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PRELIMINARY ANALYSIS OF THE SAFETY AND ENVIRONMENTAL IMPACT OF THE TRITIUM SYSTEMS TEST ASSEMBLY*

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ABSTRACT

The Tritium Systems Test Assembly (TSTA) is a facility dedicated to the development of technologies associated with the D-T fuel cycle of future fusion reactors while demonstrating that TSTA can be operated safely with no significant losses to the environment. During the initial design stage of TSTA, a safety analysis was performed which investigated the effects of major subsystem component failure, the meteorology and seismicity of the site and their possible effect on the facility, and accident scenarios which result in tritium releases. Major releases of tritium to the environment are considered highly improbable since they require a concurrent failure of primary and secondary containment, along with either a breach of the building or a failure of the Emergency Tritium Cleanup system. Accidental releases caused by natural phenomena (earthquake, tornado, etc.) are considered highly improbable (< 10^{-7}/yr).

INTRODUCTION

Environmental and safety considerations resulting from the operation of the Tritium Systems Test Assembly (TSTA) have been examined and covered in a Preliminary Safety Analysis Report (PSAR). In the PSAR we considered the effects of failures of system components, of accidents caused by human errors, and of natural phenomena. The PSAR was prepared before the design of TSTA was finalized so that potential problems could be recognized and appropriate design changes made. The PSAR is updated and revised as changes and additions are made in the system. In this paper we report the significant conclusions of the PSAR.

Description of TSTA

The TSTA, under construction at the Los Alamos Scientific Laboratory (LASL), is a facility dedicated to the development, demonstration, and testing of technologies associated with the deuterium-tritium fuel cycle of future fusion reactors. One of the principal goals of TSTA is to demonstrate that these can be accomplished safely with no adverse effect on site personnel, the general public, or the environment. The major risk at the facility results from the large quantity of tritium, 150 grams ($\sim 1.5 \times 10^6$ Ci) handled at the facility.

An artist's early concept of the TSTA is shown in Fig. 1 while Fig. 2 shows the relationship between the various subsystems of the main process loop and the auxiliary subsystems. The TSTA consists of a gas loop which can simulate the proposed fuel cycle for a fusion reactor, plus auxiliary subsystems. The fuel loop and most of the support subsystems are contained in one large room which has its own ventilation system and is kept at a pressure less than those of the areas which do not contain tritium. The gas loop is designed to process up to 360 moles per day of DT. The fuel, mostly DT, is mixed with helium and impurities to simulate the products of a fusion burn. This stream is split and fed to the Vacuum subsystem (VAC) and the Fuel Cleanup subsystem (FCU). In VAC helium is removed and the remaining mixture is cyclically pumped with a compound cryopump and subsequently transferred to the FCU. The FCU converts the tritiated impurities to either the oxide or gas depending on which of two loops is used. The output of FCU is a gaseous stream of the hydrogen isotopes. (A detailed discussion of the operation of FCU is given in another paper at this conference.) The Isotope Separation System (ISS) takes the output of FCU and converts it to streams of T_2, DT, D_2, and a waste stream of H_2. These streams are then stored for moving until time to complete the fuel loop.

The environmental and safety subsystems which support the main process fuel loop are:

- Secondary Containment (SC)
- Tritium Waste Treatment (TWT)
- Emergency Tritium Cleanup (ETC)
- Tritium Monitoring (TM)

Secondary containment is an integral part of most of the subsystems of TSTA. The primary goal of TSTA is to doubly contain all components of the primary process loop where a significant risk of the release of multi-curie quantities of tritium exists. Some of the large components of VAC may not have secondary containment due to the low

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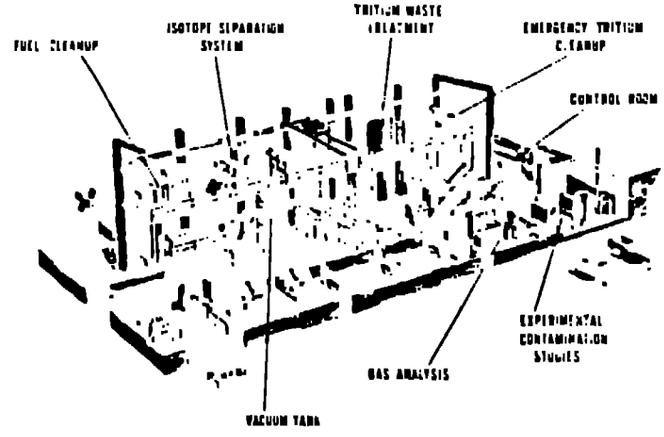
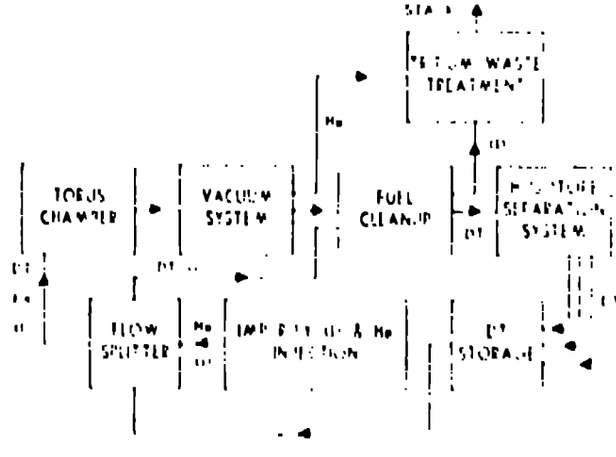


Figure 1. Artist's concept of the TSTA.



pressure of the tritium gas and the size and complexity of the vacuum system. However, at present we are re-evaluating the need for secondary containment of VAC. Most failures which result in tritium leaks will be handled by SEC with the tritium removed by the TWT.

The TWT is designed to provide for removal of tritium from routinely generated gaseous effluents. The detritiation factor for TWT is assumed to be approximately 10^6. The ETC will be used in the event of large accidental releases into the main experimental room housing the fuel loop. For a release of 100 grams of tritium into the room and with the ETC operating the total release to the environment is calculated to be less than 1 Ci.

The TM subsystem will monitor rooms, enclosures, exhaust duct, stack and process systems of the TSTA. When a major release is detected in the room, the duct isolation valves automatically close isolating the room from the environment. This action is taken independent of the computer system. If any two of the room, duct, or stack monitors detect a major release, the ETC will automatically begin processing the room air.

One of the most important subsystems from an operational standpoint is the Master Data Acquisition and Control subsystem (MDAC). Except for a few hardwired safety systems, the fuel loop and the support equipment are controlled and/or monitored by the computer subsystem. Details of the TSTA are given in another paper at this conference.

Safety Analysis

Each of the subsystems of TSTA was analyzed in detail with a Failure Modes and Effects Analysis (FMEA) to evaluate the adequacy of the safety features of the design, identify critical failure modes, and recommend alternatives or precautions that will minimize the probability or effect of the failures. The failures were considered with respect to the effect on the operations of TSTA, the effect on the personnel of TSTA as well as on the general public, and the environment. In approximate decreasing order of severity, these consequences are:

I. Tritium Release to the Environment
   - Ia. Major Release
   - Ib. Minor Release
II. Tritium Release to the Experimental Facility
   - IIa. Major Release
   - IIb. Minor Release
III. Safety Hazard to TSTA Personnel (non-tritium related)
IV. Major Loss of Experimental Capability
V. Minor Loss of Experimental Capability
VI. No Effect on the Operation of TSTA or a Safety Hazard

The basis of the FMEA was to assume a failure of a system component and to follow its effect through the subsystem and, if necessary, through other subsystems to determine the ultimate result of the failure. In our analysis, only failures of major components (critical to safety) were analyzed. It was beyond the scope of our analysis to do more detailed FMEA, event or fault trees, or probabilistic risk analyses. With the FMEA, single point failures which would lead to either consequence Ia or IIa were determined. The possibility of these failures was then eliminated or substantially reduced by redesign of the system or if this was not possible, measures were taken to mitigate the effects of the failure.

The effects of failures induced by outside forces (external to the operation of TSTA) both man-made and caused by natural phenomena were also determined with this analysis. Except in a few cases we did not attempt to assign probabilities or frequency of occurence for any of the assumed failures. We felt that the data on which there would be based were too limited to give meaningful results. One of the goals of TSTA is to provide a data base for failure rates for components used in tritium service.

Effects of Normal Operations of TSTA

The predominant hazard to personnel at the TSTA facility will be potential tritium exposures which result from the use and handling of tritium and components contaminated with tritium. Inert-atmosphere gloveboxes will minimize oxidation and permeation to the room atmosphere should leaks occur within gloveboxes. Maintenance of contaminated components of the various subsystems will either be done in these gloveboxes or in temporary glove-fitted plastic enclosures whose atmosphere will be processed by a small tritium cleanup system or by the TWT. Air-supplied plastic suits will be worn by maintenance personnel when necessary.

TSTA will have approximately 150 g of tritium at the facility. A breakdown of the expected inventory in each subsystem is given in Table I.

TABLE I

Expected Tritium Inventory

System	Quantity	Form
[illegible]	[illegible]	Gas
[illegible]	[illegible] g	Gas or Liquid
[illegible]	[illegible] g	Gas
[illegible]	0.1 g	Gas
TWT	[illegible] g max	Gas

The [illegible] of maximum release rate of tritium to the environment [illegible] during the [illegible]. The breakdown of where this release comes is given in Table II.

TABLE II

Expected Tritium Release per Year

[illegible]	[illegible] Ci
ETC	[illegible] Ci
TWT	[illegible] Ci
Maintenance	[illegible] Ci

Based on this rate, the maximum dose commitment to persons in uncontrolled areas persistently exposed to this release was calculated to be 1 mrem/yr and the projected population dose to be less than 0.2 man rem/yr. For these calculations, the tritium was assumed to be completely oxidized, the critical organ to be the body water, the biological half-life of tritium in the body to be 10 days, the quality factor of tritium to be 1, the breathing rate to be 2.64 x 10^{-4} m^3/sec and the skin intake to be 63% of that inhaled. The doses were then determined using average normalized-concentration isopleths based on site and demographic data. Based on LASL experience, no significant increase in tritium concentration in vegetation, soil, or ground water is expected as a result of this small chronic release rate of 200 Ci/yr.

The design dose criterion (i.e., that dose which will not be exceeded) for normal working operations is 1 rem/yr for TSTA personnel. Normal operations include startup, shutdown, checkout, repair, and maintenance, and minor component malfunctions or leaks likely to occur during the life of the facility.

Accident Analysis for the TSTA

Most anticipated accidental releases resulting from failures in the TSTA will be handled by the secondary containment with the tritium release processed by the TWT. TSTA personnel should not receive any dose from any of these releases unless the involved glovebox is also breached. If a release of ~10 curies in a secondary containment occurs, the glovebox will be automatically purged with the contaminated atmosphere processed by the TWT. The expected release to the environment from such a 10-curie spill will be approximately 10 μCi - 10 μCi.

Failures leading to the release of tritium into the main experimental room either result from leakage from one of the components which do not have secondary containment, or a double breach of primary and secondary containments. Abnormal releases to the environment would usually require a three-fold failure of primary and secondary containments along with either a breach of the main experimental room or failure of the ETC.

The more credible accidents involve releases of tritium gas rather than oxide. Tritium gas conversion to tritiated water in a large room such as the TSTA cell is a slow process even when catalyzed by exposed metal surfaces.

Using the results of the EMFA, the significant postulated accidents and their consequences in terms of exposures are given in Table II.

As expected, the accidents which have potentially the most serious consequences result from tritium releases from the systems with the largest tritium inventories. The most serious postulated accident results from the rupture of the ISS columns and surrounding vacuum jacket accompanied by a fire resulting in the loss and oxidation of the total inventory of ISS (approximately 100 grams) to tritiated water vapor. With the ETC operations, only approximately 1 curie is expected to be released to the environment. However, if the ETC fails and the total amount is quickly stacked, the maximum dose at the site boundary is 2.9 rem.

A few potential major accidental releases to the environment were analyzed in some detail. One accident scenario that was studied because of the proximity of the facility to the local airport is an aircraft accident involving penetration through the roof of the TSTA building. In the scenario, the inventory of the cryogenic isotope separation system (100 g) is released, oxidized by the accompanying fire and lost to the environment through the roof. With the plume rise from the heated gases, the resultant dose to an exposed person at the site boundary (0.4 km distant) is 1 rem. An unlikely loss of the entire TSTA inventory, oxidized and stacked, would result in a dose of less than 5 rem at the same boundary point.

The probability of damage to the TSTA facility from natural phenomena is judged to be small. No tornados or hurricanes have occurred in recorded history at Los Alamos. The probability of flooding is considered to be nonexistent. The response of the building to wind and seismic loading was analyzed and building has been judged to be suitable for TSTA.

Any wind (tornado or other) that could structurally damage the building, somehow resulting in a release of tritium at ground level, would also rapidly dilute the tritium concentration. For instance, the maximum dose to a member of the public (resulting from a release of the total inventory of 150 g of oxidized tritium at ground level) is < 1 rem if the wind is as high as 4 mph (4 m/s), which the TSTA building has already experienced and withstood with no known effect.

An earthquake that could possibly cause some damage to the building is one with a maximum acceleration of 0.3 g. Such an earthquake has a probability of occurrence of 10^{-4} yr^{-1}. The worse damage that could result is cracking of the walls with one or more concrete blocks from the walls falling on unprotected equipment. The result is a possible breach of primary and secondary containment barriers with subsequent loss of tritium gas which may somehow be ignited upon release. The tritiated water vapor escapes to the environment through the breach in the wall and is carried downwind to populated areas.

The nearest site boundary or public area in the highway next to the Los Alamos airport, 4.[illegible] m to the north across an intervening deep canyon. Winds from the south toward the airport or nearby townsite are invariably accompanied by a Pasquill Category D condition or better (A-C). The same is true for winds up the mesa. Category D winds are usually quite strong whereas weaker winds in that direction are usually accompanied by more unstable conditions (Category A-C). Category E and F meteorological conditions normally occur at night and are accompanied by westerly winds and thus blow away from populated areas. Thus for the above scenario a Pasquill Category D with a wind speed of 1 m/s was chosen. The result is a χ/Q of 7 x 10^{-9} $s\,m^{-3}$ and a maximum whole body dose at the site boundary of 4[illegible] rem for a ground-level release of the total inventory of 150 g of tritium at T_2O.

The probability of occurrence of such an accidental release is extremely small since it

TABLE III SUMMARY OF POSTULATED ACCIDENTS

Failure	Releasable Inventory Ci	Releasable Inventory Form	Mitigation Method[1]	Release to Stack Ci	Boundary[2] Site Whole Body Dose (mrem)	Whole Body Worker Dose Rate[3] (mrem/min)
1. a) Rupture or large leak from torus or duct work which is not secondary contained.	100	DT	A	100	7×10^{-6}	2.1×10^{-3}
			B	1×10^{-4}	3×10^{-7}	2.1×10^{-3}
b) Same as 1a, accompanied by a fire.	100	DTO/HTO/T_2O	A	100	3×10^{-1}	97
			B	1×10^{-4}	3×10^{-7}	97
2. a) Rupture of cryopump.	5.8×10^4	DT	A	5.8×10^4	3.9×10^{-3}	1.3
			B	5.8×10^{-2}	2×10^{-4}	1.3
b) Rupture of cryopump accompanied by fire or a detonation in the pump.	5.8×10^4	HTO/T_2O	A	5.8×10^4	170	5.6×10^4
			B	5.8×10^{-2}	2×10^{-4}	5.6×10^4
3. a) Rupture of distillation columns to vacuum jacket.	9.7×10^5	DT, T_2	C	1	3×10^{-3}	0
b) Same as 3a, followed by a breach of the vacuum jacket.	9.7×10^5	DT, T_2	A	9.7×10^5	0.07	21
			B	1	3×10^{-3}	21
c) Same as 3b accompanied by a fire, release at 50 m	9.7×10^5	D_2O, DTO, T_2O	A	9.7×10^5	2.9×10^{-1}	9.1×10^5
			B	1	3.0×10^{-3}	9.1×10^5
4. a) Leakage of transfer lines from NBI and IMS to FCU into secondary containment.	3000	DT, T_2	C	3×10^{-3}	9×10^{-6}	0
b) Same as 4a followed by breach of secondary containment	3000	DT, T_2	A	3000	2×10^{-4}	6.4×10^{-2}
			B	3×10^{-3}	9×10^{-6}	6.4×10^{-2}
c) Same as 4b, accompanied by a fire	3000	DTO, D_2O, T_2O	A	3000	9	2.9×10^{-1}
			B	3×10^{-3}	9×10^{-6}	2.9×10^{-1}

[1] Mitigation Method

A -- Ventilate Experimental Room

B -- Process Room Air with Emergency Cleanup System. Release form is tritiated water vapor

C -- Process Contaminated Air with Tritium Waste Treatment System

[2] This is maximum dose commitment and includes the skin intake. The dose is determined from Fig. B-1. The dose to the skin itself is discussed in section 6.1. Site boundary is 400 m from TSTA

[3] Worker Dose per minute of exposure. It is expected for personnel to exit from the room in less than 30 seconds. The calculations also assume uniform mixing in the room

takes a natural phenomenon with a very low probability to begin with (10^{-4} yr^{-1}) accompanied by winds of a right magnitude and direction, coupled with blocks falling in the right place, causing the release of a large fraction of the inventory that is somehow ignited.

Although the above scenario already borders on the incredible with an overall probability very likely in the order of 10^{-5} yr^{-1} or less, consideration is being presently given to selective hardening of the concrete block wall over critical components.