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**EXPERIMENTAL TRITIUM CLEANUP SYSTEM
AVAILABILITY ANALYSIS FROM 1984 TO 1992**

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ABSTRACT

This report gives the availability percentage of the Experimental Tritium Cleanup System (ETC) at the Tritium Systems Test Assembly (TSTA), which is a fusion research and technology facility at the Los Alamos National Laboratory. The component failure reports, the numbers of components, and operating times or demands are all given in this report. Sample calculations of the failure rates obtained from these data are given in the appendices. While future fusion experiments might use different or more advanced means to detritiate room air, the analysis of this system gives a data point for an actual detritiation system. Such a data point can be extrapolated for comparison with fault tree results on system designs, or can be used in a Bayesian failure rate analysis for estimating reliability of a new type of system. The nine years of testing operations on TSTA's ETC result in a reasonable average availability value of 92% for the maximal tritium release event. The failure rates for new systems are expected to be lower than for the TSTA ETC, since improvements will be made in the design of the room air detritiation system based on the TSTA system experiences. Nonetheless, these TSTA data should be useful for future fusion reactor design work and safety assessment tasks.

SUMMARY

This report summarizes the operating experiences and evaluates the availability of the Experimental Tritium Cleanup System (ETC) at the Tritium Systems Test Assembly (TSTA). This system has never been needed at TSTA for room air detritiation, but it has been tested for system operability tests, maintenance tests, and safety assurance periodic checks. The data obtained for this system may not be strictly applicable to future systems, because a different means of detritiating air might be used. Nonetheless, this data point can be useful because it is a definite indicator for an existing, standby fusion system, and can be used for Bayesian estimation of future system reliability.

ETC operating experiences for system operability testing and for more than eight years of standby operations have been examined. Operating times and failure reports were analyzed to evaluate availability and provide failure rates for the main components (compressors and exhaust pressure valve) in the ETC system. These failure rates were then used to determine the ETC system average availability.

The results of this data analysis do not compare very favorably to published information. The failure rates calculated for the large and small ETC compressors, which are the primary components for the entire system, are larger than compressor failure rates given in the literature for industrial and nuclear fission power applications. The difference is most likely because of the limited number of hours that the ETC system has operated (less than 500 hours). Since the ETC has never been called upon, only two hours of testing each month accumulate as ETC operating time. Even with high failure rates obtained from limited ETC operations, scoping calculations show that the average ETC availability is 92% for the maximum tritium release event (electric power availability was not included, but it is a very small contributor). As more operating time from testing is gained, the component failure rates should decrease and the system availability should correspondingly increase. It is also noted that the compressors for the ETC are used in modes of operation different than what the manufacturer intended. The compressors were meant for continuous operation. At TSTA, the ETC compressors are not run constantly, and are

only started when needed. Many of the compressor failures that occurred were a result of repeated starting attempts, as seen in the appendices.

While the data presented in this report are not steady-state values, they are still useful to illustrate the reliability growth of a standby system. The ETC component failure rates in system operability testing (also called 'burn-in') were factors of 8 to more than 20 times larger than failure rates from ETC useful life. Comparing ETC component failure rates to generic failure rates for operating components, it can be seen that standby systems typically do not generate failure rate data comparable to components that run continuously. Still, standby system data are important to fusion, because standby systems such as air detritiation will be required at large facilities.

Operational difficulties that were encountered with the ETC and their resolutions are also discussed in this report. These operational insights should be interesting to tritium facility operators and fusion designers. The ETC system logbook discusses problems with equipment below design specifications (such as an electric motor that would not cool adequately at high altitudes), equipment with features that were outside TSTA design specifications (for example, compressor manifold with barium sulfate paint), installation errors (valves installed backwards), and construction cleanliness (dirt, metal shavings in the instrument air lines). Other problems later in the ETC lifetime included correcting control computer software and educating all appropriate personnel on proper equipment use.

TSTA can process up to 130 grams of tritium a day, and can operate for extended periods of up to several weeks per processing run. Therefore, the operating experiences in this report are generally applicable to next generation fusion facilities because TSTA uses state-of-the-art technology and equipment for tritium handling. TSTA is large enough to serve as a prototype tritium storage, processing, and handling facility for supporting a large fusion experiment, such as the International Thermo-nuclear Experimental Reactor (ITER), or the Tokamak Physics Experiment (TPX).

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NOMENCLATURE

acfm	actual cubic feet per minute
cfm	cubic feet per minute
C	degrees Celsius
cc	cubic centimeters
CREDO	Centralized Reliability Data Organization
d	demand to operate
ETC	Experimental Tritium Cleanup System
ex	exhaust, also exh
FAWG	Fusion Availability Working Group
FSP	Fusion Safety Program
FTO	Failure to operate
FTR	Failure to run
FTS	Failure to start on demand
h	hour of operation
hp	horsepower
IAEA	International Atomic Energy Agency
IBM	International Business Machines
ITER	International Thermonuclear Experimental Reactor
K	degrees Kelvin
kPa	kiloPascals
LANL	Los Alamos National Laboratory
m	meters
m ³	cubic meters
mm	millimeters
MMI	Man-machine interface (the master computer displays)
MPa	megaPascals
Pa	Pascals
PC	Personal computer
PM	Preventive maintenance
ppm	parts per million
QA	Quality Assurance
rpm	revolutions per minute
TPX	Tokamak Physics Experiment
TSTA	Tritium Systems Test Assembly
TWT	Tritium Waste Treatment System (glovebox gas detritiation system)
s	second
sys	system
USDOE	United States Department of Energy
yr	year

EXPERIMENTAL TRITIUM CLEANUP SYSTEM
AVAILABILITY ANALYSIS FROM 1984 TO 1992

1. INTRODUCTION

This report is a summary of data collected at the Tritium Systems Test Assembly (TSTA), at Los Alamos National Laboratory (LANL), between 1984 and 1992 that pertain to the Experimental Tritium Cleanup System (ETC). Initial system operability tests in the 1982-1983 time frame are also included here. These failure data analysis tasks are performed to support fusion design studies and device construction, such as for the International Thermonuclear Experimental Reactor (ITER). These analysis tasks are ongoing at TSTA and at the Idaho National Engineering Laboratory's Fusion Safety Program (FSP).

The ETC is a demonstration system for room air detritiation. The data presented in this report are applicable to fusion systems that use the same or similar air detritiation systems. This report describes the operating experiences of the two compressor ETC over an 8-yr period at TSTA. This work can apply to the ITER design and possibly the proposed Tokamak Physics Experiment (TPX) design. Even though new designs might not use the same type of equipment for an ETC, the data set given here can form a point for comparison or can be used in a Bayesian analysis.

The ETC serves the tritium handling areas of TSTA. The ETC is housed in the main floor area of the TSTA building. Some ETC piping ducts run outside the building, so the ductwork must be kept leak tight. Although the ETC is a standby safety system and has a short operating time, it was chosen for analysis because it is important to safety work for future reactor design studies and regulatory compliance documents.

The following chapters briefly describe the TSTA failure data base, describe the ETC system components, give the availability analysis results, and compare the results to other known reliability information.

2. TSTA FAILURE/MAINTENANCE DATA BASE

The failure/maintenance data system at TSTA^{1,2} is based on the Centralized Reliability Data Organization (CREDO),^{3,4} a system developed at Oak Ridge National Laboratory for fast reactor failure data. CREDO's development as a national reliability data base and data analysis center for advanced fission reactors was initiated in 1978 and has been funded by the U.S. Department of Energy (USDOE). CREDO was selected as the basis for a failure/maintenance data system for fusion after consideration by the informal U. S. Fusion Availability Working Group (FAWG). CREDO is a component-oriented data base that was implemented at TSTA using a personal computer (in this case, an IBM PC). The original objectives of the CREDO project at TSTA included:

- Adapting CREDO for use in fusion availability/reliability programs
- Programming the data base on the IBM PC with Knowledgeman software
- Collecting the appropriate data on systems at TSTA
- Testing the adapted data base with these data

Minor changes in the original CREDO data collection forms were made to make them more applicable for fusion systems.

The IBM PC was programmed using logical tables to contain the data.^{4,5} Three types of data are entered into the data base. These are: engineering data, event data, and component operating data. Engineering data contain descriptions of each system component as fully as possible by involving a one-time submission of data, such as component type, model number, and operating parameters. The engineering data file uses a unique identifying number to track the component through its lifetime. The event data portion of the data base describes each reportable event or failure in any TSTA system, and uses a unique event report number for each event. Reportable events include component failures, events that lead to unscheduled repair or maintenance, and unanticipated changes in normal operating conditions due to a component

failure. A quarterly report that gives the operating time for the entire facility forms the operating data portion of the data base. Component operating time estimates are obtained from these overall facility operating time values.

After the engineering data are collected on the major components in a system, event data reports become the focus of the effort for collection of failure/maintenance data. At TSTA, two-part event data forms are strategically placed in holders throughout the facility, so that when a reportable event occurs, the forms are easily accessible by the operator involved in the event. The system operator or system designer fills out Part I of the form (example forms are given in Appendix D) whenever a component of a TSTA system fails or needs major adjustment. When the initial report is completed to the extent possible, it is put back in a holder. The Quality Assurance (QA) specialist inspects the holders periodically and retrieves any completed forms. Part II of the form details the corrective action taken to resolve the problem. The QA specialist routes the completed Part I forms to appropriate personnel. The corrective actions are documented by either the operator, the technician repairing the component, or the system designer during or immediately after the repair/replacement of the failed component. Then, the QA specialist picks up Part II of the form and enters this new information into the data base and assign a sequential report number. If the information is complete, the report is termed "closed". If it is incomplete, the report is termed "open" and it is returned to the appropriate personnel for completion.²

Currently, the TSTA failure/maintenance data base contains more than 540 reports. These failure reports originate from all of the TSTA systems. There is a small time lag, usually a few days (although sometimes longer), between completing Parts I and II of the form. There is also a small time lag, perhaps a week or more, between completion of Part II and entry into the data base. Small time lags such as these are not uncommon. Such time lags are found in all major installations, including nuclear power plants and chemical process plants, and can be months in duration.

3. EXPERIMENTAL TRITIUM CLEANUP SYSTEM DESCRIPTION

The TSTA facility is described in reference 6. TSTA construction was completed in 1983, and pretritium introduction testing was performed in 1983 and early 1984. The facility performed its first tritium run (commissioning) on June 25, 1984. The main compressor for the ETC system, the heart (or prime mover) of the system, was tested extensively in 1983. With the logbook citations, we know the operating demands, successes and failures, and have an estimate of the system operating time. The ETC system description that follows here is taken from references 7, 8, and 9.

The ETC tritium removal from air is based on the catalytic conversion of elemental tritium (HT or T_2) to the oxide form (T_2O or HTO). The tritium oxide is removed from the air by drying with molecular sieve beds. The primary ETC components are:

- Compressors, that draw contaminated air from the TSTA building into the system, compress the air to 0.34 MPa (50 psia) and simultaneously heat the air by adiabatic compression to 150 C, which takes between 30 minutes to an hour, depending on which compressor is used,
- Catalyst bed, to convert molecular hydrogen isotopes to oxide form,
- Cooler, to cool the air down to 38 C after exiting the catalyst bed,
- Refrigerated dryer, which removes water from the air stream by condensation,
- Storage tanks, to store the tritium contaminated water, and
- Molecular sieve beds, that remove most of the remaining moisture from the air before it is sent to the stack or recycled.

These components are discussed in more detail below, based on information given in references 8 and 9.

The ETC has been designed to have a tritium decontamination factor of $1\text{E}+06$. That is, if $1\text{E}+06$ Curies tritium (100 grams) were released into the TSTA building, proper system operation would ensure that less than 1 Curie would exit the facility stack. Early tests showed that a decontamination factor of $1\text{E}+04$ had been easily reached, and system modifications have since proved to make the system more efficient. To

clean up a 100 gram tritium release, the ETC would run for about 20 hours using the large compressor, or 50 hours with the small compressor. The compressors do not run simultaneously; the smaller compressor is a backup for the larger unit.

Figure 1 gives a schematic diagram of the ETC system. Fortunately, the ETC has never had to be called upon to mitigate an actual tritium release into the 3,000 m³ TSTA building. However, there have been numerous tests of the system to insure its readiness in case an actual operational demand were to occur. This information, taken from the ETC logbook, is outlined in Appendix C.

Figure 1. ETC flow schematic diagram. (taken from reference 8)

Compressors. There are two compressors that move room air through the ETC system. The large compressor moves $0.66 \text{ m}^3/\text{s}$ (1400 actual cfm). This compressor (designated as compressor 1) is a reciprocating unit, with a single stage and two opposing cylinders having double acting pistons. The pistons are driven by a set of two 4-notch v-belts that turn the compressor pulleys at 500 rpm. The compressor belts are driven by a 480 Volt alternating current electric motor, fed from commercial power. There are two gas tight distance pieces between the cylinders and the crankcase to eliminate contact between the process air and the crankcase lubricating oil. The compressor has Teflon honed cylinder liners and Teflon piston and rider rings. An aftercooler was not installed, so that exit air, heated by adiabatic compression, would heat the catalyst bed (although it can take up to 60 minutes for the hot air to heat the bed up to optimal temperatures). This compressor is leak tight to allow for the cleanup of the experimental contamination studies laboratory room without contamination of the main room of the TSTA building. The compressor unit is located in a pit sunken from the main floor of the TSTA building. 3.8 m^3 of concrete was added to strengthen the pit floor for the compressor, and the floor is isolated to prevent vibrations from the unit being transmitted to the main floor. Cooling water is supplied to this compressor.

The second compressor is a rotary screw unit, designed to be oil-free. This smaller compressor, designated as compressor 2, moves only $0.28 \text{ m}^3/\text{s}$ (600 cfm), roughly 2.5 times smaller than compressor 1. A 75 kilowatt (100 hp) induction motor drives this unit. Cooling water is also supplied to this compressor unit. The compressor is not gas tight in its rotary compression stage, therefore some gas leakage would likely occur during operation. Exhaust gases from this compressor would take up to 30 minutes to heat the catalyst bed to optimal temperatures. Compressor 2 is located on the main floor of the TSTA building, near the pit for compressor 1. Compressor 2 is designed to be a backup to compressor 1, because compressor 2 is not leaktight.

Both compressors are protected by relief valves in case of over-pressure. The relief valves are followed by rupture disks. Rupture disk exhaust is connected to the facility vent stack. The piping between the

valves and disks is connected to the suction side of the compressors, so that a slow leak past the relief valve will be returned to the system.

Catalyst bed. The catalyst bed contains about 0.23 m^3 of ceramic pellets coated with precious metal (palladium/platinum) to oxidize the tritium in the air stream. It is critical that the conversion efficiency be high (the bed kept hot), because any tritium not oxidized will not be collected and will be sent to the TSTA stack. The catalyst bed is designed to reduce the hydrogen isotope concentration to 1 part per billion (1 ppb) when operated at $0.5 \text{ m}^3/\text{s}$ (1066 cfm), 450 K, and 0.35 MPa. The catalyst bed is housed in a stainless steel vessel, with the minimal number of ports required for manual catalyst changeout. The stainless steel chamber can withstand pressures up to 0.7 MPa and temperatures up to 755 K.

When tritium reacts from the air stream moving through the catalyst, tritiated water will remain on the catalyst surface, coating the surface so that the efficiency of the catalyst to convert elemental tritium to tritiated water will be reduced. Heating the catalyst drives off the tritiated water molecules, so that more efficient conversion can take place. The catalyst bed has a hydrogen gas injection system to add room temperature (20 C) hydrogen to the bed. The addition of hydrogen increases the surface temperature of the catalyst, thus increasing the efficiency. Since the catalyst bed must be efficient in tritium conversion, any poisoning of the catalyst is an important safety concern. The catalyst bed temperature is closely monitored to diagnose possible contamination.

Cooler. The air cooler cools hot exhaust air from the catalyst bed. The cooler is a shell-and-tube heat exchanger, with air on the tube side and water on the shell side. The design flow rate for air is $0.5 \text{ m}^3/\text{s}$ (1066 cfm) at 0.31 MPa. The air temperature across the cooler is from 460 K to 294 K. The heat exchanger shell is made of carbon steel, and the tubes and tubesheet are stainless steel. The air cooler and its piping are insulated.

Refrigerated dryer. The dryer functions to remove as much water and water vapor from the air stream as possible, so that the downstream

molecular sieve beds are not heavily loaded with water. The compressed air dryer uses freon refrigerant with a centrifugal moisture separator. The freon condenser is water cooled. The dryer handles $0.5 \text{ m}^3/\text{s}$ (1066 standard cfm) air flow at 310 K and 0.31 MPa. The typical water loading is 6570 ppm, but the dryer can handle up to 31,000 ppm. Exhaust air is used to pre-chill incoming air, to help reduce the load on the refrigerator. The dryer uses gravity to drain tritiated water to the storage tanks.

Storage tanks. Tritiated water from the refrigerated dryer is held in three stainless steel storage tanks. Two tanks are 57 liter size, and the third is 757 liters. If the smaller tanks overflow, the liquid will flow into the larger tank. The tank sizes are meant to help segregate the water by tritium concentration. The smaller tanks are used in the first six hours of ETC operation, when 99% of the tritium release is expected to be recaptured. Based on system testing experience, a rule of thumb is that the tritium concentration in the TSTA building would reduce by a factor of 10 for every three hours of ETC operation. Therefore, in the first six hours, 99% of the tritium would be collected. The storage tanks can withstand pressures up to 0.79 MPa. Water in the tanks can be unloaded to molecular sieve beds for disposal. If a large release occurred, and the tritium levels in the water are high, a determination will be made whether it is economically feasible to recover the tritium. If the tritium is recovered, it will be done on site or the water can be packaged and sent to another USDOE site for recovery.

Molecular sieve beds. These beds provide the final step in drying the air stream before the air is recirculated to the TSTA building. The tritiated water vapor will be adsorbed on these beds. The air is passed through either one or two of the four beds. Of the four beds, two are used for experiments, and two are held in readiness for emergency use (to clean up the air in the TSTA building). All of the bed chambers (large tanks) and piping are made of stainless steel. Each bed holds 1.1 m^3 of type 4A molecular sieve, and the beds are sized to accept 2,000 ppm water load in the incoming air stream, reduce that water load to 1 ppm in the outgoing air stream, and to not saturate for up to 24 hours of continuous usage.

One of the beds can be regenerated by heating. This design provision was installed to demonstrate that a large bed can be regenerated by heating. An air heater is included in the ETC system to heat an air stream up to 755 K. The air heater is a 100 kilowatt air circulation heater, operating on 480 Volt electrical power. It is made of stainless steel, and delivers 0.4 m³/s (850 standard cfm) of air. The hot air flows counter to normal system flow, and the refrigerated dryer condenses any liberated tritiated water from the beds. If the molecular sieve needs to be replaced, there are gloveboxes under each of the beds to allow gravity flow into waste drums. Fresh molecular sieve would be loaded into the beds from the mezzanine, thus allowing replacement without undue contamination spread.

The molecular sieve would of course be regenerated before there was any thought of disposal. In the event of a large tritium release inside the TSTA building, most of the tritium would be captured in the water storage tanks, but substantial amounts would also be adsorbed in these molecular sieve beds. If that was the case, then there would be a decision about regeneration and then molecular sieve replacement, similar to the decision described earlier for the storage tanks.

Valves. The ETC valves and piping are typically made of stainless steel. There are air operated valves and manual isolation valves. The air operated butterfly valves are controlled from the TSTA control room and take air pressure from the TSTA compressed air lines at 0.79 MPa. Most of the valves are not redundant. The valves and piping are helium leak tight because they have to contain 0.34 MPa system pressure so that the ETC can maintain its efficiency. The high temperature valves are metal sealed, and other valves have teflon seats. The air ducts are made of galvanized steel. System pressure in cleanup and regeneration modes is controlled by pressure regulating valves and local controllers with remotely controlled set points. Valve EXHV1, which is an important compressor exhaust pressure regulating valve, is a large air operated needle valve.

4. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE DATA AND AVAILABILITY ANALYSIS

This system is unlike others examined at TSTA (references 10, 11, and 12). The ETC has only been operated during system checkout and operability tests, and during periodic system testing. Even then, the system is only partially exercised, because it is imprudent and not cost effective to allow the molecular sieve beds to adsorb simple water from atmospheric humidity, rather than tritiated water. Other safety-related systems at TSTA are operated continuously (such as the tritium monitoring and gaseous waste detritiation systems) and consequently have failure data that better reflects actual performance. Most of the ETC system is tested during each bi-weekly test, but since the molecular sieve beds are not tested, only the response of key system components to the test will be evaluated in this report. Because this system has experienced so little operating time, system performance data (such as pipe or tank leakage) are not plentiful enough to make failure rate determination meaningful. This analysis then dwells on the main ETC system component (compressors and exhaust valve) failures and the overall system responses to testing demands over the system checkout period and the 8 years of TSTA operations.

Of the 540 reports in the TSTA data bank, 61 refer to the ETC. Appendix B gives the summary descriptions of ETC failure reports from the TSTA failure/maintenance data bank, and Appendix C gives pertinent excerpts from the ETC logbook. Information regarding the type and number of failures for the compressors and exhaust valve from these two sources is summarized in Table 1. Compressor 1 has had 14 failures to start and 15 failures to run. Compressor 2 has had 10 failures to run and no failures to start. The valve EXHV1, which controls system backpressure (consequently keeping the catalyst bed hot to efficiently remove tritium from the gas stream), has experienced 5 events where it could not operate adequately to control pressure. We also see that the ETC system began to operate more reliably beginning in 1987. Therefore, the transition date from early life or pre-operational testing to useful life is assumed to be January 1, 1987. This assumption is discussed further in Appendix A.

TABLE 1. ETC FAILURE EVENTS FROM THE FAILURE REPORTS AND LOGBOOK

<u>Citation Source</u>	<u>Event Date</u>	<u>Component Name</u>	<u>Failure Mode</u>
Logbook	09/20/82	Compressor 1	Fail to run (FTR)
Logbook	11/17/82	Compressor 1	Fail to run
Logbook	11/19/82	Compressor 1	Fail to run
Logbook	11/19/82	Compressor 1	Fail to run
Logbook	11/19/82	Compressor 1	Fail to run
Logbook	12/09/82	Compressor 1	Fail to run
Logbook	06/21/83a	Compressor 1	Fail to run
Logbook	06/21/83b	Compressor 1	Fail to run
Logbook	06/21/83c	Compressor 1	Fail to run
Logbook	07/12/83	Compressor 1	Fail to run
Logbook	10/27/83	Compressor 1	Fail to run
Logbook	12/20/83	Compressor 1	Fail to run
report #004	01/03/84	Compressor 1	Fail to run
report #051	07/09/84	Compressor 1	Fail to run
report #143	08/13/85	Compressor 1	<u>Fail to run</u>
		Compressor 1 total	15 FTR events
		0 FTR events after 1986	
Logbook	02/16/83	Compressor 1	Fail to start (FTS)
Logbook	02/22/83	Compressor 1	Fail to start
Logbook	11/22/83	Compressor 1	Fail to start
Logbook	12/20/83	Compressor 1	Fail to start
Logbook	01/21/84a	Compressor 1	Fail to start
Logbook	01/21/84b	Compressor 1	Fail to start
Logbook	01/21/84c	Compressor 1	Fail to start
Logbook	08/28/85	Compressor 1	Fail to start
report #006	01/16/84	Compressor 1	Fail to start
report #099	03/13/85	Compressor 1	Fail to Start
report #135	07/17/85	Compressor 1	Fail to start
report #141	08/07/85	Compressor 1	Fail to start
report #256	08/17/86	Compressor 1	Fail to start
report #285	11/26/86	Compressor 1	<u>Fail to start</u>
		Compressor 1 total	14 FTS events
		0 FTS events after 1986	

TABLE 1. ETC FAILURE EVENTS FROM THE FAILURE REPORTS AND LOGBOOK (con't)

<u>Citation Source</u>	<u>Event Date</u>	<u>Component Name</u>	<u>Failure Mode</u>
Logbook	12/01/82	Compressor 2	Fail to run
Logbook	03/10/83	Compressor 2	Fail to run
Logbook	03/17/83	Compressor 2	Fail to run
report #013	02/06/84	Compressor 2	Fail to run
report #047	06/13/84a	Compressor 2	Fail to run
report #047	06/13/84b	Compressor 2	Fail to run
report #090	02/20/85a	Compressor 2	Fail to run
report #090	02/20/85b	Compressor 2	Fail to run
report #123	06/15/85	Compressor 2	Fail to run
report #251	06/06/86	Compressor 2	<u>Fail to run</u>
		Compressor 2 total	10 FTR events
			0 FTR events after 1986

note: there were no logbook entries or failure reports for compressor 2
failing to start on demand: Compressor 2 total 0 FTS events

Logbook	08/22/83	Valve EXHV1	Fail to operate (FTO)
Logbook	11/22/83	Valve EXHV1	Fail to operate
report #007	01/16/84	Valve EXHV1	Fail to operate
report #089	02/20/85	Valve EXHV1	Fail to operate
report #100	03/13/85	Valve EXHV1	<u>Fail to operate</u>
		Valve EXHV1 total	5 FTO events
			0 FTO events after 1986

Note: Scanning these data shows that the ETC reached a transition between pre-operational reliability and useful life reliability at the beginning of 1987. Therefore, to define the component reliability change between pre-operation and useful life, the time periods of 1982-1986 and 1987-1992 are compared in this report.

Scanning the event dates from Table 1 also shows that as the system pre-operational tests were performed, personnel dealt with component failures. Drive belt problems with compressor 1 were eventually solved by using steel belts and correct belt tension to preclude slipping, overheating and smoking, squealing, flapping, or any other sort of major problem. Software problems in controlling the units have been solved. Early problems with the valve controller units and associated computer control circuitry (miswiring, etc.) for the valve controllers have been corrected. These are expected repairs and corrections that occur as any system matures.

The operating data for the compressors were gathered from the logbook, operating procedures, and from interviews with TSTA operators. The operating time and number of start demands for the pre-operations test phase were counted from the logbook. After the ETC system began to exhibit good reliability in the 1987 to 1992 time frame, the operating time and demands were estimated from the operating procedures. The transition time from the bi-weekly to monthly compressor operability tests was August 30, 1990. Therefore, each compressor was tested twice a month until September 1990, then only once a month thereafter. The ETC logbook for the latter years of operation was not kept as rigorously as the first several years, because Preventive Maintenance (PM) record sheets were used to record typical ETC tests.

The estimated number of start demands and operating time for the compressors are given in Table 2. The values given in the table are conservatively low for several reasons. First, only documented runs were counted from the logbook (judging by the dates in the logbook, not all weekly runs were recorded after the PM sheets were introduced in 1985). Also, personnel do not remember exactly when compressor 1 became operational in 1982, so only the logbook entries from the latter part of that year have been counted.

Table 2 also yields the total ETC system information, because the compressors do not run simultaneously. Compressor 2 is always a backup to compressor 1, but it is tested separately. Therefore, the total run time for both compressors combined equals the system testing hours, or 448.4 hours, from late 1982 through 1992.

TABLE 2. COMPRESSOR START DEMANDS AND OPERATING TIME FROM 1982 TO 1992

<u>Compressor number</u>	<u>Information source</u>	<u>Number of Start demands</u>	<u>Operating hours</u>
Compressor 1	1982 logbook	18	8.2
	1983 logbook	36	32.0
	1984 logbook	12	11.8
	1985 logbook	14	16.5
	1986 personnel	26	26
	1987 personnel	26	26
	1988 personnel	26	26
	1989 personnel	26	26
	1990 personnel	20	20
	1991 personnel	12	12
	1992 personnel	12	12

Compressor 1 recorded totals: 228 start demands, 216.5 operating hours

For 1987 and on, 122 start demands, 122 operating hours

Compressor 2	1982 logbook	3	0.9
	1983 logbook	24	30.4
	1984 logbook	24	42.6
	1985 logbook	12	10.0
	1986 personnel	26	26
	1987 personnel	26	26
	1988 personnel	26	26
	1989 personnel	26	26
	1990 personnel	20	20
	1991 personnel	12	12
	1992 personnel	12	12

Compressor 2 recorded totals: 211 start demands, 231.9 operating hours

For 1987 and on, 122 start demands, 122 operating hours

Total ETC run time from 1982-1992 is $216.5 + 231.9 = 448.4$ hours

Using the data presented in Tables 1 and 2, failure rates were calculated for the main ETC components. The early operation time frame (1982 to 1986) and later operation (1987-1992) are compared in Table 3. Comparing the hourly (/h) and demand (/d) failure rate values given in Table 3, it is evident that the pre-operational phase (also called burn-in) had more failures and a shorter operating time than the later operational time. Pre-operations testing uncovered many so-called "burn in" failures, and it is typical that the failure rates will be higher during initial, pre-operational testing. The point estimate (or average) failure rates are much larger in the pre-operational phase, from factors of 8 for the valve to over 20 for compressors failing to run, than in the useful lifetime phase of operation.

There are several cases to consider for the ETC average availability. The entire system has not been modeled with a fault tree for this exercise, so this result is only a scoping value. However, the reliability of the major components have been considered. Four major events for the compressors and the exhaust pressure control valve function must be considered to estimate the ETC average availability. The four compressor cases are: a) compressor 1 fails to start and compressor 2 also fails to start; b) compressor 1 fails to run and compressor 2 fails to start; c) compressor 1 fails to start and compressor 2 fails to run; and d) both compressors fail to run. These four cases must be combined with the EXHV1 valve failure rate to obtain a bound on the system unavailability over a 20 hour (100 grams of tritium release)¹⁴ cleanup mission. The 20 hour cleanup time assumes compressor 1 operates. The smaller compressor would need about 50 hours for the same cleanup mission. To arrive at an average availability estimate, the mission time is halved, assuming that compressor 1 fails halfway through the mission (at 10 hours) and compressor 2 picks up half of its own mission time (25 hours). The failure probabilities for the four cases are discussed below.

The useful life component failure rates from Table 3 are used in these calculations. An important assumption here is that these failure rate calculations were based on a failure rate for zero failures over the 1987-1992 time period. While there are different approaches for calculating the mean failure rate for the zero failures case,^{15,16,17} using the 50% chi-square distribution with two degrees of freedom produces

TABLE 3. FAILURE RATE CALCULATIONS FOR THE TSTA ETC SYSTEM

Component type	Failure mode	Demands (d)		Point estimate Failure rate	95% upper bound
		Number of events	or run time (h)		
<u>Pre-operations Time Frame (1982-1986)</u>					
Compressor 1	FTR	15	94.5 h	1.6E-01/h	2.4E-01/h
Compressor 1	FTS	14	106 d	1.3E-01/d	2.1E-01/d
Compressor 2	FTR	10	109.9 h	9.1E-02/h	1.5E-01/h
Compressor 2	FTS	0	89 d	7.8E-03/d (a)	3.4E-02/d
Valve EXHV1	FTO	5	204.4 h	2.4E-02/h	5.1E-02/h
<u>Useful Life Time Frame (1987-1992)</u>					
Compressor 1	FTR	0	122 h	5.7E-03/h (a)	2.5E-02/h
Compressor 1	FTS	0	122 d	5.7E-03/d (a)	2.5E-02/d
Compressor 2	FTR	0	122 h	5.7E-03/h (a)	2.5E-02/h
Compressor 2	FTS	0	122 d	5.7E-03/d (a)	2.5E-02/d
Valve EXHV1	FTO	0	244 h	2.8E-03/h (a)	1.2E-02/h

(a) The point estimate failure rate for zero failures is calculated by using a 50% chi square distribution on 0 events, as given in [15].

a conservative failure rate value. The four compressor cases are outlined below:

Compressor 1 FTS and compressor 2 FTS, 1 demand each, the probability =
 $(5.7E-03/d)(1 \text{ demand})(5.7E-03/d)(1 \text{ demand}) = 3.2E-05$ for both
compressors failing to start when called upon

Compressor 1 FTR and compressor 2 FTS, using 20 hours as the basis for an
ETC system mission, the probability = $(5.7E-03/h)(20 \text{ hours})(5.7E-03/d)$
 $(1 \text{ demand}) = 6.4E-04$ for both compressors being unavailable

Compressor 1 FTS and compressor 2 FTR, using 1 start demand and 50 hours
for an ETC system mission, the probability = $(5.7E-03/d)(1 \text{ demand})$
 $(5.7E-03/h)(50 \text{ hours}) = 1.6E-03$ for both compressors being unavailable

Compressor 1 FTR and compressor 2 FTR, using 10 hours as the basis for an
ETC system mission for compressor 1 and 25 hours for compressor 2, the
probability = $(5.7E-03/h)(10 \text{ hours})(5.7E-03/h)(25 \text{ hours}) = 8.1E-03$ as
an average value of both compressors being unavailable

These results must be combined with valve EXHV1 failing to operate. Using 25 hours as the mid-point of the longest run time to find the average valve failure probability gives $(2.8E-03/\text{hour})(25 \text{ hours}) = 7.0E-02$. Combining this result with the four cases above gives a sum of about 0.08. Therefore, the average ETC system availability based on these data is $1 - 0.08 = 0.92$, or 92%. Even though these failure rates may not be constant values, the availability is in the 90% range. The 92% availability value can be compared to earlier ETC work by Bruske¹³. Bruske made an estimate of the ETC failure probability using fission reactor-based failure rate data and found a point estimate value of $1E-02$ over a 24 hour mission time, in other words, 99% available. The ETC availability value obtained from operating experience derived estimates for the maximal run time is 7% lower than Bruske's estimate. These results agree quite well, especially when considering that the ETC component failure rates are probably not constant values. Also, for smaller releases (less than 100 grams of tritium), the ETC would need to run for a lesser amount of time, and the average availability for shorter runs would be higher than 92%.

The average availability value for the ETC is dominated by the EXHV1 valve failing to operate as required. The valve failure rate from ETC

experience is larger than other values in the literature, as shown in the next section. Further study would be needed to definitely ascertain the true ETC availability value, accounting for all ETC components rather than just the major system components.

Another possibility to consider for ETC availability is human intervention to repair the ETC system. Personnel could enter the area wearing bubble suits and affect repairs if the system were not too badly damaged.¹⁴ For example, bubble suited personnel could repair one compressor if both have failed, or repair a stuck valve. It is noted that bubble suit work can lead to contamination during an off-normal event,¹⁸ but with caution, personnel intervention is possible in many of the failure events cited in the Appendices, although working in suits would take time. Future experiments would house the ETC components in a separate room, where bubble suits would not typically be needed to perform any repairs.

5. RESULTS COMPARISON TO OTHER EXPERIENCES

Compressor failure rates, air operated valve failure rates, and overall system failure rates are compared in this section. Failure rate values from a variety of sources have been collected and shown in Table 4. There is a wide discrepancy in the reported values. Rates for ETC compressors failing to start show the least discrepancy, a factor of about 2 more than published values. Compressor hourly failure rates vary by a factor of about 60, and the largest discrepancy is with the exhaust valve. Some of these discrepancies could be caused by differences in calendar hours versus operating hours, types of compressors and usage (standby versus continuous operation), component boundary differences (such as inclusion of the compressor motor with the compressor unit), or other factors. Still, the wide discrepancy leads us to suspect that the TSTA values are not steady state (constant) failure rate values. This is reasonable because of the short operating time of the ETC system. The existing TSTA values need to be compared strictly to standby component failure rates. Unfortunately, readily available data sources are not so comprehensive as to have standby compressor information. Nonetheless, these ETC data are still valuable for fusion safety work.

The overall system failure rate or availability is not as easily compared to other work because of design differences and the fact that much of this information from other facilities is sensitive or proprietary. However, Bell and Ballantyne²⁵ report an average failure rate for an emergency detritiation system on the Joint European Torus activated gas handling system of $8E-04/\text{hour}$. For a 20 hour run, the overall failure probability of this system would be 0.016, or 98.4% available, compared to TSTA's 92% available. Hedley et al.²⁶ qualitatively state that the Mound Laboratory continuous air detritiation system has implemented several improvements, such as installing a third compressor with complete spare parts availability, to increase system reliability. Gildea²⁷ also qualitatively addressed reliability of the Sandia Tritium Facility cleanup system. That system has also functioned quite well over 70,000 hours of operation, but both the Mound and Sandia systems are more similar to the TSTA Tritium Waste Treatment system, which has also had good reliability over its lifetime.¹⁰

TABLE 4. COMPARISON OF COMPRESSOR AND AIR OPERATED VALVE FAILURE RATES

<u>Component</u> <u>Name</u>	<u>Failure Rate</u> <u>(/h or /d)</u>	<u>Upper Bound</u> <u>Failure Rate</u>	<u>Failure</u> <u>Mode</u>	<u>Reference Number</u> <u>for Data Source</u>
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Compressor	3E-03/d	1E-02/d	FTS	13
	5E-03/d	1.5E-02/d	FTS	19
	2.9E-03/d	2.7E-02/d	FTS	20

TSTA ETC compressor 1, FTS = 5.7E-03/d, upper bound = 2.5E-02/d

TSTA ETC compressor 2, FTS = 5.7E-03/d, upper bound = 2.5E-02/d

Compressor	4E-05/h	1.2E-03/h	FTR	13
	1E-04/h	1E-03/h	FTR	19
	9.6E-05/h	2.2E-04/h	FTR	20
	3.4E-05/h	not given	all	21
	1.9E-02/h	2.9E-02/h	all	22

TSTA ETC compressor 1 FTR = 5.7E-03/h, upper bound = 2.5E-02/h

TSTA ETC compressor 2 FTR = 5.7E-03/h, upper bound = 2.5E-02/h

Air-operated

Valve	1E-06/h	not given	blocked	21
	1.2E-06/h	3.5E-04/h	all	23
	1E-06/h	1.5E-06/h	FTO	24

TSTA ETC valve EXHV1, FTO = 2.8E-03/h, upper bound = 1.2E-02/h

6. CONCLUSIONS AND RECOMMENDATIONS

The ETC system has been investigated to determine its average availability. An average point estimate availability is 92% for the largest tritium release event. While the component failure rate results do not appear to be steady state (constant) values, they are still valuable. Other valuable information has been found about problems with early ETC operation. Carlson et al.⁸ and the ETC logbook provide several examples of typical problems that can occur with system design and construction. One pre-operational event, a motor winding short circuit, occurred because the compressor 1 motor was not properly qualified by the manufacturer to operate at an altitude of 2195 m. Another event occurred when the paint in the compressor exhaust manifold began flaking off and circulating in the system. The barium sulfate paint began corroding the system humidity monitors and there was also a concern that the paint would also contaminate the catalyst beds. The logbook also states that there were occasions where valves had been installed backwards. Foreign materials, such as dirt and metal shavings, were found in the instrument air lines, and foreign materials were found in the compressor 1 pistons, etc. Other operational problems included computer software problems, compressor motors drawing too much starting current for other TSTA electrical loads to be continued simultaneously, and operator education to properly operate the equipment. These problems are recorded in Appendix C and by Carlson et al.⁸

These failure rate data are important to consider for standby systems, such as other air detritiation systems. While systems such as the TSTA ETC may not be used for larger applications,²⁸ these data can be used to augment any generic failure rate data applied to standby components. Since standby equipment has the potential to degrade while waiting to operate, higher failure rates than those found in generic data handbooks would probably be appropriate. We recommend that TSTA ETC data be rechecked periodically to determine how much variation there might be in the component failure rate values given in this report.

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STATISTICS FOR FAILURE RATES

APPENDIX A

STATISTICS FOR FAILURE RATES

The failure rates for Tritium Systems Test Assembly (TSTA) large compressors and the exhaust pressure control valve in the Experimental Tritium Cleanup System (ETC) were calculated. The failure rates per operating hour and per compressor start demand were determined. Examples of the calculations are given in this appendix.

Several notes should be made about the calculations:

- The ETC has never had to run for an actual tritium release inside the TSTA building, even though the system has used over 100 grams of tritium in the process systems. The data used here are from system initialization and pre-operational testing and from periodic equipment tests in the useful life phase. These data are presented in Tables 1 and 2 in the main body of this report.
- Some operations from 1982 and 1983 were counted for ETC compressor starts, faults, and run times. The first overall facility tritium run was performed at TSTA on June 25, 1984. The ETC was not required to be operational at that point in time because it is only a demonstration system. Since the ETC exhibited good reliability beginning in 1987, its lifetime was divided into the 1982-1986 early life phase and the 1987-1992 useful life phase. Operational failure rates were calculated based on 1987 and later demands and operating hours.
- Events where the compressors tripped off line for a valid concern (overtemperature, high vibration, etc.) were not counted as fault events. Operational occurrences such as those must be an expected part of system operations. Electric power outages were not counted as compressor faults, either.

Failure rate calculations for compressors

The point estimate, lambda, or average failure rate per unit time is:

$$\lambda = X/t = (\text{total number of failures})/(\text{total amount of operating time})$$

where X = Total number of component failures
 t = Total time of component operation, in hours, h

The number of demands (d) can be substituted for operating time, t, to yield a demand failure rate. Confidence bounds for lambda are based on formulas (28.1) and (28.2) in reference A-1. These equations are:

$$\text{Lower 5\% Confidence Bound on } \lambda = CL/(2*t)$$

$$\text{Upper 95\% Confidence Bound on } \lambda = CU/(2*t)$$

where CL = 5% Lower Chi-squared statistic = Chi-squared(.05,2*X)
 CU = 95% Upper Chi-squared statistic = Chi-squared(.95,2*(X+1))

The failure counts and hours of operation from Tables 1 and 2 of the main report are given below for each of the components:

<u>Component</u> <u>type</u>	<u>Failure mode</u>	<u>Number</u> <u>of events</u>	<u>Demands (d)</u> or <u>run time (h)</u>

Pre-operations Time Frame (1982-1986)

Compressor 1	Fail to Start	14	106 d
Compressor 1	Fail to Run	15	94.5 h
Compressor 2	Fail to Start	0	89 d
Compressor 2	Fail to Run	10	109.9 h
Valve EXHV1	Fail to Operate	5	204.4 h

Component type	Failure mode	Number of events	Demands (d) or run time (h)
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Useful Life Time Frame (1987-1992)

Compressor 1	Fail to Start	0	122 d
Compressor 1	Fail to Run	0	122 h
Compressor 2	Fail to Start	0	122 d
Compressor 2	Fail to Run	0	122 h
Valve EXHV1	Fail to Operate	0	244 h

Considering compressor 1 in the 1982-1986 time frame and the failure to run failure mode, the failure rate is:

$$\text{Lambda [fail to run]} = X/t = 15/94.5 = 1.6\text{E-}01 \text{ failures/hour}$$

$$\text{CU} = \text{Upper Chi-squared statistic} = \text{Chi-squared}(.95, 2*(15+1)) = 46.2$$

$$\text{Upper 95\% Confidence Bound} = 46.2/(2*94.5) = 2.4\text{E-}01/\text{hour}$$

note: the Chi-Squared distribution values were taken from reference A-2.

The case of compressor 2 failure to start is more complex because the traditional means to find a point estimate would yield a failure rate of zero failures per demand. Therefore, from reference A-3, a 50% median Chi-squared distribution with two degrees of freedom is used to calculate the average failure rate. For compressor 2 failing to start in the preoperational time frame:

$$\text{Lambda [fail to start]} = \text{Chi-squared} (0.5, 2(X+1))/2*d$$

$$\text{Chi-squared} (0.5, 2(0+1)) = \text{Chi-squared} (0.5, 2) = 1.39$$

$\text{Lambda [fail to start]} = 1.39/(2*89) = 7.8\text{E-}03/\text{demand}$

The 95% upper bound is found in the typical way:

$\text{CU} = \text{Upper Chi-squared statistic} = \text{Chi-squared}(.95, 2*(0+1)) = 5.99$

$\text{Upper 95\% Confidence Bound} = \text{CU}/(2*d) = 5.99/(2*89) = 3.4\text{E-}02$
failures/demand

The other failure rates, particularly those in the 1987-1992 time frame, are calculated in the same manner. The failure rate values and upper bounds are given in Table 3 of the main report.

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APPENDIX B

SUMMARY DESCRIPTIONS OF EMERGENCY TRITIUM CLEANUP

SYSTEM FAILURE REPORTS FROM 1984 TO 1992

APPENDIX B

SUMMARY DESCRIPTIONS OF EMERGENCY TRITIUM CLEANUP SYSTEM FAILURE REPORTS FROM 1984 TO 1992

This appendix gives brief summaries of each of the Emergency Tritium Cleanup System (ETC) failure reports from the Tritium Systems Test Assembly (TSTA). Table B-1 lists the summary information for each of the failure reports in chronological order. The report numbers, referred to as identification numbers in the main body of the report, are unique.

While TSTA began tritium operation on June 25, 1984, the construction activity for most systems was completed in 1983 or earlier. There are logbook entries that cite ETC tests and problems in the 1982, 1983, and early 1984 time frame. Appendix C gives logbook run times, start demands, and discusses operational problems for the ETC compressors and other equipment.

The ETC has been test operated over the entire time that TSTA has been operational. The ETC has never been used for actual cleanup of test cell air, because no significant amount of tritium has ever been released into the TSTA test cell. Since the entire ETC is not tested (to avoid loading the emergency molecular sieve beds with hydrogen from atmospheric humidity instead of tritium), some of the reports cited here will not be analyzed for failure rates. Other equipment, such as system piping, has not been used for enough hours of test operation to give statistically significant failure rates.

The ETC is operated from TSTA's Master Data Acquisition and Control computer (MDAC) in the control room. The control room displays of system parameters and alarms are referred to as the man-machine interface (MMI).

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES

<u>TSTA</u> <u>Report</u> <u>Number</u>	<u>Event</u> <u>Date</u>	<u>Component</u>	<u>Description of Event</u>	<u>Failure Effect</u>	<u>Method of Detection</u>
004	01/03/84	Comp 1	Compressor 1 was running with 100% load but the belts were slipping and an abnormal noise was heard. The unit was shutdown to investigate the problem. A bearing needed to be replaced.	Fail to run	Audible notice
006	01/16/84	Comp 1	When starting up Compressor 1, a loud knocking was heard coming from the unit. The cylinder ports were opened, and a piece of metal from a sheared off alignment pin was found and removed.	Fail to Start	Audible notice
007	01/16/84	Valve	The ametex controller for exhaust valve EXHV1 would not operate correctly after installation. The regulator was examined. A broken gasket was found in the ametex controller, and a new gasket was obtained by using a gasket from another TSTA valve.	Fail to Start	Operational Occurrence
013	02/06/84	Comp 2	During an ETC test run, compressor 2 shut down after 2.5 hours on a motor overload signal. A wiring fault allowed the spurious signal to be created. The wiring ground was corrected.	Fail to run	Operational Occurrence
018	12/20/83	TM	The ETC tritium monitor was reading unstable. A new preamplifier board was installed upon delivery 36 days later.	No effect	Operational Occurrence

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

Report Number	Event Date	Component	Description of Event	Failure Effect	Method of Detection
029	04/02/84	Valve	ETC valve CBV3 indicates that it is not open when it is open. A micro-switch was out of alignment on the valve. It was repaired.	No effect	MDAC Panel review
033	05/14/84	Valve	ETC valve CV13 will not shut by command until another valve is actuated via a solenoid. The problem was resolved.	No effect	Operational Occurrence
040	04/01/84	TM	The ETC tritium monitor was turned on, but it would not read true (the ETC was not on, and there was no tritium in the ETC piping, but the TM would not read true. The electrometer board was replaced.	No effect	Operational Occurrence
043	05/31/84	Comp 2	Compressor 2 was noted to be running hot. The enclosure cover was opened and the discharge thermometer was noted to be out of position. It was reinstated.	No effect	Operator walkdown
044	05/31/84	Filters	The HTO system filters were clogged with dirt about one minute after the system began to operate. The filters were backflushed to remove the dirt. New filters are being designed to be less susceptible to clogging.	No effect	Operational Occurrence
047	06/13/84	Comp 2	Compressor 2 shut down two times due to discharge temperatures being higher than allowed limits. The actual temperatures were probably high, but the T-CDIS2 probe read low. No repair was stated.	Fail to run	Operational Occurrence

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

Report Number	Event Date	Component	Description of Event	Failure Effect	Method of Detection
051	07/09/84	Comp 1	Operators noted that compressor 1 will not restart from the control room if there is a power glitch or a loss of power. The local control panel reset button must be used to restart Comp 1.	Fail to run	Operational
076	01/10/85	Storage tanks	MMI reads low volume in the storage tank. Tank pressure must be higher for instruments to read correctly.	No effect	MMI inspection
078	01/10/85	MDAC	The ETC humidity controls on the MDAC should be solid red, not blinking. This requires a software change. It was changed 4 days later.	No effect	MMI inspection
079	01/10/85	Cat. bed	Catalyst bed B was running at a high and negative differential pressure. Instrument needed repair.	No effect	Operational
080	01/14/85	Comp 1	Thermocouple on the north cylinder was reading too low to be accurate. A connector on the signal conditioning card for the thermocouple was replaced.	No effect	MMI inspection
081	01/14/85	Comp 1	The filter on compressor 1 was apparently running higher differential pressure than expected. The problem was traced to software and was corrected to display proper value.	No effect	MMI inspection
082	01/14/85	Comp 1	MDAC should have been giving a certain reading during the test run, but it did not. At 100% load, MDAC reads 0% load. The reading corrected itself after a brief time.	No effect	MMI inspection

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

TSTA					
Report Number	Event Date	Component	Description of Event	Failure Effect	Method of Detection
086	01/21/85	Dryer	When the refrigerating dryer is taken from remote to local, something in the unit starts to chatter. Problem traced to operator's improper usage.	No effect	Operational Occurrence
088	02/17/85	MSB	The radiation reading at the output of molecular sieve bed #4 reads full scale negative. Corrected by repairing signal conditioning card.	No effect	MMI inspection
089	02/20/85	Valve	The valve EXHV1 would not let the exhaust pressure down below 44 psig. After the test, the valve was examined. A control screw had moved, not allowing the signal from the valve controller to reposition the valve. Screw was reset.	Reduced ETC efficiency	Operational
090	02/20/85	Comp 2	Compressor 2 shut down on alarms several times but it restarted because the software keeps the start contact energized. The software was corrected.	Fail to run	Operational Occurrence
091	02/20/85	Dryer	The refrigerated dryer would not keep running, it would shut down about 1 minute after starting. On inspection, operators realized they were starting the unit incorrectly.	Reduced ETC efficiency	Operational Occurrence
092	02/20/85	Comp 2	Compressor 2 spuriously started. During execution of the startup program, Compressor 2 started before the start command was reached. The software was changed to better control the unit.	Spurious Start	Operational Occurrence

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

<u>TSTA</u> <u>Report</u> <u>Number</u>	<u>Event</u> <u>Date</u>	<u>Component</u>	<u>Description of Event</u>	<u>Failure Effect</u>	<u>Method of Detection</u>
096	02/25/85	Dryer	The dryer had alarms showing on the MDAC. Patch cords from the MDAC patch panel were found to be missing. New cords were installed and the alarms cleared.	No effect	MMI inspection
099	03/13/85	Comp 1	Compressor 1 would not start on demand. A patch cord was missing from the MDAC patch panel. Personnel cautioned about patch cord removal.	Fail to Start	Operational
100	03/13/85	Valve	Overpressure on compressor 1 discharge. The EXHV1 valve was not controlling pressure correctly, due to a pneumatic line that was cut. The cut was due to the line being pinched in the controller access door. The line was repaired.	Fail to operate	Operational Occurrence
101	03/13/85	Comp 1	Due to the fault described in report #100, the compressor overpressure grew enough to blow the rupture disks. The unit was shut down and the disks were replaced by the typical flange bolting in place, with graphoil seals.	Fail to run	Operational Occurrence
108	04/09/85	MMI	Some MMI parameters for ETC are always in alarm. Limits need to be increased.	No effect	MMI inspection
109	04/09/85	Dryer	The refrigerated dryer is not large enough to handle all the heat from the catalyst beds. Moisture could enter the MSBs instead of being removed from the gas stream. System pressure was decreased. Cooling water temperature was decreased and the equipment works.	Decreased ETC efficiency	Operational Occurrence

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

TSTA					
Report Number	Event Date	Component	Description of Event	Failure Effect	Method of Detection
111	05/13/85	Comp 1	When compressor 1 was started for a test, the motor circuit breaker MCC-C B1 tripped off line. The motor was inspected for damage, and the breaker was reset and the motor restarted.	Fail to Start	Operational Occurrence
122	06/06/85	Valve	The valve CV-11 was purging compressor #1 with nitrogen gas. The valve stuck half closed, wasting nitrogen.	No effect	Operational Occurrence
123	06/15/85	Comp 2	Compressor 2 spuriously stopped, but the cause could not be determined because the start circuit is continuously energized, so the unit restarted almost immediately. Software people will correct.	Fail to run	Operational Occurrence
135	07/17/85	Comp 1	Compressor 1 spuriously shut down on test startup. The belt had jumped a notch. The belts were repositioned and retightened in an hour. The system ran correctly when started to check out the belt maintenance.	Fail to run	Operational Occurrence
139	07/30/85	Valves	The MDAC indication shows the vent and overfill valves for ETC are closed when they are really open. Microswitches were installed backwards. Rewired the microswitches to read to the MDAC correctly.	No effect	MMI inspection
141	08/07/85	Comp 1	During a maintenance test, Compressor 1 experienced belt slippage and unusual noise in the motor. The compressor was shut down to investigate. Belts were tightened in 2 hours. The motor was tested for another hour.	Fail to run	Operational Occurrence

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

Report Number	Event Date	Component	Description of Event	Failure Effect	Method of Detection
143	08/13/85	Comp 1	Compressor was under full load, but began making loud belt noises. One of the two drive belts was stretching and losing tension. Belts will be replaced when new ones arrive in 4 wks.	Fail to run	Operational Occurrence
150	08/21/85	Valve	ETC valve CV10 indicated incorrectly in the control room. The microswitch was out of alignment. Two operators needed 20 minutes to correct the alignment.	No effect	MMI inspection
160	09/17/85	Valve	ETC valve MSBV11 indicated incorrectly in the control room. A nut was loose on the microswitch. It was tightened.	No effect	MMI inspection
164	09/20/85	Circuit breaker	While running at full load in a MSB bypass configuration, the belts to compressor 1 began slipping badly. A flash of light was seen from the control room, and an alarm indicated that the breaker to Comp 1 had opened. The emergency diesel was supplying good power. There was no reason found for the breaker to open. Comp 1 belts were retightened and it was operated again to verify the corrective action.	Fail to run	MMI alarm
189	03/04/86	CBED	The control room indication for CBED 1 was reading cooler than it should. A misaligned signal conditioning card was found and realigned in an hour.	No effect	MMI indication

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

Report Number	Event Date	Component	Description of Event	Failure Effect	Method of Detection
190	03/04/86	CBED	The control room indication for CODIS read cooler than it was. Another misaligned signal card was found and fixed, in about one hour.	No effect	MMI inspection
223	02/11/86	MDAC	The ETC parameters read 'off' when they should read 'on'. A loose connector in the MDAC was found and fixed in 30 min.	No effect	MMI inspection
226	03/04/86	ducting	The part of the input ducts that run outside the building and around to the compressors were degraded and leaking slightly. Seals were degraded because of weathering or sunlight exposure. Room temperature vulcanizing sealant was used to repair the seals in about 6 hrs.	No effect	Operational Occurrence
227	03/04/86	MDAC	Outputs on the MMI should not be red for non-alarm conditions. This should be changed. Change took 30 minutes.	No effect	MMI inspection
250	07/01/86	Valve	Pressure reading is low during a test. The water pressure regulating valve is malfunctioning. The valve was taken apart and cleaned, then tested by running the system again.	No effect	MMI alarm

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

<u>TSTA</u> <u>Report</u> <u>Number</u>	<u>Event</u> <u>Date</u>	<u>Component</u>	<u>Description of Event</u>	<u>Failure Effect</u>	<u>Method of Detection</u>
251	06/06/86	Comp 2	During a test (bypassing the MSBs), compressor 2 shut down and would not immediately restart. The local control panel setting was changed and then the compressor restarted. At the end of the test, compressor 2 would not shut down on command from the control room. The computer command to stop the entire ETC had to be used to shut down compressor 2. The problem was traced to software and was corrected.	Fail to run Fail to Stop	Operational Occurrence
254	08/02/86	pipng	An operator noticed a steam leak from a fitting on an ETC steam pipe. The leak was repaired.	No effect	Operator walkdown
256	08/17/86	Comp 1	Tried to start compressor 1, and the circuit breaker opened. Tried again with the same results. Rotated the compressor motor by hand and then it started. Perhaps there is a 'dead spot' in the motor.	Fail to Start	Operational Occurrence
258	08/14/86	MDAC	The indication for waste storage tanks 1 and 2 would not read true. It was repaired from software.	No effect	MMI inspection
260	08/29/86	Cooler	While operating the ETC cooler, the pressure was noted to be too low. The pressure regulators were reset to provide better cooling water flow.	No effect	MMI inspection
263	09/05/86	MDAC	The alarm on different displays uses a red background for normal condition display. Red should only be used for alarm conditions. This was fixed.	No effect	MMI inspection

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

TSTA					
Report Number	Event Date	Component	Description of Event	Failure Effect	Method of Detection
264	09/05/86	Tank	The MDAC reads -26 gallons when it is empty. Water was in the differential pressure transducer line. The line was cleaned and the instrument reads correctly now.	No effect	MMI inspection
267	08/28/86	MDAC	Valve indications are erratic when running the ETC. A bad Computer Automated Measurement and Control (CAMAC) circuit card was found and replaced, solving the problem.	No effect	MMI inspection
285	11/26/86	Comp 1	Compressor 1 would not start when demanded from the control room. When the compressor was turned over once by hand, it would start when demanded. The compressor should be turned over weekly, because it cannot be accessed if there is a tritium release into the building.	Fail to Start	Operational Occurrence
302	04/28/87	MDAC	Display for certain valves is incorrect when running ETC for maintenance checks. The software was revised to correct the problem.	No effect	MMI inspection
303	05/04/87	Comp 2	While running compressor 2, a water leak developed at a union fitting for the compressor 2 cooler. The fitting was tightened.	No effect	Operator walkdown
304	05/04/87	Comp 2	The visi-flow visual flowmeter on compressor 2 does not work correctly. It was repaired.	No effect	Operator walkdown

TABLE B-1. EXPERIMENTAL TRITIUM CLEANUP SYSTEM FAILURE REPORT SUMMARIES (continued)

<u>Report Number</u>	<u>Event Date</u>	<u>Component</u>	<u>Description of Event</u>	<u>Failure Effect</u>	<u>Method of Detection</u>
344	09/28/87	TM	The tritium monitor on ETC MSB #3 was malfunctioning. It would not zero when required. The electrometer was removed and refurbished by the electrical shop and the 12 Volt power supply was replaced.	No effect	Operator walkdown
462	07/28/89	Comp 2	The light socket for the remote 'on' lamp is broken. The plastic socket was replaced.	No effect	Operator walkdown
499	03/05/91	Xducer	The pressure transducer for zone II failed, and sent an alarm "Loss of Zone II Differential Pressure" to the control room. The transducer was replaced.	No effect	MMI alarm

Note: there were no relevant failure reports issued on the ETC system in 1992.

APPENDIX C

SUMMARY OPERATIONS INFORMATION FROM THE ETC LOGBOOK

APPENDIX C

SUMMARY OPERATIONS INFORMATION FROM THE ETC LOGBOOK

This appendix contains excerpts from the Experimental Tritium Cleanup System (ETC) logbook kept by system operators at the Tritium Systems Test Assembly (TSTA). The log begins in September 1982, and entries for the first logbook ended in September 1985. After that time, the preventive maintenance (PM) data sheets were used to document test runs, so logbook entries became more maintenance-oriented. Logbook excerpts provide counts of equipment start demands, failure to start (FTS) occasions, failure to run (FTR) events, and run times for failure rate calculations. The FTS is defined as a failure to start up and assume load. Failure to run is defined as a successful start and then some sort of spurious shut down, for example: an incorrect trip signal, mechanical fault, or a shut down from other spurious causes. Actual trips for equipment protection were not counted, and support system faults (such as circuit breaker spurious openings) were not included because they are outside the component boundary.

Entries are reproduced here for only the information considered important to the scope of this report. Compressor start demands and run times are summed to give early lifetime (pre-1987) usage estimates. Table C-2 highlights some of the general problems associated with ETC system construction and operation. These problems are often shared by other systems.

TABLE C-1. ETC LOGBOOK EXCERPTS

Date	Description of the logged event or action
09/13/82	Compressor 2 arrived on site (compressor 1 is already installed in the system)
09/14/82	Compressor 2 was moved into position
09/20/82	Ran compressor 1 at 100% for 15 min, 25% for 10 min, and 0% for 5 min. One spurious shutdown while changing load percentage
11/17/82	Ran compressor 1 to remove WD-40 (lubricant) from the cylinders, ran for 41 min, shut down when heard belt noises. Restarted compressor 1 when maintenance personnel arrived, only ran a short time. Ran compressor 1 for 40 min while maintenance sprayed belt dressing and said slippage noise would decrease as belts are seated. Shut down compressor due to excessive noise levels in pit. Air drawing through filter covers was the problem.
11/19/82	Ran compressor 1 for 20 min to test valve positioning Ran compressor 1 for 26 min to test auto start circuitry Compressor 1 shut down on high vibration (false signal) Compressor 1 restarted, ran 9 min more Restarted test after lunch, compressor 1 ran for 16 min, but another vibration trip occurred. Believe problem is in transducer.
11/22/82	Ran compressor 1 to check on building vibration responses (about 15 min). Compressor 1 started, but the belt flapped badly, so it was shut down. Restarted, ran up to 25% load, but duct work outside on building roof was vibrating badly. Deep pulsing is being transmitted to the supports and roof.
11/24/82	Ran compressor 1 on emergency diesel power (about 15 min) Checked roof vibration again.
11/30/82	Compressor 2 is set up to run now.
12/01/82	Started compressor 2. Many problems with incorrect set points for alarm parameters and instrument readings. It was shut down. Restarted later. (total run about 15 min) Compressor 1 was started and run for about 5 min to check out the belt noise
12/02/82	Ran compressor 2 for 39 min (started and stopped compressor 2 from the control room)
12/09/82	Ran compressor 1 for 20 min to check vibration Restarted compressor 1, ran for several hours (2 hrs). Restarted at 100% load, and it tripped off. Restarted again, ran for 1.5 hours.

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

Date	Description of the logged event or action
12/15/82	Pressure tested ETC system. Found large leak on south filter cover of compressor 1. Needs new gasket. Bolt hole in separator inspection plate was blowing by.
12/17/82	Ran compressor 1 for about 15 min for vibration inspection. At 1600 hours, a loud noise was heard in main experiment room. A section of exhaust duct had collapsed. (12/20/82; The theory is that an exhaust fan causes negative pressure in the duct and the main experiment room ventilation also causes negative pressure. Between the two, there was enough negative pressure to cause the duct to collapse.)
12/20/82	Received new compressor belts.
12/21/82	Ran compressor 1 for 28 min to monitor vibrations
01/03/83	Ran compressor 1 for vibration tests (50 min) Compressor 1 would not unload at 30 min, ran out to 50 min before it would unload Ran compressor 1 for 30 min after spraying belts, no vibration or squeals were received
02/02/83	Ran compressor 2 for 15 min
02/07/83	Ran compressor 1 for 4 hours
02/10/83	Ran compressor 1 for 10 min. Tried to blow dry the water storage tanks. The valves were plumbed backwards. They were fixed.
02/11/83	Ran compressor 2 for 1 hour.
02/15/83	Ran compressor 1 for 4.5 hours for temperature testing Ran Compressor 1 for 2.5 hours for air injection testing
02/16/83	Ran compressor 1 on emergency diesel power for 40 min, then lost diesel power to the compressor. Tried to restart compressor 1, but breaker on motor control center (MCC) C had blown. Attempted another restart, but compressor 1 would not start.
02/22/83	Tried to start compressor 1, but the circuit breaker on MCC-C tripped open. Motor was shorted. It was removed to send to the electrical shop for rewinding.
02/23/83	Ran compressor 2 for 2.6 hours, testing the dryer system
03/01/83	Ran compressor 2 for 2.25 hours to test computer interfacing
03/10/83	Compressor 1 motor would not cool well enough at high elevation like TSTA. Should start motor maximum of 4 times per hour to keep temperature low. Ran compressor 2 to test new controls. It tripped and was restarted. Run about 15 min.

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

Date	Description of the logged event or action
03/11/83	Ran compressor 2 to set valve controls for it, 60 min.
03/14/83	Ran compressor 2 for hydrogen addition calibration test, about 2 hours.
03/16/83	Ran compressor 2 to set backpressure regulator, 45 min.
03/17/83	Ran compressor 2 to check orifice. Ran for 2 hours. Had a serious trip from vibration, restarted unit.
03/24/83	Ran compressor 2 for a 15 min demonstration
04/04/83	Ran compressor 1 for hydrogen injection tests, about 15 min
04/06/83	Ran compressor 2 for hydrogen injection tests, about 15 min
04/18/83	Ran compressor 2 to collect gas chromatograph samples, about 15 min
04/28/83	Ran compressor 1 for catalyst bed tests, 35 min
	Ran compressor 2 to check regulator setting, 15 min
05/11/83	Ran compressor 1 on the emergency diesel. Belts smoked to the extent that a fire was expected (no fire occurred).
05/18/83	During startup preparations for compressor 2, valve CV-5 did not open. Got it open. Compressor 2 then tripped on high exhaust pressure. The water regulating valve was erratic.
05/23/83	Started compressor 2 to check repairs to water regulating valve. Ran 2.5 hours
05/25/83	Started Compressor 1 to heat up belts for mechanic to adjust them. After 5 min, belts were smoking, turned off compressor 1. Belts were grossly misaligned. Mechanics realigned them. Started compressor 1 to check work, after 10 min the belts slipped constantly. Mechanics suggested steel cable belts. Spare belts are wrong sizes, not for 8 groove pulleys (one belt is correct at 4 groove, the other belt is a 5 groove).
05/31/83	Ran compressor 2 for 8 hour heatup testing.
06/02/83	Ran compressor 2 for a one hour heat up test.
06/06/83	Put belts on compressor 1, cut one groove off of the five groove belt. Need to run, then retighten. Compressor 1 ran fine at 100%, belts flop at 25% load.
06/21/83	Ran compressor 1 for heat up test for about 10 min, vibration trip. Ran another 10 min, another trip, then ran for 5 min, then another trip.

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

Date	Description of the logged event or action
06/22/83	Valve CV-4 did not open on demand. Valve was dirty. It is an air operated valve, using nitrogen instead of air. Compressor 2 ran for 2.25 hours.
06/23/83	Received new belts for compressor 1, ran it 1.25 hours, trip on system pressure increase, then ran another 10 min
06/24/83	Started compressor 1, ran 25 min
07/05/83	Started compressor 1, ran 30 min for heating test. Refrigerated dryer was running, too. Noise measurements near compressor 1 were 105-108 decibels. The stay time without ear protection is 7.5 min
07/07/83	Ran compressor 1 for refrigerated dryer test Mechanics observed compressor 1 for a 30 min run. Belts started to slip but pressure is correct Noisiest place during ETC operation is near valve EXHV-1, at 116 decibels. Noted that every 27 sec, compressor 1 load changed slightly, then at every 57 min, the compressor 1 oil pressure would oscillate and the belts would start to slip.
07/12/83	Ran compressor 1 for refrigerated dryer test, the belts were slipping so compressor 1 was shut down at 13 min Started compressor 2 to finish test, ran it 46 min.
07/26/83	Ran compressor 1 to investigate the problem (18 min). Then, opened inspection covers to further investigate. Found spiral marks on piston rod every 2 inches for a 10 inch length. About a tablespoon of oil (about 15 ml) was in cylinder #1, same marks and about 8 ounces of oil (about 120 ml) was in cylinder #2. Closed and ran compressor 1 for 16 min.
07/28/83	Sprayed compressor 1 belts with belt dressing, and ran compressor for about 1 hour
07/29/83	Ran compressor 1 for 4.6 hours, for a dryer test. Heard a noise. Upon investigation, found the housing on the pulley end of the motor was hot. Could be a bearing is going out.
08/03/83	Started compressor 1 for technicians to check it out. 12 min run. Technicians said belts were too tight, loaded bearings wrong. Bearings are starting to get bad, but not too bad yet.
08/08/83	Mechanics arrived to change compressor 1 oil and belts.
08/09/83	Sprayed dressing on belts, ran compressor 1 for 3 hours. Valves COV-3, COV-4 did not open on demand, blown fuses. Refrigerated dryer tripped off from faulty pressure switch. The dryer discharged pieces of black and silver material. R. Carlson thinks it is catalyst.

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

Date	Description of the logged event or action
08/10/83	Drained another 2.5 liters of water from the dryer. It had more black and silver material in it.
08/21/83	Ran heating test with compressor 1, 1 hour. Ran heating test with compressor 1, 30 min. Had problem with valve EXHV-1, bad controller.
08/24/83	Inspected valve controllers, dirt in and on diaphragms (very fine brown deposit) and metal shavings from pipe threading were in instrument air lines.
10/25/83	Dirt was flushed from system with air and 21 gallons (about 80 liters) of water. Water from the fourth flushing came out clear.
10/27/83	Started compressor 1, would not run due to software problems. When it started and went to 100% load, software caused the compressor to shut itself down. Waited 20 min for motor cool down. Restarted compressor 1 for a 2.5 hour run. Stopped compressor 1, started compressor 2, and ran it for 1 hour. Compressor 2 did not stop correctly, the valves began to close before the compressor stopped.
11/04/83	Checked out compressor 2 problem, it is a software problem.
11/09/83	Ran compressor 1 for 45 min for a ventilation test.
11/17/83	Noticed both belts on compressor 1 had jumped over one notch outwards. Will replace belts. Will try an 'O' notched belt.
11/22/83	Started compressor 1. Computer malfunction. Restarted compressor 1 for a 15 min run. EXHV-1 valve is erratic. replaced 3-way transducer on valve EXHV-1. Restarted compressor 1, tested refrigerated dryer - dryer acts like it is plugged on the outlet. Compressor 1 ran for another 2 hours.
11/28/83	Mechanics suggested a 10 notch belt pulley, and if that doesn't help, then try using an idler pulley for keeping proper belt tension at all speeds.
12/20/83	Started compressor 1 - it would not start due to a software problem. Got it started and ran for 45 min, but run terminated before planned time due to excessive belt slippage and smoking. It took 20 min for the smoke to clear from the building. Started compressor 2, it ran for 1.5 hours.

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

Date	Description of the logged event or action
01/03/84	<p>Started compressor 1, ran it for 1.5 hours. Had to shut it down due to belt slippage and abnormal noise emanating from the motor.</p> <p>Restarted compressor 1, turned it off 1 min later due to high vibrations. Reset switches and breaker on MCC-C, but when restart was tried, it tripped on high vibration again. People smelled a faint 'electrical smell' near the switches.</p> <p>Mechanic looked at compressor 1 motor - and turned it over by hand. They heard a faint ticking noise throughout the motor. Stethoscoped the motor and confirmed that the bearings are going out. The bearings need replacement. Will attempt to replace the bearings with the motor in place.</p>
01/09/84	<p>Started compressor 2, ran for 15 min</p> <p>Started compressor 2 again, ran it for 7.5 hours</p>
01/16/84	<p>Compressor 1 knocking was a .05 cm piece of steel stuck to the south face of the north piston. While working in the compressor, we took some paint samples. Analysis showed barium and sulphur, the combination needed to deteriorate the ETC system probes.</p>
01/19/84	<p>Compressor 1 was reassembled. Testing gave the same noise. The inspection cover for the north piston was opened, and a 0.5 cm long piece of wire was found and removed. The next compressor 1 test was good. It ran for 5 min at 100% load.</p>
01/21/84	<p>Started compressor 1. It tripped the main breaker in the 5501 building. Breakers were reset. Restarted compressor 1. It tripped the breaker open again. We depowered the stack fan to reduce electrical loads and then restarted compressor 1. It worked fine, so we turned it off after 2 min. Returned fan load, restarted compressor 1 and it tripped the main breaker again.</p>
01/31/84	<p>Started compressor 1, ran it for 3.25 hours</p>
02/06/84	<p>Started compressor 2, ran for 2.5 hours, then it tripped on motor overload.</p>
02/08/84	<p>Mechanics inspected compressor 2, it would not start. It had a 'motor overload' signal identical to the one received on 02/06/84. The mechanics found a wire pushed in too far, making contact on its insulation. Compressor 2 was run for 1 minute to verify that it was fixed.</p> <p>Tried removing paint from compressor 1. Used paint remover, acetone, and hysol dissolver.</p> <p>Started compressor 2, ran it for 35 min, shut it down due to electrical power brown out of 5501 building. Test run was terminated due to loss of air conditioning for TSTA computers.</p>

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

Date	Description of the logged event or action
02/15/84	Ran compressor 2 for 6 hours to test for vibrations and operation of the refrigerated dryer
02/23/84	Ran compressor 2 for 5.75 hours to make hydrogen addition tests. Noted a leak from the top flange on Molecular Sieve Bed #4. It was tightened up.
02/27/84	Ran compressor 2 for 45 min
03/01/84	Ran compressor 2 for 45 min
03/05/84	Ran compressor 2 for 1 hour
03/07/84	Ran compressor 1 in the regeneration mode for 1.5 hours
03/08/84	Ran compressor 2 for 1 hour
03/12/84	Ran compressor 2 for 1 hour
03/15/84	Ran compressor 1 for 2.5 hours
03/19/84	Ran compressor 1 for 2 hours. Note - mechanics need to come out to tighten the belts.
03/22/84	Ran compressor 2 for 30 min
03/23/84	Ran compressor 1 for 8 min, ran compressor 2 for 3 min
03/26/84	Ran compressor 2 for 1.25 hours
03/28/84	Ran compressor 2 for 5 min
03/29/84	Ran compressor 2 for 30 min
04/05/84	Ran compressor 2 for 4 min
04/11/84	Ran compressor 2 for 30 min for ventilation/room pressure test
04/13/84	Ran compressor 2 for 30 min for ventilation/room pressure test. Compressor 2 is hot to the touch, leaking air from the unloader.
05/29/84	Ran compressor 2 for 1 hour
06/12/84	Ran compressor 2 for 11 hours in an extended run
06/19/84	Ran compressor 2 for 3 min
06/20/84	Loaded molecular sieve into ETC beds MSB 1, 2, and 3. Each bed held 5.67 barrels.

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

Date	Description of the logged event or action
09/18/84	Compressor 1 will be discharging out temporary piping routed out the front doors. This test is for positive removal of paint and solvents from the exhaust manifold. We can't poison the catalyst beds any further. Compressor 1 ran for 2.25 hours.
01/10/85	Ran compressor 2 for 45 min
01/21/85	Ran compressor 2 for 45 min
02/04/85	Ran compressor 2 on emergency diesel power for 1 hour
02/11/85	Ran compressor 1 for 2 hours
02/20/85	Ran compressor 2 for 45 min
02/25/85	Ran compressor 1 for 1 hour
03/06/85	Ran compressor 2 for weekly run, 1 hour
03/13/85	Started compressor 1, the computer failed so it was started locally. 5 min later we shut down compressor 1 because valve EXHV-1 would not control pressure.
03/27/85	Ran compressor 1 for 1 hour
04/01/85	Ran compressor 2 for 1 hour
04/09/85	Compressor 1 was run 8 hours for an extended run test
04/15/85	Ran compressor 2 for 1 hour
05/13/85	Ran compressor 1, but the circuit breaker on MCC-C tripped after 4 min. Restarted compressor 1 and ran for 1 hour.
06/06/85	Ran compressor 1 for 1 hour
06/13/85	Ran compressor 2 for 45 min
06/17/85	Ran compressor 1 for 45 min
06/24/85	Ran compressor 2 for 1 min
07/17/85	Ran compressor 1 for preventive maintenance, but a belt jumped a notch (a groove) on the pulley belt after 3 min. Compressor 1 was shut down.
08/12/85	Started compressor 2 for catalyst bed heatup test, ran for 1 hour
08/13/85	Started compressor 1, ran for 5 min, but it was shut down due to belt problems.

TABLE C-1. ETC LOGBOOK EXCERPTS (con't)

<u>Date</u>	<u>Description of the logged event or action</u>
08/14/85	Ran compressor 2 for 1 hour
08/15/85	Ran compressor 2 for 1 hour
08/28/85	New belts were put on compressor 1 by the mechanics. We tried to start compressor 1, but it would not start from the control room. The computer was having a software problem.
09/04/85	Started compressor 1, mechanic suggested that compressor 1 should be operated by increasing the system starting pressure before going to 100% load, and on shutdown going to 25% load before decreasing system pressure. Tried this, but the pressure overshoot system limits by 8 to 9 psi (55 to 63 kPa). Compressor 1 ran for 1.5 hours.

It should be noted that at the late 1985 point in time, the ETC system began to use preventive maintenance (PM) sheets to record operating information as well as the logbook. Therefore, the logbook citations began to take on more of a maintenance nature, that is, component care - such as oiling, cleaning, belt tension checks, etc. These entries are not reproduced here because they would add very little to understanding the system.

From 1982 through September 1985, the compressors had these start demands and run times recorded:

	<u>Total Number of</u> <u>Start Demands</u>	<u>Minutes</u> <u>of Run Time</u>	<u>FTS</u>	<u>FTR</u>	<u>other</u>
Compressor 1 - 1982	18	490	0	6	0
Compressor 1 - 1983	36	1925	4	6	0
Compressor 1 - 1984	12	705	3	0	0
<u>Compressor 1 - 1985</u>	<u>14</u>	<u>992</u>	<u>2</u>	<u>3</u>	<u>0</u>
Compressor 1 - total	80	4112	9	15	0
Compressor 2 - 1982	3	54	0	1	0
Compressor 2 - 1983	24	1882	0	2	1
Compressor 2 - 1984	24	2556	0	1	0
<u>Compressor 2 - 1985</u>	<u>12</u>	<u>601</u>	<u>0</u>	<u>0</u>	<u>0</u>
Compressor 2 - total	63	5033	0	4	1

After 1985, the weekly runs were continued for almost 5 more years. Each compressor was operated for about an hour each week over that time period. Failure events were cited in the Failure/Maintenance data base. Other operating tests can be considered as successes. The bi-weekly compressor runs (that is, each compressor ran twice a month) were changed to monthly compressor runs (each compressor tested once a month) at the end of August 1990. The same run time (i.e., an hour) is used, but the reduced frequency of runs reflects that the system reliability has grown and that the system has operated reliably enough to meet technical requirements without more rigorous testing.

Table C-2 gives highlights from the ETC logbook regarding initial equipment problems. These problems are typical of those that plague many systems. The underlined events in the table include equipment with incorrect specifications, equipment that did not meet desired specifications, equipment constructed incorrectly, foreign material intrusion during construction, and other problems. This information is useful to be able to predict future faults for other systems similar to the ETC.

TABLE C-2. NOTABLE LOGBOOK EVENTS DURING ETC STARTUP AND TESTING

<u>Event date</u>	<u>Event description from the ETC logbook</u>
11/22/82	Ran compressor 1 to check on building vibration responses (about 15 min). Compressor 1 started, but the belt flapped badly, so it was shut down. Restarted, ran up to 25% load, but <u>duct work outside on building roof was vibrating badly.</u> Deep pulsing is being transmitted to the supports and roof.
12/17/82	At 1600 hours, a loud noise was heard in main experiment room. <u>A section of exhaust duct had collapsed.</u> (12/20/82; The theory is that an exhaust fan causes negative pressure in the duct and the main experiment room ventilation also causes negative pressure. Between the two, there was enough negative pressure to cause the duct to collapse.)
02/10/83	Ran compressor 1 for 10 min. Tried to blow dry the water storage tanks. <u>The valves were plumbed backwards.</u> The valves were fixed.
02/22/83	Tried to start compressor 1, but the circuit breaker on MCC-C tripped open. <u>Motor was shorted.</u> It was removed to send to the electrical shop for rewinding.
03/10/83	<u>Compressor 1 motor would not cool well enough at high elevation like TSTA.</u> Should start motor maximum of 4 times per hour to keep temperature low.
05/11/83	Ran compressor 1 on the emergency diesel. <u>Belts smoked to the extent that a fire was expected (no fire occurred).</u>
06/22/83	<u>Valve CV-4 did not open on demand. Valve was dirty. It is an air operated valve, using nitrogen instead of air.</u>
08/09/83	... <u>The dryer discharged pieces of black and silver material.</u> R. Carlson thinks it is catalyst.
08/10/83	Drained another 2.5 liters of water from the dryer. <u>It had more black and silver material in it.</u>
08/24/83	Inspected valve controllers, <u>dirt in and on diaphragms (very fine brown deposit) and metal shavings from pipe threading were in instrument air lines.</u>
10/25/83	<u>Dirt was flushed from system with air and 21 gallons (about 80 liters) of water.</u> Water from the fourth flushing came out clear.
12/20/83	... ran [compressor 1] for 45 min, but run terminated before planned time due to excessive belt slippage and smoking. <u>It took 20 min for smoke to clear from the building.</u>

TABLE C-2. NOTABLE LOGBOOK EVENTS DURING ETC STARTUP AND TESTING (con't)

<u>Event date</u>	<u>Event description from the ETC logbook</u>
01/03/84	<p>Started compressor 1, ran it for 1.5 hours. Had to shut it down due to belt slippage and <u>abnormal noise emanating from the motor.</u></p> <p>Restarted compressor 1, turned it off 1 min later due to high vibrations. Reset switches and breaker on MCC-C, but when restart was tried, it tripped on high vibration again. People smelled a faint 'electrical smell' near the switches.</p> <p>Mechanics looked at compressor 1 motor - and turned it over by hand. They heard a faint ticking noise throughout the motor. <u>Stethoscoped the motor and confirmed that the bearings are going out.</u> The bearings need replacement. Will attempt to replace the bearings with the motor in place.</p>
01/16/84	<p><u>Compressor 1 knocking from a 0.05 cm piece of steel stuck to the south face of the north piston.</u> While working in the compressor, we took some <u>paint samples.</u> <u>Analysis showed barium and sulphur, the combination needed to deteriorate the ETC system probes and poison catalyst.</u></p>
01/19/84	<p>Compressor 1 was reassembled. Testing gave the same noise. The inspection cover for the north piston was opened, and a <u>0.5 cm long piece of wire was found and removed.</u> The next compressor 1 test was good. It ran for 5 min at 100% load.</p>
02/08/84	<p><u>Tried removing paint from compressor 1. Used paint remover, acetone, and hysol dissolver.</u></p>
02/23/84	<p>... <u>Noted a leak from the top flange on Molecular Sieve Bed #4.</u> It was tightened up.</p>
09/18/84	<p>Compressor 1 will be discharging out temporary piping routed out the front doors. <u>This test is for positive removal of paint and solvents from the exhaust manifold.</u> We can't poison the catalyst beds any further.</p>

APPENDIX D

TRITIUM SYSTEMS TEST ASSEMBLY

FAILURE/MAINTENANCE DATA FORMS

APPENDIX D

TRITIUM SYSTEMS TEST ASSEMBLY FAILURE/MAINTENANCE DATA FORMS

This appendix shows examples of the data collection forms that are placed in strategic locations around the facility. The part I and part II forms are shown. More information about these forms is found in the main report and its references.

TSTA FAILURE AND CORRECTIVE MAINTENANCE REPORT FORM 1

Subsystem _____ Originator _____ Report Date ____/____/____
TSTA Parameter No. or Name _____ Event Date ____/____/____ Event Time ____:____:____
Subsystem Parameters at Time of Failure _____
Subsystem Configuration at Time of Failure _____
Method of Detection _____ Occurrence Title _____
Event Narrative _____

Initial (Immediate) Action _____
.....

COMPONENT FAILURE DATA (Originator - complete the remainder of this form as fully as possible)

Component Description _____
Cause: Software ____ Personnel ____ Material ____ Design ____ Procedure ____ Other (Specify) _____
Failure Cause Narrative _____

Failure Effects: Subsystem: _____ Hours Lost _____
Unit: _____ Hours Lost _____

Other Items Affected: _____

Proposed Long-Term Corrective Action _____

Remarks _____

TSTA Report Number (filled in by QA) _____

TSTA FAILURE AND CORRECTIVE MAINTENANCE REPORT FORM 2

TSTA Report Number (filled in by QA) _____ Corrective Action Taken: Corrected by TSTA Operational Personnel _____
Corrected by TSTA Repair/Design Personnel _____
Other (Specify) _____

Failed Component _____ Serial Number _____ Model Number _____

Critical Part (s) _____

Problem with Component: Electrical _____ Mechanical _____ Software _____ Other (Specify) _____

Describe Corrective Maintenance Taken to Correct Failure _____

Special Maintenance Equipment Required _____

Time Required for Component Repair/Replacement (hours/manhours) (i) Total ____/____ (ii) Administrative ____/____

(iii) Logistics ____/____ (iv) Indirect Repair ____/____ (v) Direct Repair ____/____ (vi) Retest ____/____

(vii) Restart ____/____

Time Since Last (i) Maintenance _____ (ii) Testing _____

Unusual Circumstances Causing Long or Short Repair/Replacement Time:

Assessability _____ Size and Weight of Component _____ Connections _____ Contamination _____ (Level _____)

Other (Specify) _____

Method Used for Verification of System Operational Status _____

Corrective Action Completed On ____/____/____ By _____

Distribution

F. Adams, EG&G Mound
J. L. Anderson, LANL
J. R. Bartlit, LANL
P. Ballantyne, AECL
A. Boschi, ENEA
S. J. Brereton, LLNL
R. Buende, IPP
G. Cambi, ENEA
R. E. Carlson, LANL
V. Chuyanov, ITER Co-center
S. Ciattaglia, ENEA
I. Cook, Culham
J. N. Doggett, LLNL
B. Everman, ORNL
M. Gouge, ORNL
W. Gulden, IPP
W. Hedley, EG&G Mound
S. K. Ho, UCB
J. P. Holdren, UCB
M. S. Kazimi, MIT
I. Kirillov, Efremov
B. N. Kolbasov, Kurchatov
W. Kramer, Kfk
J. Levine, PPPL
G. Pearson, UKAEA
P. I. Petersen, GA
S. J. Piet, ITER Co-center
Y. G. Prokofiev, Efremov
J. Raeder, IPP
P. Rocco, JRC-Ispra
G. Saji, ITER Co-center
Y. Seki, JAERI
S. Sood, CFFTP
J. S. Strebkov, Institute of Power Engineering
G. L. Taylor, LANL, (4)
L. Topilski, Kurchatov
C. Wong, GA
M. Wykes, JET

**DATE
FILMED**

8/11/93

END