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INTRODUCTION

A major objective of the Tritium Systems Test Assembly (TSTA) has been to develop and integrate all the tritium technologies required for on-site DT-fuel processing at fusion reactors. The TSTA has been in operation for nearly four years, processing a tritium inventory that has now grown to over a million Curies (100 grams). Except for the large plasma-chamber cryopumps, which are being installed for operation in late 1988, all technologies originally defined have been demonstrated during extended periods of continuous tritium operation.[1] The subsystems that comprise the operational TSTA process loop are: a 4-column cryogenic distillation system for isotope separation (ISS); a massive uranium tritide bed assemblage (UTB) for off-loop storage; a tritium load-in/load-out station (LIO); two multipurpose tritium gas handling and transfer systems (TP1, TP3); a gaseous impurity injection station for tokamak impurity simulation (IMS); and a complex fuel cleanup system (FCU), based on hot-metal chemistry and cryogenic adsorption. These subsystems and their interconnections are shown in Fig. 1.

This work addresses a second but equally important objective of the TSTA - demonstrating that the large tritium inventories required for fusion reactors can be routinely handled, without radiation exposure to operating personnel and without significant environmental releases. The techniques by which TSTA has achieved low releases and personnel exposures include (1) high-integrity primary piping systems that exclude contact between tritium and organic materials, (2) a secondary containment system that encloses all primary tritium piping in a controlled environment, (3) an efficient, all-purpose tritium waste-treatment plant with 100% availability, and (4) ultrasensitive, real-time diagnostics for anticipating and preventing releases, and for detection and location of tritium leaks in a low-risk mode.

PRIMARY PIPING SYSTEM

TSTA process piping was assembled from commercially available components, but special standards were applied, including: (1) all-metal construction of piping, pumps, and instrument sensors; (2) hermetic, nonlubricated mechanisms for valves and pumps; and (3) exclusion of all elastomers, plastics, liquid metals, and organic or halogenated lubricants. The only exception to the no organics rule is that polyimide stem tips are used in the standard TSTA valves, which are bellows-sealed, and pneumatically operated, by remote controll. A previously described by vacuum system [2] that meets TSTA requirements comprises a two-stage metal-bellows pump in series with a moving-spiral pump. This system has provided leak-free, reliable gas transfer and evacuation functions for virtually every operation conducted at TSTA. All valves, pumps, and transducers can be removed and replaced without cutting or welding because they are installed with zero-clearance coined-gasket fittings. Although a typical TSTA system contains hundreds of fittings, leak integrity is comparable to that of an all welded system; yet serviceability is excellent because faulty components can be readily replaced. Table I lists the types and quantities of typical TSTA piping components, and our experience with failures and leakage in 4 years of tritium operations.

TABLE I
INTEGRITY OF TSTA PRIMARY CONTAINMENT
(45 MONTHS EXPERIENCE)

	TSTA TOTAL	TYPICAL GLOVEBOX
TUBING LENGTH (METERS)	>1000	~150
NUMBER OF BRAZES/WELDS.	>2000	~300
NUMBER OF FITTINGS	>2000	~300
BELLOWS-SEALED VALVES	> 200	~ 30
TRANSDUCERS (PRESSURE, FLOW)	> 100	~ 15
BELLOWS/SCROLL TRANSFER PUMPS	> 9	~ 4
LEAKS AND FAILURES EXPERIENCED:		
BRAZES/WELDS/TUBING	1	
FITTINGS (ORIGINAL-REPAIRED)	20	
FITTINGS (REPEAT LEAKAGE)	0	
BELLOWS PUMPS (4000 HRS)	1	
TRANSDUCERS	10*	
BELLOWS VALVES (SEAT LEAK)	2	
BELLOWS VALVES (BODY LEAK)	1	
INTEGRATED LEAKAGE (ATM ML/S)		2×10^{10}

* COMMON MODE DESIGN FLAW - 10 UNITS

SECONDARY CONTAINMENT

TSTA process piping standards require that each process system be enclosed in a dry nitrogen glovebox. Tritium piping that interconnects process systems runs in vacuum tight conduit, while the atmospheres of interconnected gloveboxes remain isolated from each other (Fig. 2). The gloveboxes and interconnecting conduit are assembled from commercial vacuum hardware components. The gloveboxes normally contain static dry nitrogen, and each box is purged automatically upon detection of high oxygen (2%) or tritium (1 mCi/m^3) concentration.

For a typical glovebox fresh purge gas flows once through to the tritium waste treatment system at a flow rate of only 2 m^3/h. At this small flow rate, all 12 TSTA gloveboxes can be purged simultaneously (in parallel) without exceeding the dynamic capacity of the waste treatment system.

TRITIUM WASTE TREATMENT

The TSTA tritium waste treatment system [3] differs from similar systems at many other installations in that it was designed as a single system to process effluents from all sources-glovebox purging, passbox flushing, service vacuum pump exhausts, as well as the gaseous impurity streams from the TSTA processes themselves (Fig. 3). If conversion efficiency falls off, waste gases are automatically recycled through the catalyst until the tritium concentration is low enough for stacking. The system also has reserve effluent-gas storage capacity, and all critical components have in-line redundancy.

COMPUTER-AIDED LEAK TESTING AND DIAGNOSTICS

All tritium control and containment features discussed previously were incorporated into the design of TSTA from the beginning, though many details have been improved as a result of our early operating experience. One final technique (computer-assisted diagnostics) is a bonus resulting from our adoption of computer control and remote instrumentation. Computer control was chosen for operational rather than safety considerations; nevertheless the high degree of leak tightness evidenced by our primary piping would have been difficult to achieve without this elegant diagnostic capability.

The features of our computer diagnostic system are shown in Figure 4. Every valve position and analog parameter at TSTA is scanned automatically every few seconds and recorded on hard disk every minute; both the real-time and disk-archived data are continuously available from graphic terminals in the control center and many remote locations. The history of any number of TSTA parameters can be extracted from disk files for any previous period using a program called GETARC (Get Archive Data), and then plotted in any combination using another program called PLTARC (Plot Archive Data). This software has been used many times to successfully diagnose malfunctions and to quickly locate failed components.

A similar computer program called TREND allows a user to plot up to six parameters simultaneously in real time during operations. This software capability allows us to track the tritium concentration in a glovebox, for example, along with the pressures in several different sections of piping in the same glovebox. When a positive step function on a specific pressure sensor coincides with a sudden steady increase in glovebox tritium concentration, this pinpoints the leak location to a particular section of piping (Fig. 5). Extremely small leaks can then be precisely located by using a hose connected sniffer probe attached to an external tritium ion chamber (Fig. 6).[4] In new systems which have not yet been exposed to tritium we can apply this leak detection technique while using deuterium "spiked" with about 1% tritium as the test gas. This enables us to locate and repair leaks in a low-risk mode. As integrity of the system improves we can increase the sensitivity of the method by increasing the tritium concentration of the gas. Leaks of any magnitude that develop during tritium operations can be located by this technique without shutting down the operation.

Another example of the use of the TREND software is to monitor tritium content of waste gas discharged from the top of a cryogenic distillation column to the TSTA waste treatment system. This is the standard method for removing helium during normal processing, and the real-time graphic capability is essential to avoid throwing away excessive tritium. The parameters plotted in real time are the total flow rate and the concentration of tritium (as HT) in the discharge stream. The operation can be continued safely as long as the monitored tritium discharge rate (flow rate times tritium concentration) remains low and relatively constant. A TREND plot of this operation is presented as Fig. 7.

Figure 8 illustrates how the TREND program is used to monitor the efficiency of the tritium waste treatment system during operation. The parameters plotted are the tritium concentrations at the waste system input and at the output. The ratio of input to output concentration is the conversion efficiency. If a high concentration of tritium is detected in the waste treatment input tank, steps can be taken to enhance conversion efficiency before any significant portion of the waste gas is processed.

TABLE II
TSTA TRITIUM CONTAINMENT RECORD
(JUNE 1985 MARCH 1988)

INVENTORY (MAXIMUM):	> 1 Million Ci
THROUGHPUT (TOTAL):	>10 Billion Ci
HTC WASTE PROCESSED:	40 Thousand Ci
LOW LEVEL WASTE (PAPER): (< .02 mCi/cu M)	30 Cu Meter
STACK RELEASES:	33 Ci
PERSONNEL EXPOSURE: (Total to 15 People)	150 Person-mREM

RESULTS

The results of our efforts at tritium control and containment, as summarized in Table II, have been gratifying. Because of the integrity of the primary piping, several TSTA gloveboxes have gone through many weeks of tritium operations before requiring a purge for high tritium concentration. Figure 9 is a PLTARC record of the radiation levels in three such gloveboxes during a recent week-long tritium operation. Other glovebox systems have been operated with small tritium leaks which either have not been located, or upon which repair has been deferred pending procurement or fabrication of replacement components. Even for these typically leaky systems, the glovebox tritium concentrations are easily maintained below 20 mCi/m^3 (55 ppb) by a slow purge of 2 m^3/h (Fig. 10).

TSTA's releases to the atmosphere over nearly 4 years of operation have totaled less than 35 Ci (80% as HTO), and the largest monthly release was 3.5 Ci (Fig. 11). Most of this, which is derived from continuous stack bubbler data, represents the unrecovered portion of the approximately 40,000 Ci that has been treated by the TSTA waste treatment system. The remainder has come from untreated releases during low-level maintenance operations, mostly on the nonsecondarily contained waste treatment systems themselves.

Under current Dept. of Energy regulations [5] a member of the general public is allowed to receive 170 mRem/yr radiation exposure from all sources, natural and manmade. Cumulative tritium exposure to the entire TSTA operating staff to date totals less than 180 person-mrem. Thus it has taken 3 1/2 years for the entire staff of 15 persons, working in a facility that now processes over one million Curies of tritium, to accumulate the annual exposure allowed to a single member of the general public. This amply demonstrates the level of radiation safety that is possible in a well-designed tritium facility.

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[2] D. O. Coffin, J. Vac. Sci. Technol. A, 20, 1126 (1982)

[3] R. V. Carlson, S. P. Cole, and F. A. Damiano, Fusion Technology, 8, 2184 (1985)

[4] J. L. Anderson, D. O. Coffin, J. E. Nasise, R. H. Sherman, and R. A. Jalbert, Fusion Technology, 8, 2413 (1985)

[5] U. S. Dept. of Energy Order 5480.1, XI, "Requirements for Radiation Protection" (1981)

PRELIMINARY FIGURES

Fig. 1. Operational process systems of the Tritium Systems Test Assembly (TSTA)

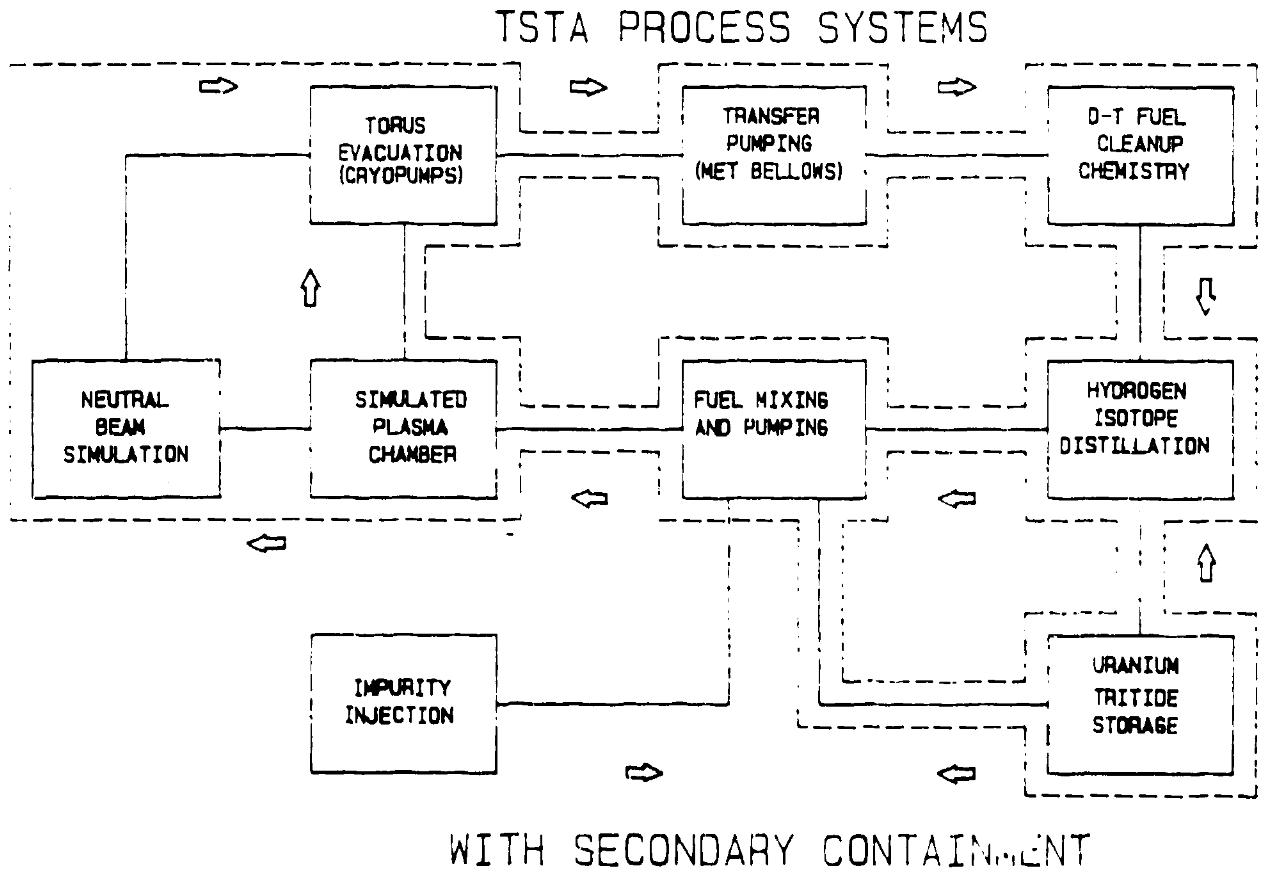

Fig. 2. Purging and isolation configuration for a typical TSTA glovebox.

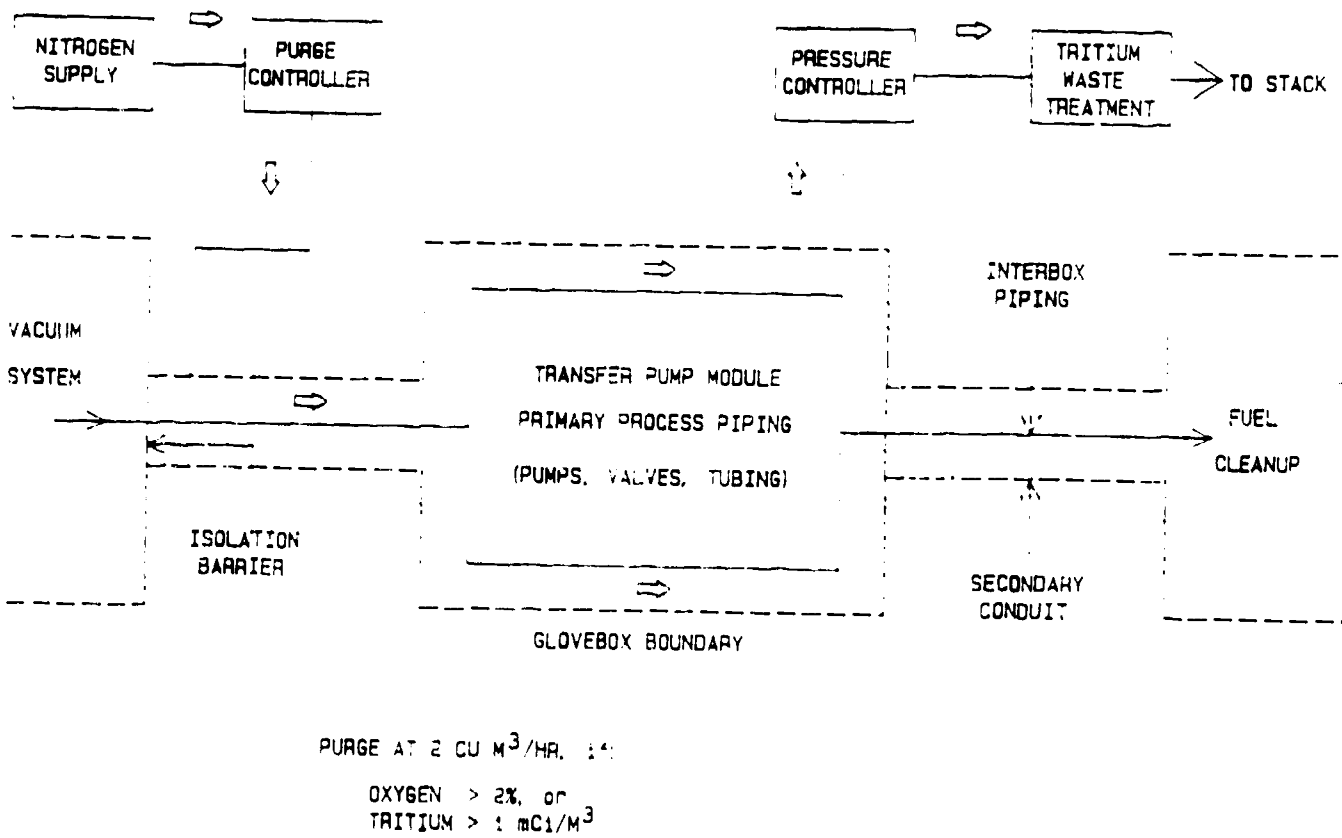

Fig. 3. Sources and flow paths of the
TSTA tritium waste treatment system.

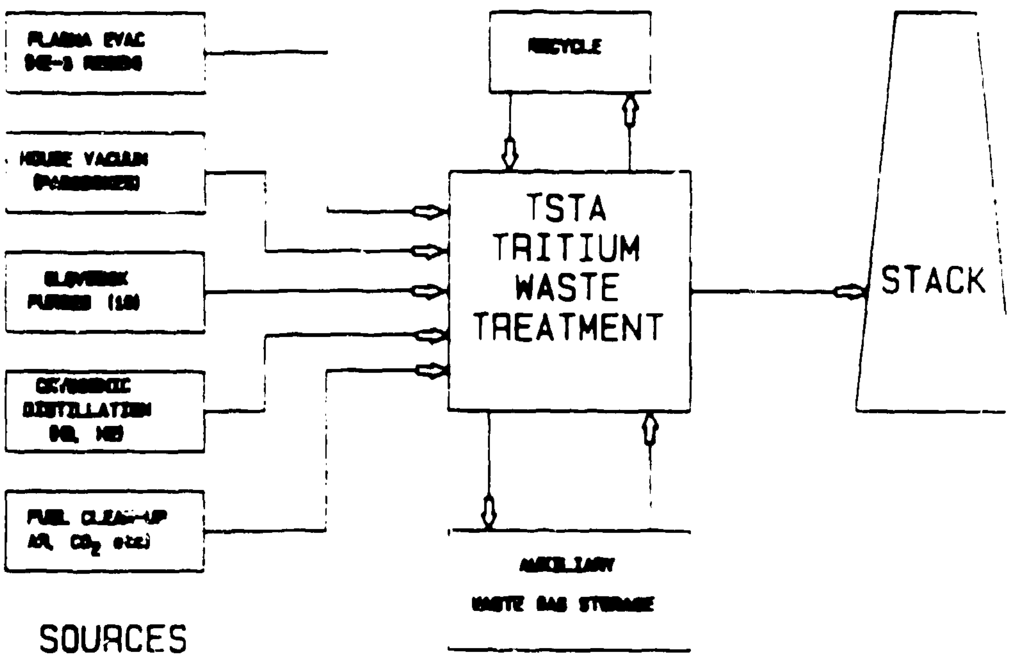

Fig. 4. Diagnostic features of the TSTA computer system.

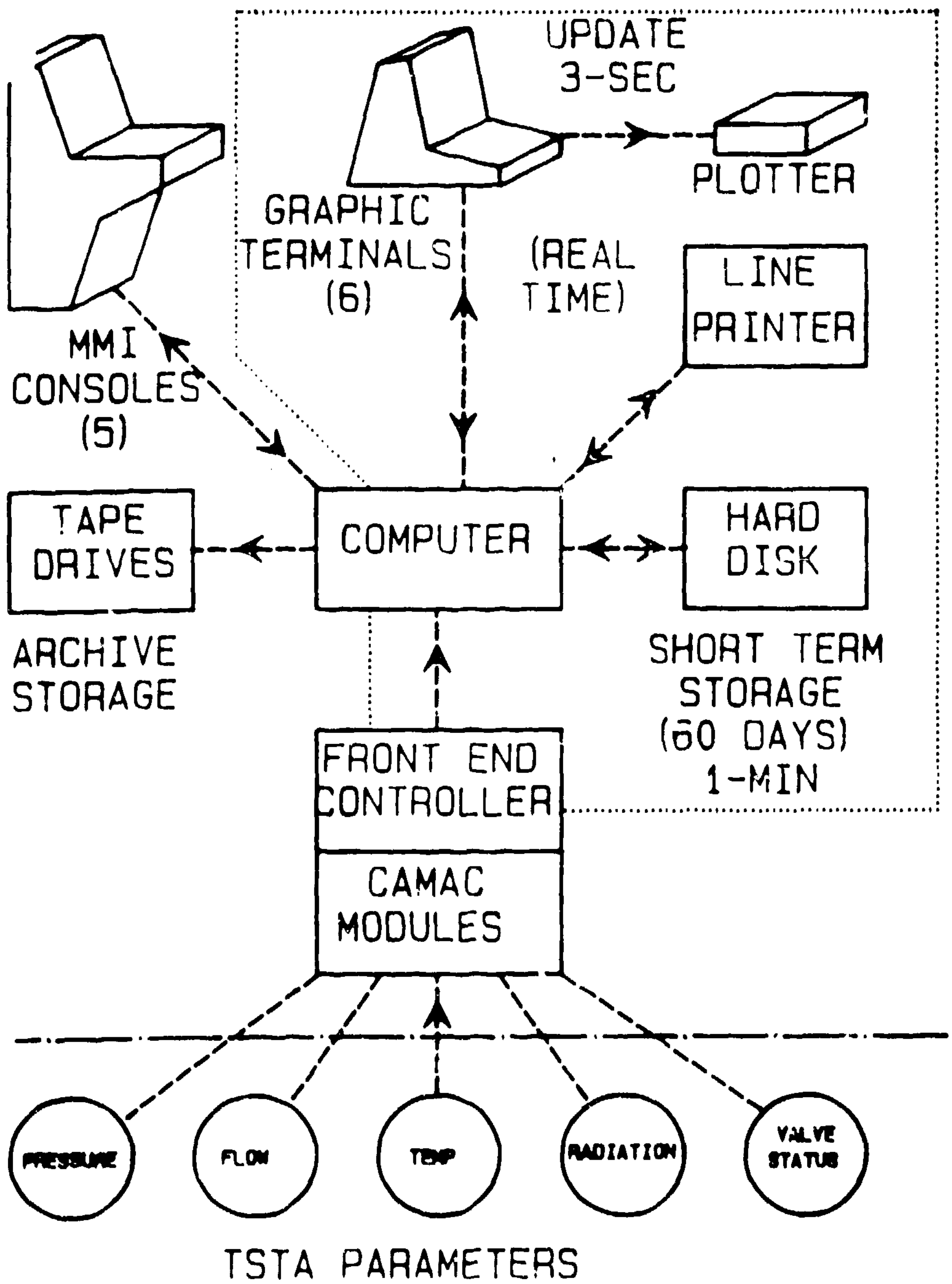

Fig. 5. Using the computer TREND program to correlate a tritium leak with a specific pressure sensor.

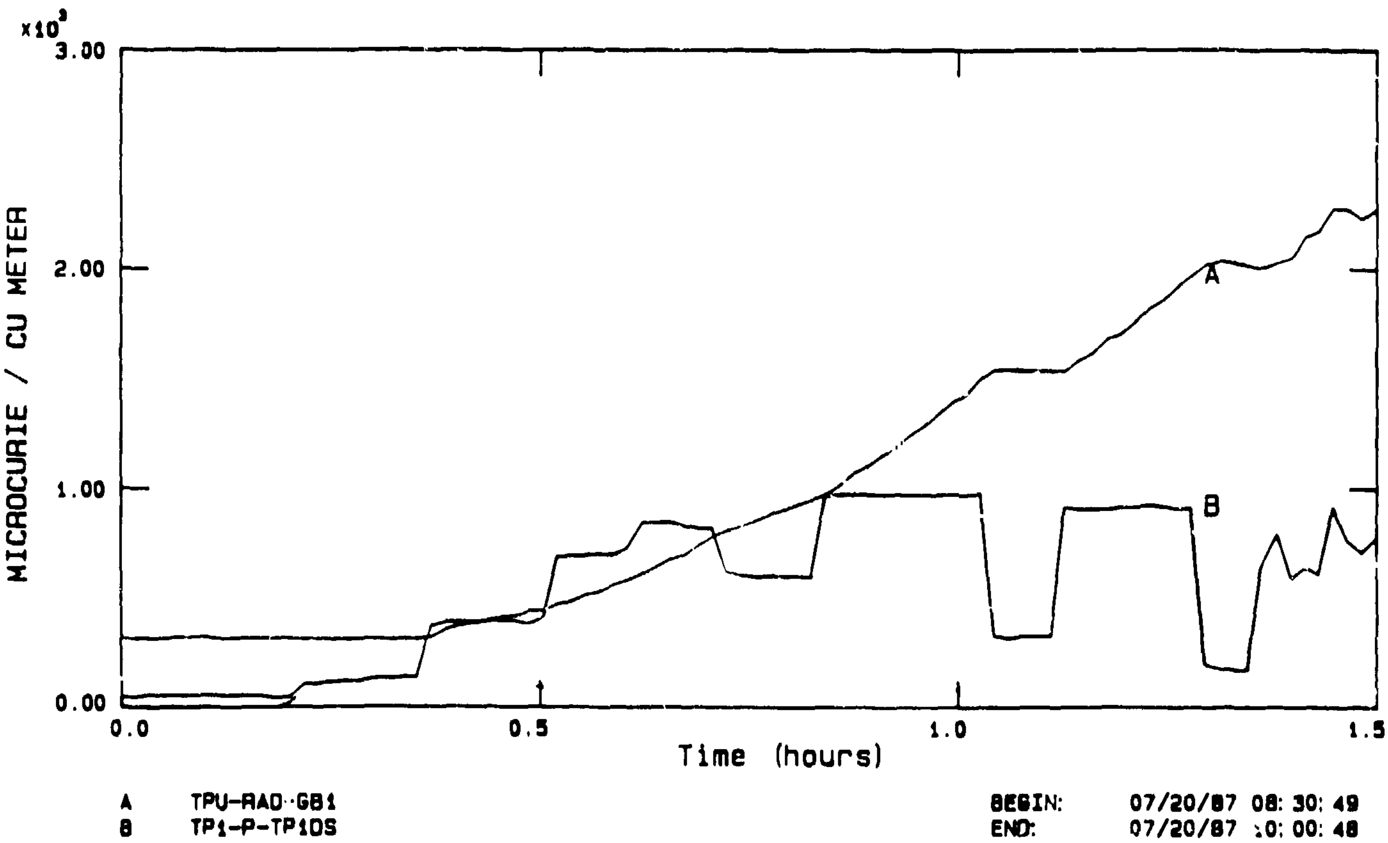

Fig. 6. Leak testing in a glovebox, using an external tritium detector and pump.

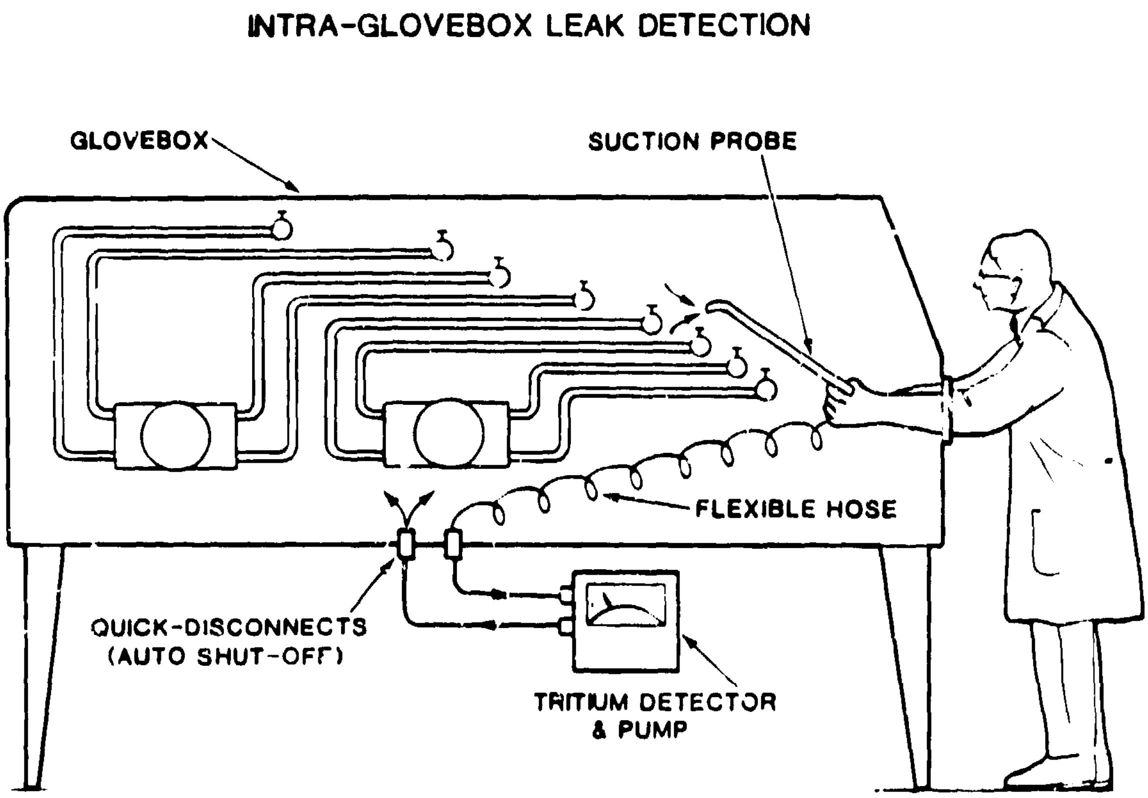

Fig. 7. Using the TREND program to monitor tritium in a gaseous waste discharge stream.

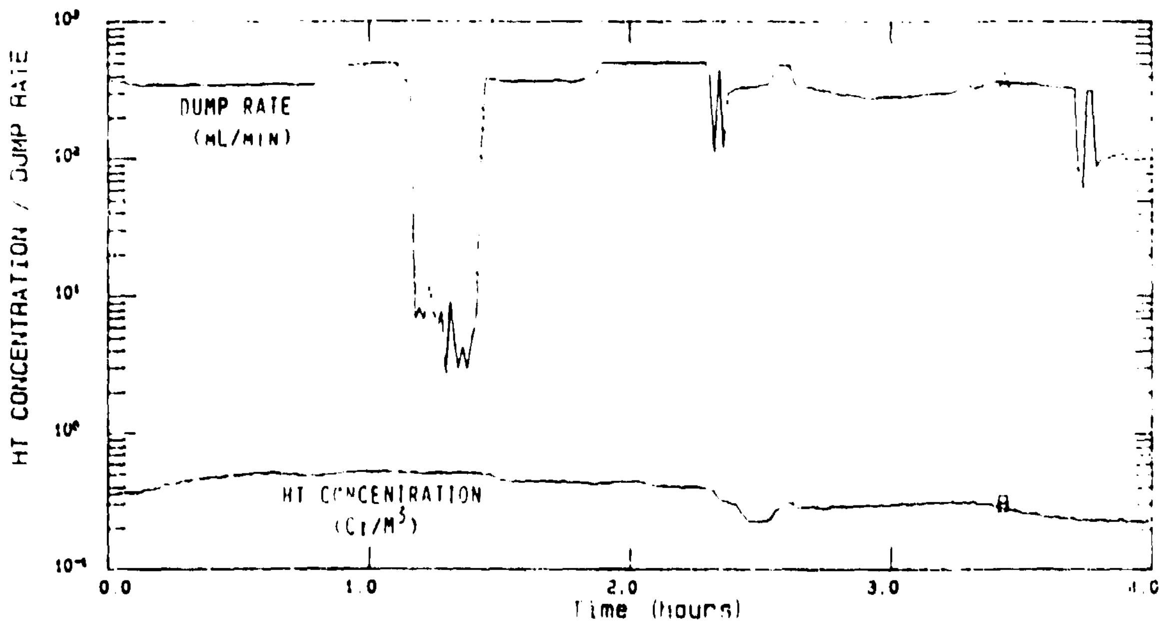

Fig. 8. Monotoring efficiency of the waste treatment process with the TREND program.

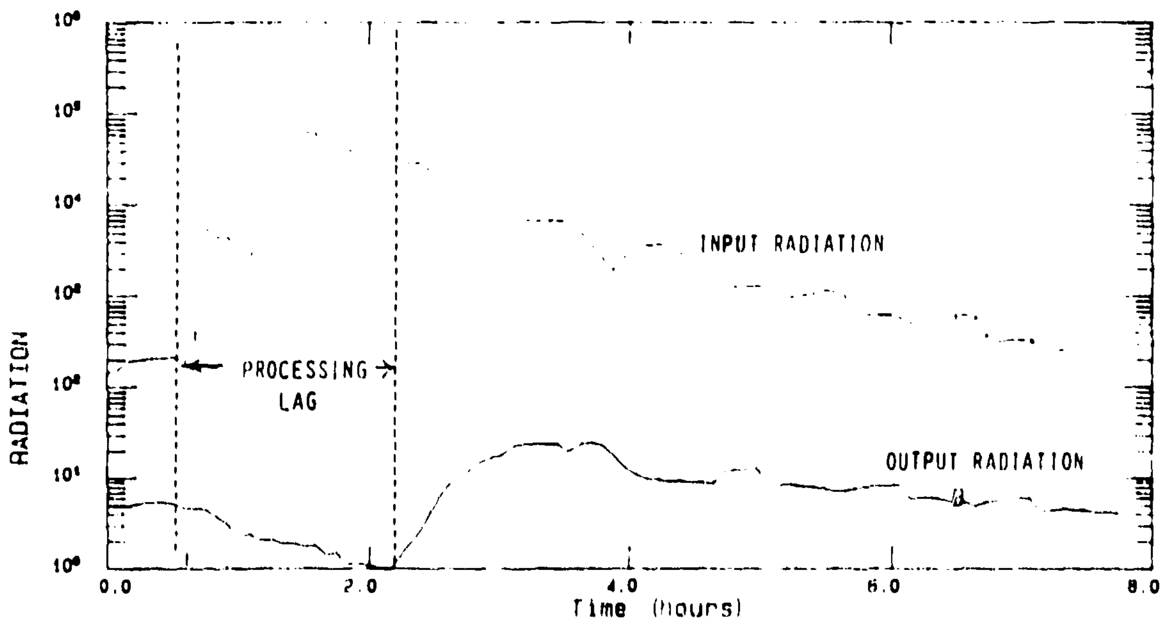

Fig. 9. Tritium radiation levels in three nonpurged gloveboxes during a week of typical tritium operations (no identifiable leaks).

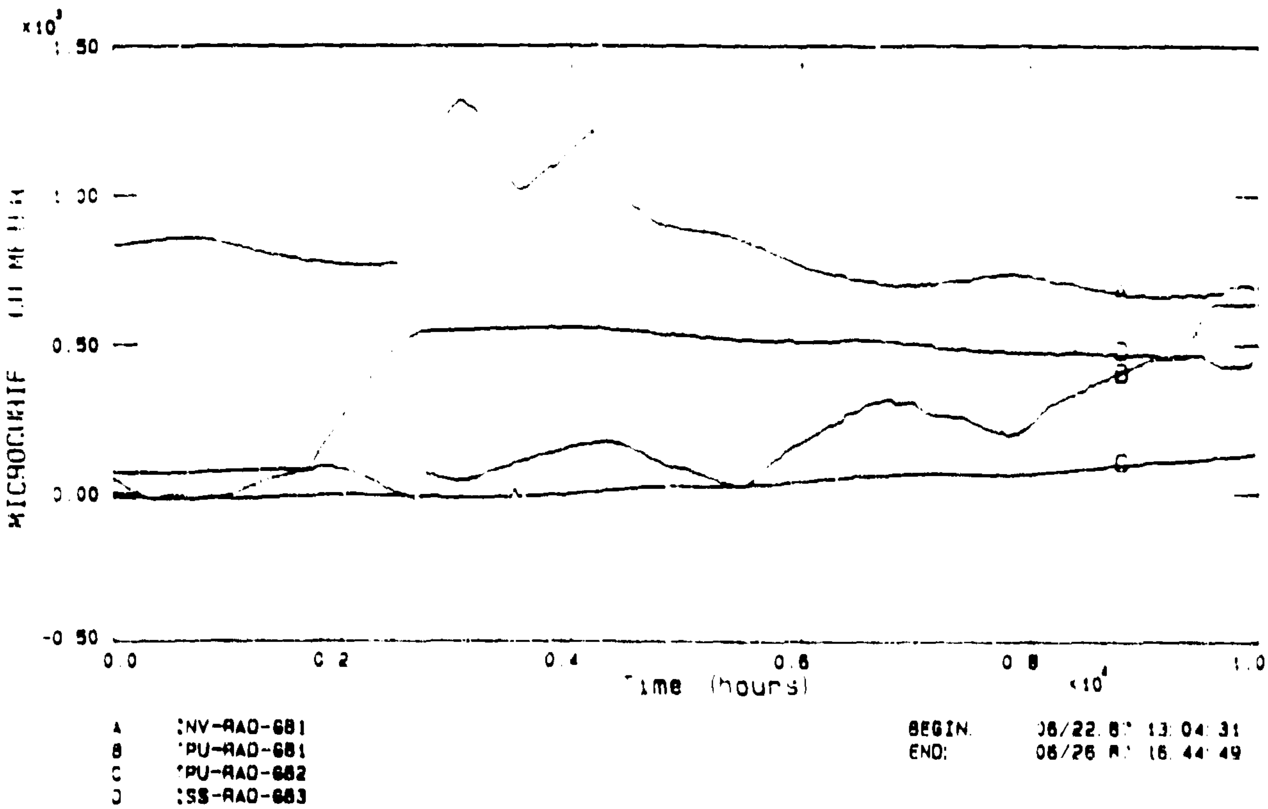

Fig. 10. Tritium radiation levels in three purged gloveboxes during a week of typical tritium operations with small leaks present.

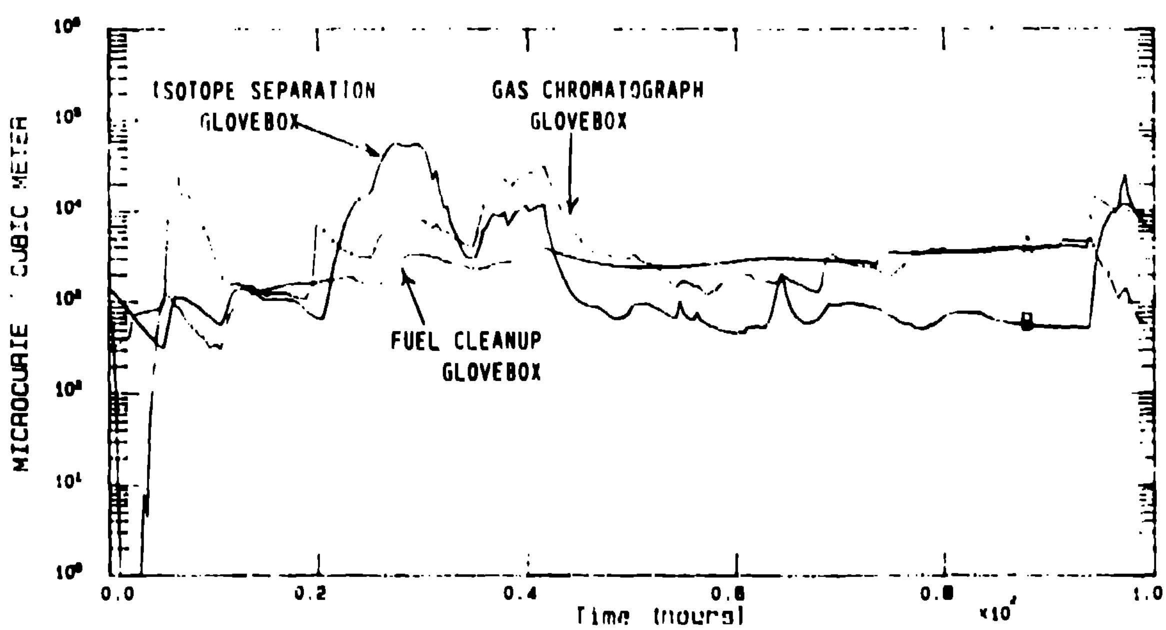

Fig. 11. Tritium stack emissions from TSTA:
June 1985 through March 1988.