LA-UR-82-2650

Conf-820948--4

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--82-2650

DE83 000667

TITLE: THE DEVELOPMENT OF TRITIUM TECHNOLOGY AT THE TRITIUM SYSTEMS TEST ASSEMBLY

AUTHOR(S): James L. Anderson and John R. Bartlit

SUBMITTED TO: 12th Symposium on Fusion Technology, Julich, Germany, September 13-17, 1982

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

THE DEVELOPMENT OF TRITIUM TECHNOLOGY AT THE TRITIUM SYSTEMS TEST ASSEMBLY

JAMES L. ANDERSON and JOHN R. BARTLIT*
Los Alamos National Laboratory P. O. Box 1663, MS-C348,
Los Alamos, NM 87545 (USA)

ABSTRACT

The Tritium Systems Test Assembly (TSTA) at the Los Alamos National Laboratory is dedicated to the development, demonstration, and interfacing of technologies related to the deuterium-tritium fuel cycle for large scale fusion reactor systems starting with the Fusion Engineering Device (FED) or the International Tokamak Reactor (INTOR).

This paper briefly describes the fuel cycle and safety systems at TSTA including the Vacuum Facility, Fuel Cleanup, Isotope Separation, Transfer Pumping, Emergency Tritium Cleanup, Tritium Waste Treatment, Tritium Monitoring, Data Acquisition and Control, Emergency Power and Gas Analysis systems. Discussed in further detail is the experimental program proposed for the startup and testing of these systems.

1. INTRODUCTION

The Tritium Systems Test Assembly (TSTA) at the Los Alamos National Laboratory is dedicated to the development, demonstration, and interfacing of technologies related to the deuterium-tritium fuel cycle for large scale fusion reactor systems starting with the Fusion Engineering Device (FED) or the International Tokamak Reactor (INTOR). The construction and equipment installation phase of the project will be completed in the summer of 1982 and initial tritium-free check out will begin immediately. Initial tritium testing will begin in the fall.

The TSTA project will develop and demonstrate the fuel handling cycle for fusion power systems and the requisite personnel and environmental protection system associated with the fuel cycle. The principal objectives of TSTA can be concisely stated: (1) demonstrate the fuel cycle for fusion power reactors; (2) develop, test, and qualify equipment for tritium service in the fusion program; (3) develop and test environmental and personnel protective systems; (4) provide a final system that can be used for demonstration and as an example that could be directly copied at a fusion facility; (5) demonstrate long-term reliability of components; (6) demonstrate long-term safe handling of tritium with no major releases or incidents; and (7) investigate and evaluate the response of the fuel cycle and environmental packages to normal, off-normal, and emergency situations.

The TSTA fuel cycle will process tritium at the rate of 1 kg per day; thus it is essentially a full-scale fuel cycle for FED or INTOR. The on-site tritium inventory at TSTA will be 150 g.

2. TSTA PROCESS LOOP AND SYSTEM DESCRIPTION

The TSTA main process loop and auxiliary systems are depicted in Fig. 1. Although the TSTA loop /1/ and its component systems have been described in detail previously, a brief description here is essential for understanding the proposed experimental program to be discussed in this paper.

*This work supported by the Office of Fusion Energy, US Department of Energy.

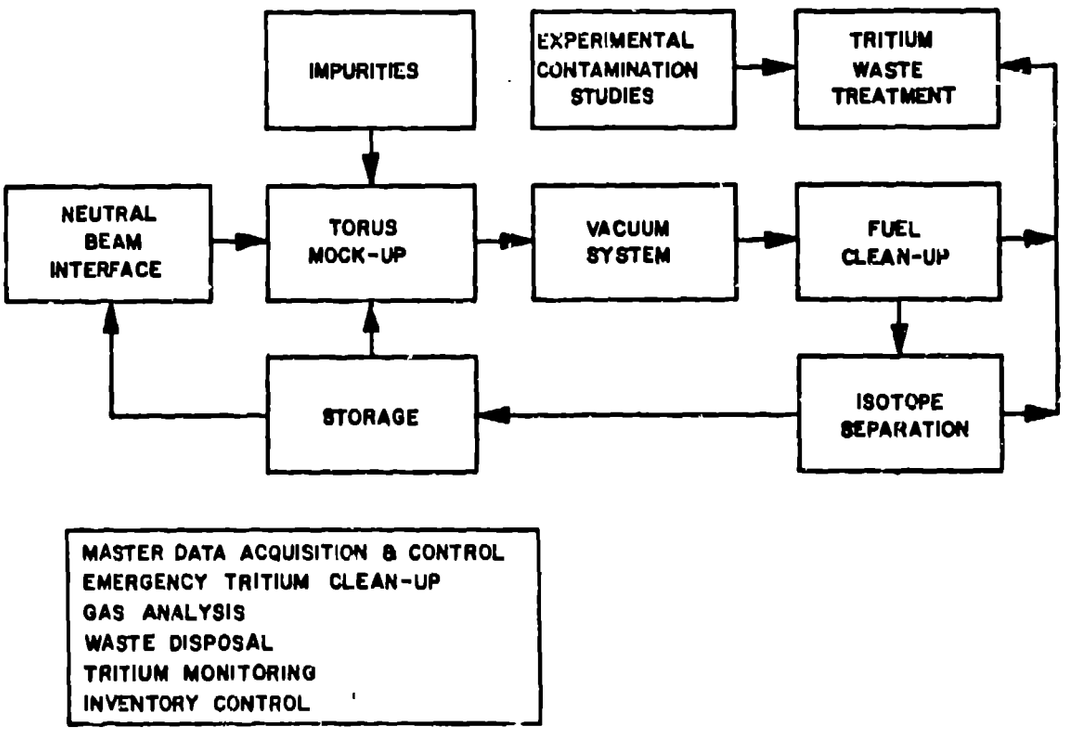

Fig. 1. Main process loop and auxiliary systems.

2.1 Torus mock up

No plasmas will be handled at TSTA. Simulated fuel and impurity mixtures are injected into, and evacuated from, a mock torus consisting of a vacuum vessel approximately 1 m^3 in volume.

2.2 Vacuum system

Evacuation of the mock torus is done by one of three prototype compound cryopumps /2/ designed to pump both hydrogen isotopes and helium at speeds of 16 m^3/s and 1.6 m^3/s respectively. The pump configurations are: (1) chevrons at 4 K surrounding molecular sieve at 4 K; (2) chevrons at 4 K in front of charcoal at 4 K; and (3) a pump incorporating chevrons at 4 K and cryotrapping of helium in continuously-generated layers of argon frost at 4 K. Regeneration of cryopumps is done with turbomolecular, rotary scroll, or metal-bellows backing pumps/2/.

2.3 Fuel cleanup

Impurities of tritiated water, methane, ammonia, and argon are removed from the DT fuel stream down to 1 ppm and the contained tritium recovered for reuse through a series of processes including gettering on activated metals, absorption on molecular sieves at 77 K, catalytic oxidation at 800 K, and freezeout /3/.

2.4 Isotope separation

A series of four, interlinked, cryogenic distillation columns is used to separate the purified stream of hydrogen isotopes into four desired product streams /4/. The product streams are: (1) a tritium-free stream of HD for waste disposal; (2) a stream of high-purity D_2 for simulated neutral beam injection; (3) a stream of DT for simulated reactor

refueling; and (4) a stream of high purity T_2 for refueling and for studies on tritium properties and effects on materials.

2.5 Tritium waste treatment and emergency tritium cleanup

TSTA includes two tritium scavenging systems, each of similar concept but different capacity, for capturing tritium from wastes or leaks which might otherwise reach the environment. The first system, Tritium Waste Treatment (TWT), can process 0.025 m^3/s of tritium-contaminated gases from various process systems or from glove box atmospheres. The second, Emergency Tritium Cleanup (ETC) /5/, can process 0.65 m^3/s of facility room air in the event of tritium release from a breach in both the primary and secondary walls of doubly-contained tritium vessels and piping. Both scavenging systems are designed to achieve decontamination factors of 10^5 - 10^6 using catalytic recombination of tritium to water, followed by air drying by condensation (ETC) and molecular sieves (TWT and ETC).

2.6 Other systems

A variety of auxiliary systems perform needed functions at TSTA. Systems included are: (1) tritium monitoring - in general, active monitoring of tritium concentrations in stack emissions and facility room air is done by ion-chamber instruments; (2) transfer pumping - a specially-developed, all-metal bellows pump is the principal type of pump used; (3) data acquisition and control - full computer control is effected by redundant central processing units (two Data General Eclipse C330 minicomputers) backed up by redundant safety computers (two LSI-11/23s); (4) emergency power - back-up power for TSTA is available instantaneously from batteries and for extended periods (at least 30 hours) from a diesel generator set; 5) gas analysis - the principal instruments for analysis are on-line gas chromatographs, mostly with thermal conductivity detectors, and one or more helium ionization detectors; (6) uranium hydride storage beds - when not being processed, hydrogen isotopes are stored at low pressure on uranium beds; (7) inventory control - tritium inventory is monitored periodically by transferring gases to a standard volume where pressure, temperature, and composition can be determined with an expected overall accuracy of tritium assay of 0.25 percent; and (8) experiment contamination studies - TSTA includes a small laboratory room (5.5 m x 3.7 m) for studies on room cleanup, optimum surface coatings, surface monitoring, and rates of tritium conversion to water vapor in the field.

3. EXPERIMENTAL PROGRAM AT TSTA

In broadest terms, the experimental program consists of testing the performance characteristics (off-normal as well as normal) and the reliability of the original TSTA components and any second-generation additions or alternatives that arise. Within this scope, the enumeration of specific details focuses on the current areas of greatest technical concern.

3.1 Vacuum system

Basic pump performance, as measured by pump speeds and regenerability, using mixtures of D, T, He, and impurities in the three prototype pumps is, of course, important. In addition, experiments will be run to answer the following questions:
(1) What are the effects on speed and regeneration of increased helium levels? (2) What pump conditions (pressures and durations) result in "thermal runaway," that is, the uncontrollable reevaporation of condensed gases? (3) What temperatures, rates of temperature change, and temperature relationships between the two pumping surfaces constitute the

optimum regeneration procedure from the standpoint of being the most rapid yet manageable? (4) What pumping/regeneration cycle maximizes pump utlization without producing unacceptable tritium inventories? (5) To what extent does degradation of helium pumping speed occur due to tritium and thermal cycling? (6) What are the best procedures for repairing or replacing valves, transducers, seals, and entire pumps?

3.2 Fuel cleanup

Important provisions of overall tests on the Fuel Cleanup System include plans to investigate:

(1) the effect of increased helium in the feed; (2) the impurity removal effectiveness of getter and absorption beds as a function of temperature and flow rate; (3) the fraction of theoretical bed capacity utilized at first breakthrough of impurities in the bed outlet stream; (4) the kinetics (flow dynamics) of impurity regeneration from molecular sieve beds; (5) the oxidation efficiency of the catalytic oxidizer as a function of temperature and percent excess oxygen; (6) the life of the oxidation catalyst; (7) the efficiency of DTO trapping in the DTO freezeout unit as a function of operating temperature; and (8) the refill, replacement, or repair of beds, valves and instruments.

3.3 Isotope separation

Specific experiments have been planned for the Isotope Separation System to determine: (1) product purities as a function of column reflux ratio and flow fraction withdrawn from the top of the column; (2) the effect on column performance of increased helium in the feedstream; (3) the time after startup to reach steady-state operation; (4) the column efficiencies (measured as the Height Equivalent to a Theoretical Plate - HETP); (5) the maximum allowable vapor velocity in the columns which permits smooth liquid flow down the column, that is, avoids flooding; (6) the system response to sudden variations in feed rate or composition; (7) the optimum control characteristics in terms of instrument time constants and gains; (8) the effect of tritium decay heat on column operation; and (9) the effect on column plugging of condensable impurities in the feedstream.

3.4 Tritium scavenging systems

A number of questions must be answered experimentally about the Emergency Tritium Cleanup (ETC) system for room air or the smaller Tritium Waste Treatment (TWT) system for gaseous process wastes. These questions include the following:
(1) What is the recombiner catalyst efficiency as a function of temperature? (2) What are the best procedures for regenerating saturated molecular sieve beds in situ using heated dry nitrogen and for loading-out and refilling saturated beds when they must be replaced? (3) What are the patterns of flow of room air to the ETC and what is the resulting room purge efficiency in the the experimental contamination laboratory? (4) What is the life of the recombiner catalyst? Which, if any, catalyst poisons present problems? (5) What are the optimum conditions for water swamping (water addition) between the first and second stage dryers?

3.5 Experimental contamination studies

The experimental contamination studies will be an important and continuing effort at TSTA for the indefinite future. Experiments in the first phase are planned to study the following:

(1) the efficiency and performance of a small tritium cleanup (gas detritiating) system; (2) surface contamination, outgassing and permeation properties of construction materials (wood, concrete, tile, etc.) and surface coatings for short term exposures (< 1 week); (3) contamination and outgassing properties in metals, glasses, and plastics used in tritium containment systems at high concentrations and for long exposures; (4) the relationship between total tritium in surfaces and amount measured by surface survey probe and by wiping removable tritium; (5) methods such as heating, use of detergents, physical removal of surface layer, etc. to decontaminate small articles, large surfaces and large equipment; and (6) gas conversion rates of T_2 and DT to oxide forms under realistic release situations.

Later experiments in the experimental contamination laboratory may address safety issues associated with getter materials for the storage of tritium at low pressure, with electrolysis cells for recovery of tritium from contaminated waters, and with protective clothing. Studies on protective clothing deal with finding the best materials and design with regard to comfort, durability, and minimum contamination in addition to achieving a high overall protection factor.

3.6 Other systems

Generally, the auxiliary systems, such as tritium monitoring, gas analysis, transfer pumping, power, and data acquisition and control, are services that are better developed than the process systems. With three exceptions, auxiliary systems will be subjected to few experiments beyond straightforward system checks. The exceptions are the uranium hydride storage beds, inventory control, and the experimental contamination studies discussed above.

Experiments to be performed on the hydrogen storage beds will measure the kinetics of hydrogen uptake and evolution as a function of percent bed saturation, and will determine repeatability or cyclability of bed operation. The questions to be answered by early experiments on inventory control will focus on the overall fraction of hydrogen isotopes in TSTA which can be recovered for assay and the overall accuracy of that assay.

4. EXPERIMENTAL RESULTS TO DATE

Although construction of the TSTA flow loop was completed just this past summer and no tritium has yet been introduced into the system, preliminary experimental results using hydrogen (protium) and deuterium are available from two systems. The systems are the vacuum system and isotope separation system.

4.1 Compound cryopumps

Very early results on one of the three TSTA compound cryopumps were reported previously /6/. Since then, more complete results on all three pumps have been obtained pumping gas mixtures of $He/H_2/D_2$, as well as mixtures including nitrogen and argon. The most important results are summarized in Table I and Fig. 2. We see that the best pump performance, both in terms of speed and capacity, is achieved by the pump incorporating an argon spray for pumping helium (LLNL design). However, a drawback of the design is the requirement of adding about 30 atoms of argon for each atom of helium pumped. The speeds for pumping deuterium by the three pumps in Fig. 2 were:

LANL - 2.85 $\ell/s\text{-}cm^2$, LLNL - 6.6 $\ell/s\text{-}cm^2$, and

BNL - 6.6 $\ell/s\text{-}cm^2$.

Table I.

DESCRIPTION OF PUMPS
AND EXPERIMENTAL RESULTS

	Los Alamos	LLL	BNL
Cooling	2-Phase Flow	He Reservoir	
DT pump		4 K Chevrons	
DT area	0.28 m^2	0.9 m^2	0.24 m^2
He pump	M.S. 5A	Argon Frost	Charcoal
He area	0.16 m^2	1.1 m^2	0.13 m^2
DT speed	8 000 ℓ/s	60 000 ℓ/s	16 000 ℓ/s
He speed	1 600 ℓ/s	22 000 ℓ/s	3 000 ℓ/s
Specific Speed for D_2	2.85 ℓ/s cm^2	6.6 ℓ/s cm^2	6.6 ℓ/s cm^2
Specific Speed for He	1.0 ℓ/s cm^2	2.0 ℓ/s cm^2	>2.0 ℓ/s cm^2
He capacity	1.0 Tℓ/cm^2	1.0 Tℓ/cm^2	6.0 Tℓ/cm^2
He capacity	1 600 Tℓ	10 000 Tℓ	>10 000 Tℓ

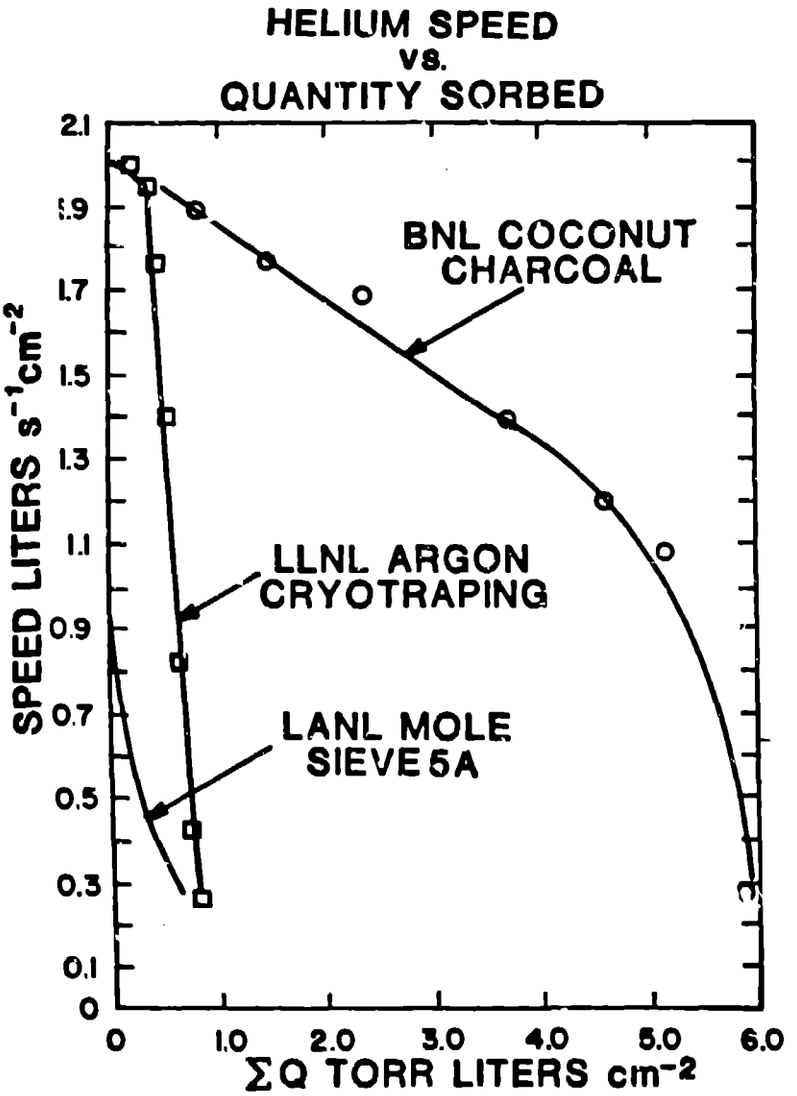

Fig. 2. Pumping speeds for helium for 3 cryopumps vs. quantity sorbed.

4.2 Isotope separation system

The cryogenic, four-column, fractional distillation system has been tested in separating the three-component mixture $H_2/HD/D_2$. Although all functions of the system cannot be tested on only three components, a number of significant op rating parameters were measured. Column efficiency was not accurately determined because a virtually complete separation of either H_2 or D_2 was produced from an equal-atom mixture of $H_2/HD/D_2$.

Two parameters were measured which are important in determining the final tritium inventory of the ISS. These are the minimum operable liquid level in a column reboiler (bottom pot on stills) and the operating liquid holdup in the column (in column packing). Stable, steady-state operation of the columns was achieved with a reboiler liquid level as low as 15 mm, as measured and controlled by a differential pressure measurement of liquid head. This is well below the design value of 50 mm. Liquid holdup in the columns was measured to be 11 percent of the volume of the empty column. This is also less than the design value of 15 percent. The measured values indicate ISS may be able to operate with a contained tritium inventory as low as 70 g instead of the design value of 110 g.

5. JTURE EXPERIMENTS WITH ALTERNATIVE OR ADDITIONAL PROCESSES

Upon completion of the experiments outlined on the TSTA as presently configured, the installation and testing of alternative or additional processes is anticipated. Although these are further away in time and therefore dependent on developments in the interim, comments on some likely prospects are appropriate.

5.1 Helium separation

High on the list of additions is equipment for separating helium from hydrogen isotopes. The separation of helium from DT is technica y feasible in the regeneration of compound cryopumps, since He and DT are pumped onto separate panels which can be regenerated (warmed) separately. However, this slower regeneration cycle may prolong unacceptably the time for pump regeneration, thus necessitating an independent process for removing helium. This process could be a palladium-alloy diffusion membrane, through which only DT will pass, or a falling liquid film condenser, in which only DT is condensed. A preliminary design for the latter has been described in the literature /7/. Such equipment may well be installed at TSTA in the future.

5.2 Components in the impurity removal train

If current tests prove successful, a device which may offer advantages for purifying DT is the palladium-alloy membrane. This device is about the same size as the hot metal beds presently used at TSTA and could be tested there with tritium. Potential advantages are the high purity of the ISS feedstream produced and the inherently continuous nature of the process.

An eventual goal of TSTA is the incorporation of a tritium-compatible electrolysis cell for dissociating DTO. Though not presently available, such a cell ideally would have characteristics of minimum tritium inventory (implying vapor-phase electrolysis) and no use of fluid electrolytes or organic materials. A cell which might prove suitable after development is the high-temperature, ceramic electrolyte cell /8/.

5.3 Fueling pellet injectors

D-T pellet injectors for fusion machines are under development at Oak Ridge National Laboratory. Successful designs could be tested in tritium service at TSTA.

5.4 Breeding blanket interface

Equipment for processing tritium and/or tritium oxide in the form extracted from a lithium breeding blanket must eventually be tested in the fuel loop. These processes are not materially different from the current impurity removal processes being tested, but interfaces must be proven.

5.5 Other experiments and developments

Commercial fusion machines eventually will require on-line methods of tritium accounting which do not interfere with normal plant operations. One such method already suggested /9/ might be the monitoring of the ^{3}He produced in the radioactive decay of tritium.

New and better cryopump designs may arise and require testing at TSTA. Process filters for gamma-emitting particulates from the torus also may need testing.

6. SUMMARY

This paper has described briefly the recently-constructed Tritium Systems Test Assembly at Los Alamos National Laboratory and has discussed the near-term and longer range experimental program planned there for developing and demonstrating tritium-compatible technology for fusion fuel processing. Available experimental results using hydrogen and deuterium are given for the cryopump and cryogenic distillation systems.

REFERENCES

/1/ ANDERSON, J.L., Proceedings of the IEEE, 69, No. 8, August 1981.

/2/ COFFIN, D.O., and WALTHERS, C.R. 8th Symposium on Engineering Problems of Fusion Research, San Francisco, CA, 13-16 November 1979, Proceedings pp. 513-517.

/3/ KERR, E.C., BARTLIT, J.R. and SHERMAN, R.H., Tritium Technology in Fission, Fusion, and Isotopic Applications, Dayton, OH, 29 April - 1 May, 1980, Proceedings pp. 115-118.

/4/ BARTLIT, J.R., DENTON, W.H., and SHERMAN, R.H. Third Topical Meeting on the Technology of Controlled Nuclear Fusion, Santa Fe, NM, 9-11 May, 1978, Proceedings pp. 778-783.

/5/ MULLER, M.E., Third Topical Meeting on the Technology of Controlled Nuclear Fusion, Santa Fe, NM, 9-11 May, 1978, Proceedings pp. 720-728.

/6/ COFFIN, D.O., and WALTHERS, C.R., 8th Symposium on Engineering Problems of Fusion Research, San Francisco, 13-16 November, 1979, Proceedings pp. 513-517.

/7/ KINOSHITA, M., BARTLIT, J.R. AND SHERMAN, R.H., 9th Symposium on Engineering Problems of Fusion Research, Chicago, 26-29 October, 1981, Proceedings pp. 1217-1220.

/8/ (a)SPACIL, H.S., AND TEDMON, C.S., JR., Electrochem. Sci., 116, 1618-1633 (1969).

(b)DOENITZ, W., AND SCHMIDBURGER, R., Int. J. Hydrogen Energy, 7, 321-330 (1982).

/9/ COFFIN, D.O., Los Alamos National Laboratory, personal communication.