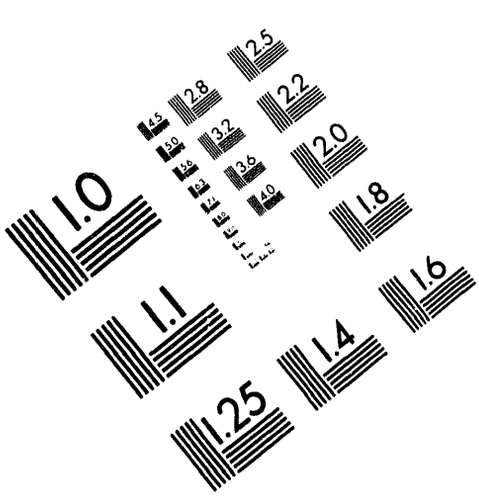
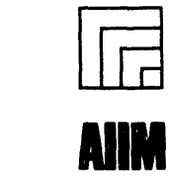
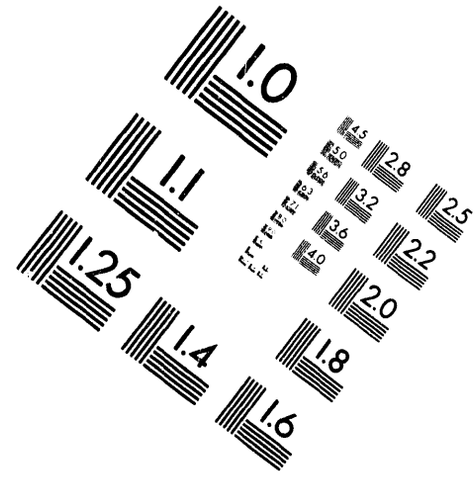
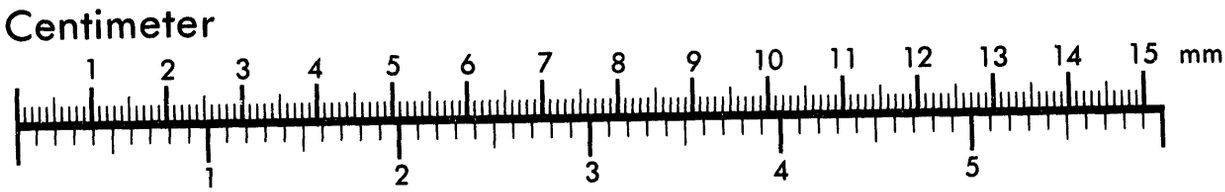
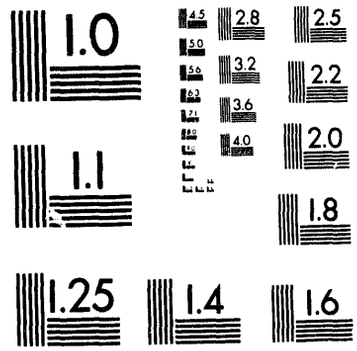


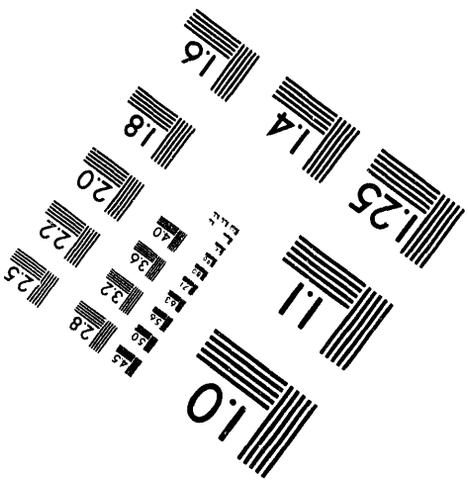


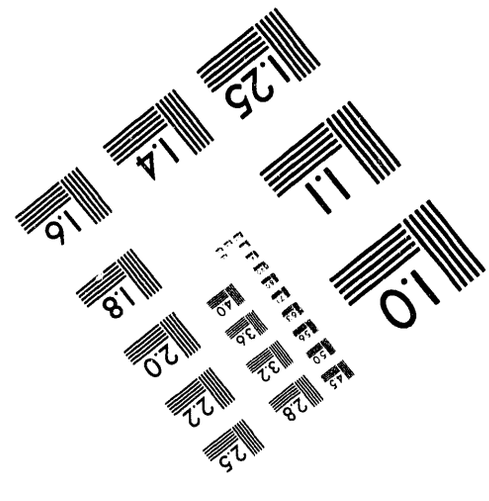
Association for Information and Image Management
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202











1 of 1

CONF-940843--2
PPPL-CFP--3149

The tritium operations experience on TFTR

A. von Halle, J.L. Anderson,[a] C. Gentile, L. Grisham, J. Hosea, J. Kamperschroer, P. LaMarche, M. Oldaker, A. Nagy, S. Raftopoulos, T. Stevenson, and the TFTR Group

Princeton Plasma Physics Laboratory
P.O. Box 451, Princeton, New Jersey, 08543 USA*

[a]Los Alamos National Laboratory
Los Alamos, New Mexico, 87545 USA

The Tokamak Fusion Test Reactor (TFTR) tritium gas system is administratively limited to 5 grams of tritium and provides the feedstock gas for the neutral beam and torus injection systems. Tritium operations on TFTR began with leak checking of gas handling systems, qualification of the gas injection systems, and high power plasma operations using trace amounts of tritium in deuterium feedstock gas. Full tritium operation commenced with four highly diagnosed neutral beam pulses into a beamline calorimeter to verify planned tritium beam operating routines and to demonstrate the deuterium to tritium beam isotope exchange. Since that time, TFTR has successfully operated each of the twelve neutral beam ion sources in tritium during hundreds of tritium beam pulses and torus gas injections.

This paper describes the TFTR tritium gas handling systems and TFTR tritium operations of the gas injection systems and the neutral beam ion sources. Tritium accounting and accountability is discussed, including tritium retention issues of the torus limiters and beam impinged surfaces of the beamline components. Also included is tritium beam velocity analysis that compares the neutral beam extracted ion species composition for deuterium and tritium and that determines the extent of beam isotope exchange on subsequent deuterium and tritium beam pulses. The required modifications to TFTR operating routines to meet the U.S. Department of Energy regulations for a low hazard nuclear facility and the problems encountered during initial tritium operations are described.

1. INTRODUCTION

The deuterium-tritium (D-T) experimental program on TFTR is well underway achieving world record performance using tritium as the feedstock gas for the neutral beam and torus injection systems. To date, peak fusion power of ~9 MW has been obtained at a corresponding central fusion power density of ~1.8 MW m^{-3}.[1] Routine, stable operation of the TFTR tritium handling and experimental systems coupled with diligent system maintenance is certainly a prerequisite of these results.

2. TRITIUM GAS HANDLING

Tritium gas is received in low pressure, 50 liter stainless steel canisters from the U. S. Department of Energy (DOE) Savannah River Site and transferred from the Tritium Receiving and Analytical Glove Box (TRAGB) onto one of three depleted uranium beds in the Tritium Storage and Delivery System (TSDS). When needed, tritium is dissociated from uranium at approximately 100 kPa as the uranium bed is heated to approximately 400°C. The tritium gas is then compressed to 270 kPa into a calibrated holding volume where it is measured, sampled and subsequently expanded into the Tritium Gas Delivery Manifold (TGDM).

The ~120 m long TGDM is coaxial in construction with an inner capillary line to conduct the tritium gas and an outer evacuated tubing to provide secondary containment. The inner diameter is small (1.6 mm) to minimize tritium inventory. The outer diameter is monitored by an ion gauge and a Quadrupole Mass Spectrometer (QMS) to provide an interlock that prevents tritium transfer if vacuum is lost or tritium is detected in this secondary containment. The TGDM delivers gas to any combination of the two Tritium Gas Injection Assemblies (TGIA) of the torus and the twelve Neutral Beam Tritium Gas Injectors (NBTGI)[2] (Fig. 1).

* Work supported by U.S. DOE Contract No. DE-AC02-76-CH03073.

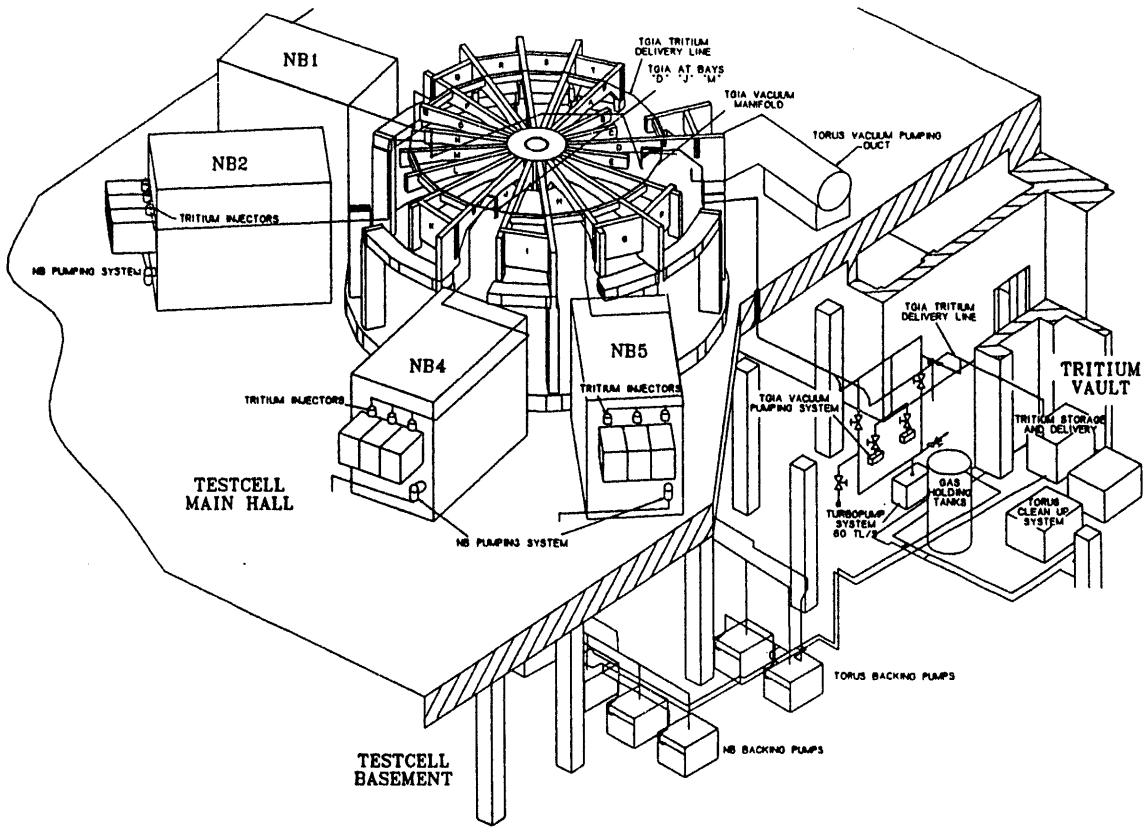


Figure 1. View of the TFTR Tritium Systems.

Tritium used in TFTR experiments is pumped by liquid helium panels in the four neutral beamlines. During cryopanel regeneration, the panels are warmed and the condensed hydrogen isotopes are vaporized and pumped, along with the effluent from the Torus Vacuum Pumping System (TVPS), into one of two Gas Holding Tanks (GHT). Each 7.6 m^3 GHT will remain subatmospheric and be considered full at less than 93 kPa. Gas in the GHT is analyzed with a QMS and tritium is measured by redundant Femto-Tech™ ionization chambers. The gas is then processed through the Torus Cleanup System (TCS) where the hydrogen isotopes are catalytically oxidized to form water which is collected on a Disposable Molecular Sieve Bed (DMSB). The DMSB is removed and replaced when it nears its loading limits for either water or tritium content. There are two types of DMSBs used at TFTR. The first, Type A, is designed to collect less than 3.7E13 Bq of tritium for long term storage or burial. The second, Type B, is designed to collect up to 9.3E14 Bq and will be sent back to the Savannah River Site for recovery of the tritium from the water.[3]

There are other systems[4] key to the operation of the tritium facility at TFTR but not necessarily part of the tritium processing cycle. The 0.5 m^3/s Tritium Vault Cleanup System (TVCS) has 20 times the cleanup capability of the TCS in order to process the atmosphere in the various rooms of the tritium facility in the event of a tritium release into these areas. This system may also be used as a backup to the TCS or for large leak mitigation in the event of a breach of torus or beamline vacuum. The Tritium Storage and Delivery Cleanup System (TSDCS) mitigates tritium in the TSDS glovebox atmosphere. The Tritium Regeneration System (TRS) is required to provide the high temperature regeneration gas for the oxygen getter bed and the molecular sieve drier beds in the various cleanup systems.

The tritium systems were designed in the late 1970's, installed in 1982, began non-tritium operation in 1990, and commenced tritium operations in the fall of 1993.

3. TRITIUM ACCOUNTING

TFTR operations in tritium are accomplished under stringent inventory limits of 1.9E15 Bq of

tritium on site and 9.3E14 Bq in any single location. This low limit has the advantage of limiting the possible site boundary dose due to a design basis accident to only 1.4 μSv, but constrains the amount of TFTR D-T operations that may occur between tritium processing cycles. At present, TFTR operations are scheduled around an on-site tritium shipment of 9.3E14 Bq every two operating weeks balanced by a similar amount of tritiated water off-site shipment during the same operating period. This amount of tritium will typically support 16 D-T pulses each employing six tritium neutral beam sources. Therefore, every attempt is made to maximize beam, plasma, and diagnostic reliability to ensure that the D-T shots are successful. A typical D-T shot will require approximately 20 deuterium shots to set up the conditions, check out the diagnostics, and establish plasma reproducibility. The neutral beams, which are conditioned in deuterium, will see hundreds of deuterium shots for every tritium pulse. It is important to note that the deuterium used for experiments and conditioning is also processed through the TCS and dispositioned on a DMSB.

Tritium inventory and accountability methods are mandated by DOE orders and all tritium transfers are measured and recorded to provide a real time record of tritium inventory. Testing and calibration of the instrumentation used to monitor the tritium inventory in the TSDS, the GHTs and the TGDM is an ongoing activity of TFTR's tritium control and accountability plan.[2] Tritium retention in the torus and the neutral beamlines, however, cannot be directly measured and is a key consideration in maintaining tritium inventory control. The amount of tritium retained in these area must be determined from differences in tritium delivery and GHT exhaust measurements. The majority of the tritium retained in the TFTR vacuum vessel will be held by the graphite tiles that make up the wall and bumper limiters of the torus and in a co-deposited layer of carbon and hydrogen isotopes removed from the limiter by the plasma and redeposited on other internal structures. Tile samples taken after a two year deuterium only run period indicate deuterium retention to be 45%±15% of the plasma fueling.[5,6] Additional mechanisms for retention include tritium adsorption on the stainless steel, copper, and aluminum surfaces of the beamlines and torus and the implantation of tritium in beam impinged surfaces.

4. TRITIUM NEUTRAL BEAMS

The bulk of plasma core heating and tritium fueling is supplied by the neutral beam injection system.[7] The beam system is comprised of four beamlines each equipped with three long pulse ion sources and oriented such that two beamlines inject tangentially co-directional to the plasma current and two inject counter-directional to the plasma current. Each of the twelve ion sources has a dedicated D-T gas injection system[8] capable of providing either deuterium or tritium gas. Hence, maximum flexibility is afforded in choosing co/counter beam gas compositions.

All neutral beam conditioning and set up injection shots are performed in deuterium as the gas usage for a beam extraction is considerable. A typical single ion source will require ~3.7E12 Bq of tritium just to establish the proper ion density in the source's arc chamber before beam extraction and another 3.7E12 Bq of tritium for every second of beam extraction. Of this ~33 torr-liters/sec of tritium flowing into the ion source during beam extraction, only 10% is introduced into the torus in the energetic neutral beam. Therefore, only ~5% of the tritium introduced into an ion source is used to fuel and heat a TFTR plasma. The remainder of tritium is captured on the beamlines cryopanels along with the deuterium required for beam conditioning on prior and subsequent shots. The ion sources are conditioned by pulsing once every 2.5 minutes into either the beamline calorimeters at full pulse length during daily start up or the torus protective plates at 50 msec pulse lengths once the day's beam injection operations have begun. Beam spectroscopy indicates that the ion source isotopic changeover is ~98% complete for tritium injection and is >99.5% complete for deuterium injection since the tritium contamination of the deuterium beam cleans up in 5-6 pulses. Beam calorimetry has shown that the effective tritium beam power is typically 10% higher than that of deuterium due to overdense source operation in tritium and the increased neutralization efficiency at lower velocity. Analysis of the Doppler-shifted optical emissions of the beam in the neutralizer has revealed that the extracted ion composition for deuterium and tritium are indistinguishable: 0.72 ± 0.04 D^+, 0.22 ± 0.02 D_2^+, 0.07 ± 0.01 D_3^+ compared to 0.72 ± 0.04 T^+, 0.23 ± 0.02 T_2^+, 0.05 ± 0.01 T_3^+.[9]

DISCLAIMER

5. TRITIUM OPERATIONS

During the past year, TFTR has successfully made the transition from a DOE general use facility to a low hazard nuclear facility. In addition to the hardware changes required for tritium operations, changes in procedures, organization, and training were implemented to operate safely and without impact to the environment. A series of integrated system test procedures were written and performed to assure the operational readiness of the tritium systems.[10] To date, all tritium systems have been successfully operated, including tritium beam injection by all twelve neutral beam ion sources. The operation of the tritium systems on TFTR is providing valuable engineering data and operational experience for both JET and ITER on the handling of tritium in a fusion device.

The commissioning and initial operations of the tritium systems over a 5 month period saw accumulated TFTR stack releases of 2.2E12 Bq of tritium, resulting in a calculated site boundary dose of 0.5 μSv. This corresponds to approximately 12% of the annual release expected from routine operations and 0.5% of the permissible annual site boundary dose. The largest single release of 4.1E11 Bq of elemental tritium occurred during a maintenance operation to sample pump oil. This also released about 3.7E10 Bq into the tritium vault which successfully initiated the TVCS. New leaks on previously leak checked tritium systems were found as full concentration tritium was introduced. Most were found to be due to elastomeric gaskets through which tritium was permeating or metal gaskets which were improperly installed or failed due to thermal cycling. After these initial operating problems, a 30% linear error of the ion chambers that sample the GHTs propagated into a tritium inventory accounting problem that resulted in an accumulation of about 4% over the TFTR site limit. D-T operations were temporarily suspended for one month to determine the cause of this accumulation, which subsequently led to the discovery of this systematic calibration error and the revision of the inventory management procedures for a clearer division of responsibilities and more effective issue communication.

Special considerations for decontamination and handling procedures for tritium systems are needed when maintenance requires a breach of primary tritium containment. These "line breaks" have been, and are, routinely and safely performed on the diagnostic systems, the tritium gas handling systems, and the neutral beam systems. In June, all twelve neutral beam ion sources were decontaminated, removed, repaired, and reinstalled successfully and without incident.

REFERENCES

1. J. Hosea, et al., "Deuterium-Tritium experiments on the Tokamak Fusion Test Reactor," 11th Topical Meeting on the Technology of Fusion Energy, 1994, American Nuclear Society, New Orleans, LA.

2. P. H. LaMarche, et al., "Tritium processing and management during D-T experiments on TFTR," 11th Topical Meeting on the Technology of Fusion Energy, 1994, American Nuclear Society, New Orleans, LA.

3. J. L. Anderson et al., "Operation of the TFTR Tritium Systems during initial tritium experiments," 3rd International Symposium on Fusion Nuclear Technology, 1994, Los Angeles, CA, accepted for publication in Fusion Engr. and Design.

4. R. A. P. Sissingh and R. L. Rossmassler, "Tritium facility at TFTR" Fusion Engr. and Design 12, 383 (1990).

5. W. R. Wampler et al., J. Vac. Sci. and Technol., A6 2111 (1988).

6. W. L. Hsu and R. A. Causey, J. Vac. Sci. and Technol., A5 2768 (1987).

7. T. N. Stevenson et al., "The 33MW TFTR Neutral Beams," 14th IEEE Symposium on Fusion Engineering, 1991, San Diego, CA,

8. M. E. Oldaker, J. E. Lawson, K. E. Wright, 15th IEEE Symposium on Fusion Engineering, 1993, Hyannis, MA.

9. J. H. Kamperschroer et al., "Observation of Doppler-Shifted T_α Emission from TFTR Tritium Neutral Beams," Rev. Sci. Instrumen. (to be published).

10. J. L. Anderson et al., "Initial Testing of the Tritium Systems at the Tokamak Fusion Test Reactor," Proc. 15th IEEE Symposium on Fusion Engineering, 1993, Hyannis, MA.

DATE
FILMED
10/13/94
END