as being applicable to subsequent fusion test facilities, research facilities, or reactor projects. The values quoted are for whole body exposures, however, the DOE manual requirements for other organs (hands, arms, bones, etc.) and other time periods (quarterly) are also applicable to TFTR and reductions between limits and design objectives shall be consistent with those of the table.

Condition	Off-Site ≥125 m		On-Site <125 m	
	Limit	Design Objective	Limit	Design Objective
Routine Operation m rem/yr [see footnotes (a) and (b)]	500 to an individual	≤100 to an individual (b)	500 in an uncontrolled area	≤100 in an uncontrolled area
	170 average population member	≤35 average population member	5000 in a controlled area	≤1000 in a controlled area
Accident rem [see footnotes (c) and (d)]	25	≤5 (d)	25	25

(a) Routine operation consists of:
   1) Normal component operation including shutdown, repair, maintenance, checkout, adjustment, etc.
   2) Operational occurrences such as leaks, loss of power, and component malfunctions that are likely to occur once or more during the life of the facility.

(b) For normal operation, defined in (a) 1) above, the off-site design objective shall be 10 m rem/year.

(c) Accident conditions consist of:
   1) Very low probability events such as "most intense predicted" natural phenomena.
   2) Low probability events such as "most probable" natural phenomena and other component failure events that are not likely to occur during the life of the facility.

(d) For those accident conditions defined by (c) 1) above, the off-site design objective shall be 5 rem, and that for (c) 2) above, 1 rem.

Table II

TRITIUM USE RESTRICTIONS

Site Inventory	50,000	Curies
"In Process" Inventory	25,000	Curies
Neutral Beam Inventory	2,200	Curies
Daily Pulses	96	
Yearly Pulses	1,000	
Tritium Releases (Yearly)	100	Curies

Table III

EVALUATION OF POSTULATED OCCURRENCES LEADING TO THE RELEASE OF TRITIUM FROM TFTR

Occurrence	Releasable Inventory (Ci)	(Form)(c)	Mitigation Method	Maximum Release (Ci)	Exclusion Boundary Dose (mrem)	R.E.C. Class (g)	Limit (mrem)	Design Obj. (mrem)	Prob. Per Year
1. Large air or N_2 leak into one neutral beamline	400	T_2	A	400	0.020	a-2	500	100	10^{-1}
			B	0.4	0.004				
1a. Same as above accompanied by internal arcing	400	HTO	A	400	4.00	a-2	500	100	10^{-1}
			B	0.4	0.004				
2. Loss of cryogenic cooling for all neutral beams	1800	T_2	A	1800	0.090	a-2	500	100	10^{-1}
			D	180	1.8				
			B	1.8	0.018				
3. Large airleak into torus	4000	T_2	A	4000	0.2	a-2	500	100	10^{-1}
			D	400	4.0				
			B	4	0.04				
4. Coil failure near tritium injection port	400	HTO	A	400	4.0	a-2	500	100	10^{-2}
			C	40	0.4				

Table III (Cont'd)

EVALUATION OF POSTULATED OCCURRENCES LEADING TO THE RELEASE OF TRITIUM FROM TFTR

Occurrence	Releasable Inventory		Mitigation Method	Maximum Release	Exclusion Boundary Dose	R.E.C. Class (g)	Limit	Design Obj.	Prob. Per Year
	(Ci)	(Form)(c)		(Ci)	(mrem)		(mrem)	(mrem)	
4a. Same as (4) plus torus perforation	4000	T_2	A	4400	4.2	a-2	500	100	5×10^{-3}
	+400	HTO	D	440	4.4				
			B	404	4.04				
			C	4400	0.60				
			B & C	44	0.44				
5. Loss of contents of one T_2 generator	24000	T_2	A	24000	1.2	a-2	500	100	5×10^{-2}
			D	2400	24.0				
			B	24	0.24				
5a. Same as (5) plus glovebox failure and fire	24000	HTO	A	24000	240	c-2	25000	1000	5×10^{-4}
			B	24	0.24				
6. General vacuum system failure	2000	T_2	A	2000	0.1	a-2	500	100	10^{-1}
			D	200	2.0				
			B	2	0.02				

Table III (Cont'd)

EVALUATION OF POSTULATED OCCURRENCES LEADING TO THE RELEASE OF TRITIUM FROM TFTR

Occurrence	Releasable Inventory		Mitigation Method	Maximum Release	Exclusion Boundary Dose	R.E.C. Class (g)	Limit	Design Obj.	Prob. Per Year
	(Ci)	(Form)(c)		(Ci)	(mrem)		(mrem)	(mrem)	
7. Failure of getter units	20000	T_2	A	20000	1.0	c-2	25000	1000	10^{-5}
			D	2000	20.0				
			B	20	0.2				
7a. Same as (7) plus fire	2000	HTO	A	20000	200	c-2	25000	1000	5×10^{-6}
			D	2000	20.0				
			B	20	0.2				
8. Massive destruction of test cell components with fire	1800	NB	No HVAC	6200	2730	c-1	25000	5000	10^{-6}
	4000	Torus	A	6200	62				
	400	Inlet				If operable			
	6100	HTO	C	620	6.2				
9. Break in vacuum line from NB during regeneration	1800	T_2	A	1800	0.09	c-2	25000	1000	5×10^{-5}
			B	1.8	0.018				

Table III (Cont'd)

EVALUATION OF POSTULATED OCCURRENCES LEADING TO THE RELEASE OF TRITIUM FROM TFTR

Occurrence	Releasable Inventory		Mitigation Method	Maximum Release	Exclusion Boundary Dose	R.E.C.(g) Class	Limit	Design Obj.	Prob. Per Year
	(Ci)	(Form)(c)		(Ci)	(mrem)		(mrem)	(mrem)	
9a. Same as (9) but with fire	1800	HTO	A	1800	18.0	c-2	25000	1000	10^{-5}
			C	180	1.8				
			B	1.8	0.018				
10. Massive break in vac line from NB	1800	T_2	A	1800	0.09	c-2	25000	1000	5×10^{-5}
			C	1800	0.09				
10a. Same as (10) but with fire	1800	HTO	A	1800	18.0	c-2	25000	1000	5×10^{-6}
			C	180	1.8				

NOTES APPLICABLE TO TABLE III

a) Ground level release: 4.4×10^{-4} rem/Ci.

b) Effective elevated release: 1.0×10^{-5} rem/Ci.

c) T_2 gives 1/200th of the dose equivalent of HTO.

d) Site boundary dose equivalents based on effective elevated release except as noted.

e) Mitigation methods:

   A. Ventilate test cell.

   B. Maintain slight negative pressure with torus or vault cleanup systems, 99.9% removal of tritium.

   C. Use HVAC plus condensation, 90% removal in 10 hours.

   D. Use catalytic oxidation plus HVAC condensation, 90% removal.*

   E. Closed system on bellows with exhaust directed to cleanup system.

f) All releases from cleanup systems are assumed to be HTO.

g) Radiation exposure criteria, Table 1.

h) Release dose equivalent rates based on 100% HTO, ground level release 2.4×10^{-6} rem/Ci.

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*This system is for reference purposes only, it will not be incorporated into the TFTR design.

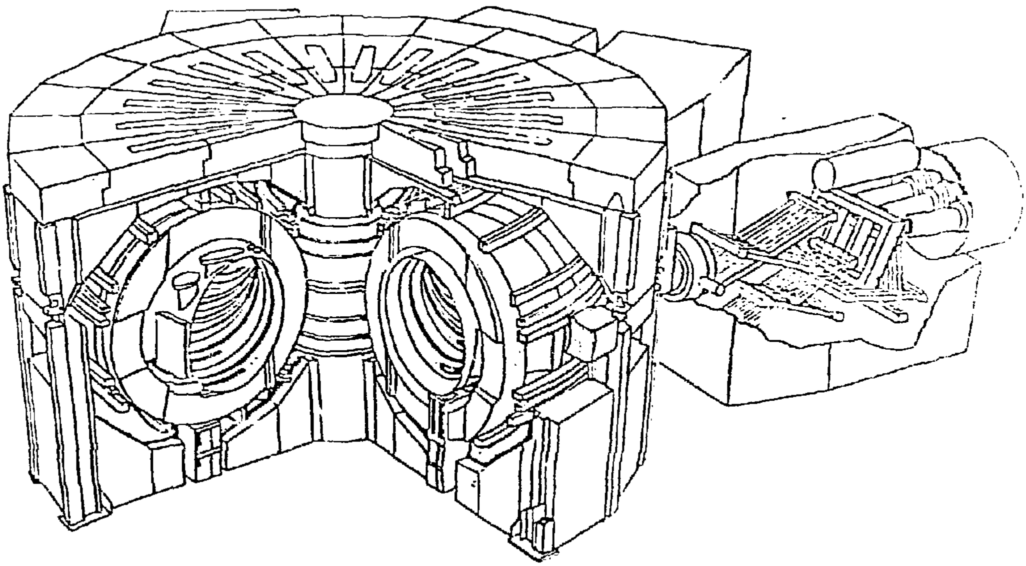


FIGURE 1 TFTR - PERSPECTIVE VIEW

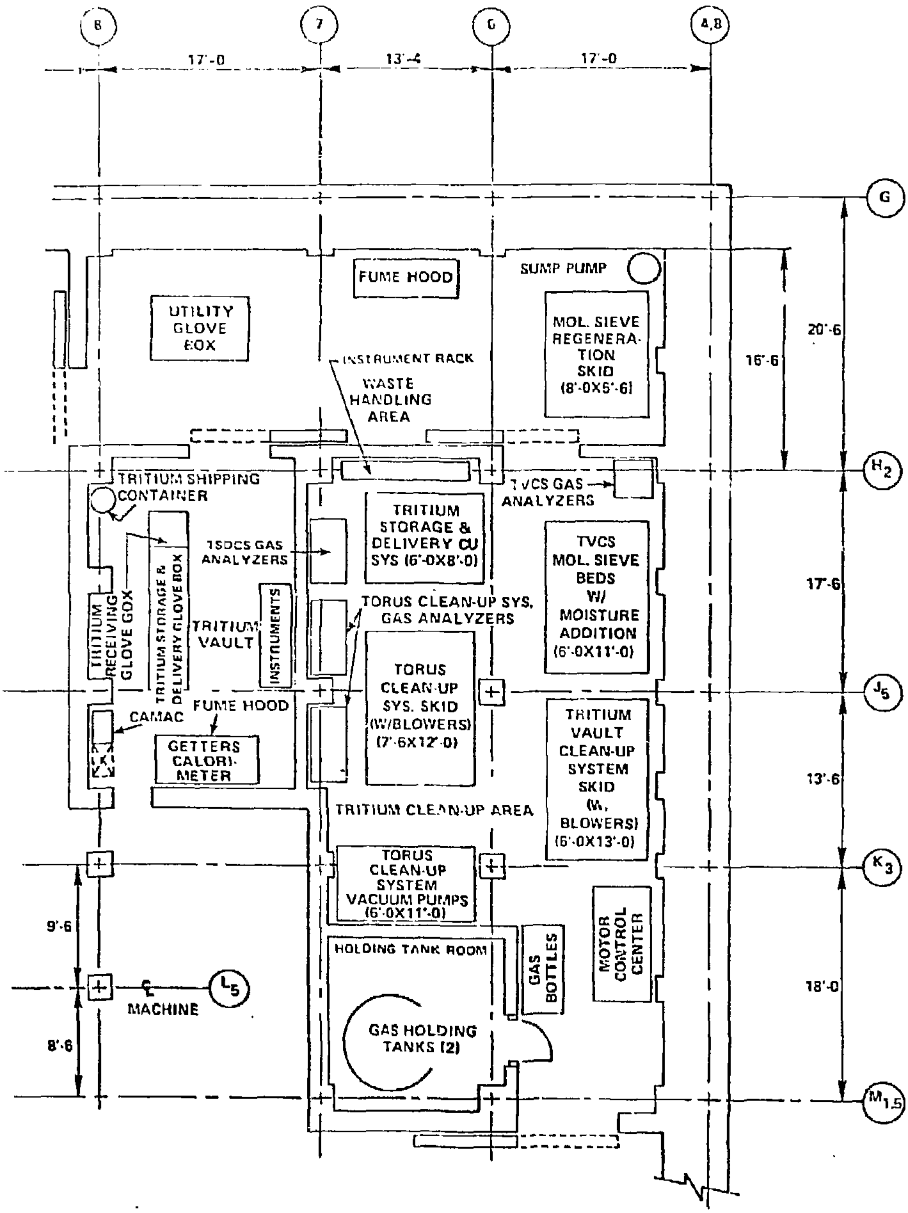
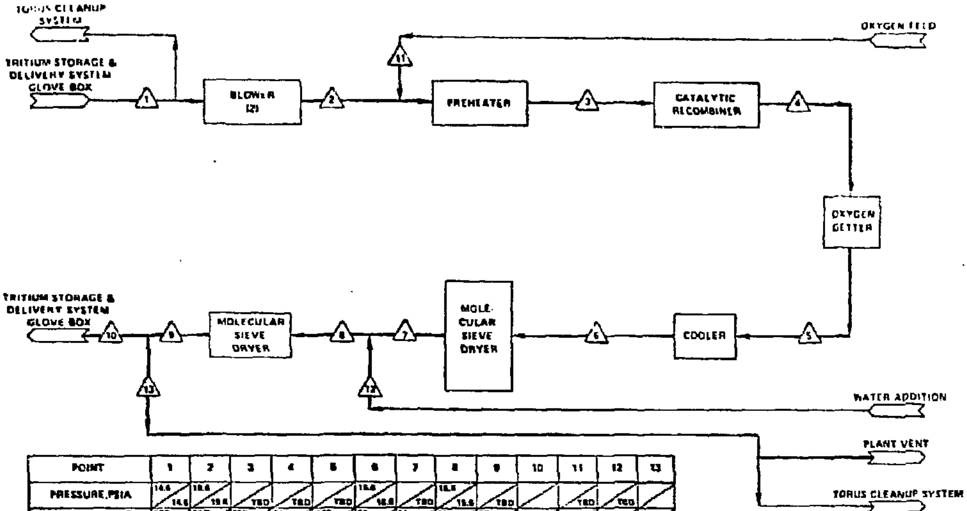


FIGURE 2 TRITIUM SYSTEMS AREA GENERAL ARRANGEMENT



POINT	1	2	3	4	5	6	7	8	9	10	11	12	13
PRESSURE, PSIA	14.6 / 14.6	18.6 / 19.6	/ TBD	/ TBD	/ TBD	18.6 / 18.8	/ TBD	16.5 / 15.6	/ TBD		/ TBD	/ TBD	
TEMPERATURE, °F @ t=0	TBD / 70	TBD / 150	350 / 305	350 / 350	390 / 380	65 / 65	65 / 70	65 / 70	65 / 81		/ 70	/ 70	
VOL. FLOW RATE, SCFM @ t=0	10 / 10	10 / 10	10 / 10	10 / 10	10 / 10	10 / 10	10 / 10	10 / 10	10 / 10		/ .02	/ .02	
COMPOSITION @ TIME t=0: N_2	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0		/ 0	/ 0	
O_2, PPM	0 / 0	0 / 0	10 / 1644	6 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0		/ 1640	/ 0	
H_2O VAPOR PPM	3 / 3	3 / 3	3 / 3	10 / 3280	10 / 3280	10 / 3280	2 / 4.78	2002 / 2005	3 / 9		/ [illegible]	/ 2000	
TOTAL $T_2H_2D_2$, PPM	3 / 3286	3 / 3285	3 / 3280	2 / 3	2 / 3	2 / 3	2 / 3	2 / 3	3 / 3		/ 0	/ 0	
T_2 μCi/CC	23.6 / 8480	23.6 / 8480	23.6 / 8480	8.2 / 8.4	8.2 / 8.4	8.2 / 8.4	8.2 / 8.4	8.2 / 8.4	8.2 / 8.4		/ 0	/ 0	
H_2	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0		/ 0	/ 0	
D_2	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0		/ 0	/ 0	
T_2O μCi/CC	0 / 0	0 / 0	0 / 0	18.3 / 8472	18.3 / 8472	18.3 / 8472	3.86 / 12.3	3.86 / 12.3	[illegible]		/ 0	/ 0	
Ar, %	100 / 99.7	100 / 99.7	100 / 99.7	100 / 99.7	100 / 99.7	100 / 99.7	100 / 100	99.8 / 99.8	100 / 100		/ 0	/ 0	

NOTE:

ENTRIES ABOVE DIAGONAL LINES ON CHART REFER TO NORMAL MODE OPERATING ON TRITIUM GENERATOR ANNULUS. ENTRIES BELOW DIAGONAL REFER TO TSDS GLOVE BOX SPILL OF 24,000 CURIES

FIGURE 3 TRITIUM STORAGE & DELIVERY CLEANUP SYSTEM PROCESS FLOW DIAGRAM

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