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TITLE: THE TRITIUM SYSTEMS TEST ASSEMBLY: OVERVIEW AND RECENT RESULTS

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THE TRITIUM SYSTEMS TEST ASSEMBLY: OVERVIEW AND RECENT RESULTS

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The fusion technology development program for tritium in the U. S. is centered around the Tritium Systems Test Assembly (TSTA) at Los Alamos National Laboratory. The TSTA is a full-scale system of reactor exhaust gas reprocessing for an ITER-sized machine. That is, TSTA has the capacity to process tritium in a closed loop mode at the rate of 1 kg per day, requiring a tritium inventory of about 100 g. The TSTA program also interacts with all other tritium-related fusion technology programs in the U. S. and all major programs abroad. This report summarizes the current status, results and interactions of the TSTA. Special emphasis is given to operations in May/June using large compound cryopumps that completed the fuel loop integration of all TSTA subsystems for the first time.

1. INTRODUCTION

Objectives of this project are to develop and demonstrate the fuel cycle for processing the reactor exhaust gas (unburned deuterium and tritium plus impurities), and the necessary personnel and environmental protection systems, for the next generation of fusion devices.

Related tasks include new component development and testing, operations under emergency and off-normal conditions, gathering of long-term reliability data, and operator training. To complete this mission, two major types of activities are under way at the facility. The first is the periodic operation of the integrated fuel reprocessing loop with a gradually increasing level of system integration and tritium inventory. The second major activity is the tritium testing of new components in experiments in separate gloveboxes. The latter are often done in collaboration with workers from other U. S. fusion programs and programs abroad.

2. INTEGRATED LOOP OPERATIONS

2.1 September 1986

In September 1986, a major five-day, round-the-clock operation of the TSTA integrated processing loop was carried out. The goals of the run were achieved as planned, and included the following accomplishments:

- integrated flow processing through all process systems except the compound cryopumps;
- the removal of impurities (up to 7% nitrogen) by the fuel cleanup system (FCU), though without continuous impurity addition or on-line regeneration and recovery of the captured impurities;

- the addition of 20 g of tritium to the flow loop, raising the in-process inventory to 50 g;
- the verification of improved flow control measures added to the loop;
- the production and analysis of tritium gas of 99.93% purity in the cryogenic distillation columns of the isotope separation system (ISS); and
- the training and use of personnel in different operating assignments to broaden staff experience and versatility.

2.1 December 1986

The September run was followed by a similar five-day, round-the-clock operation in December 1986. Goals and accomplishments of this run were the following:

- further development and improvement of flow control in the loop;
- elimination of unwanted interactions between the isotope separation system and effluent gas detritiation system;
- measurement of long time constants (several hours) for the isotope separation system to reach steady state after control changes are made; and
- changing from our previous two 12-hour shifts to three 8-hour shifts, with the night shift being a two-man shift making minimal process changes.

2.3 June/July 1987

The next major operation of the integrated process loop occurred in June 1987. The goals of this run were the following:

- to increase the in-process inventory of tritium to 100 g;
- to demonstrate the successful removal of helium-3 from tritium decay by two techniques--gettering out the tritium on uranium beds before dumping the helium, and stripping out the tritium in the distillation columns before dumping the helium;
- to provide training for personnel including two new operators;
- to produce and analyze high purity tritium (>99.9%) in the ISS; and
- to verify long-term, continuous addition of impurities (about 1% N_2 and 0.1% CH_4) and their successful removal by the cold (77 K) molecular sieve adsorption beds in the fuel cleanup system.

The inventory was raised to 90 g and all goals except the last two were achieved before operations were concluded prematurely by a broken shaft on the commercial cryogenic refrigerator used to provide cooling to the cryogenic distillation columns. An orderly shutdown under off normal conditions, without doses to personnel or releases to the environment, was achieved following the unexpected failure in off the shelf technology unrelated to tritium handling.

Following a repair and upgrade of the refrigerator by a factory representative, round the clock operations were resumed in July, for a period of 5 days, to add to the 4 days before the refrigerator failure. The tritium inventory was increased to 102 g, and the last two run goals were achieved at this time. In particular, a tritium sample of 99.98% purity was prepared in the ISS.

Impurities were added to the fuel stream continuously for 53 hours and removed by the FCU to below the limit of detection of Raman spectroscopy (low ppm levels). The impurities added were a mixture of N_2/CH_4 in 9/1 ratio and comprising 1% of the D T fuel stream flow. The effectiveness of impurity removal was further confirmed by the lack of any plugging in the cryogenic still that continuously processed the outlet flow from the FCU. On-line regeneration and processing of the captured impurities was not a part of the July round-the-clock operation.

2.4 February/March 1988

On-line regeneration and decomposition of the captured impurities was first done in operations of February/March 1988.

The run was notable, not only for the high degree of eventual success, but for two abortive starts, during the weeks of February 7 and 21, that were ended by plugging lines with condensable impurities. The problem impurities were not impurities intentionally added to the system, but were impurities that had leaked in or formed in the system from previous operations. Nitrogen and water appeared to be the main constituents.

The problems were finally solved by removing all gas from the piping, heating all components, purging with helium, and evacuating over several days, before recharging the gas to the system. Although the problems were unfortunate and caused added work, the demonstration of the ability to recover proved the wisdom of the original design philosophy of TSTA, which was one of versatility in piping and pumping capabilities.

Technical highlights of the run results were the following:

- stable operation of the ISS over many days;
- 36 hours of addition of 0.9% N_2/0.1% CH_4 to the fuel stream and the complete removal (to the limit of detection) of these impurities using the molecular sieve beds at 77 K;[1]
- on-line regeneration of these beds, followed by catalytic oxidation of the impurities to form water, complete capture of the water by freezeout from a flowing stream, and decomposition of the captured water by reaction with hot uranium to recover tritium for reuse in the fuel stream; and
- production and offloading of 11.8 g of better than 99.98% pure tritium from the ISS into a shipping container.

Figure 1 below shows the breakthrough of nitrogen impurity at a sampling point 3/4 of the bed length downstream from the entrance of the molecular sieve bed. The data indicate the bed being saturated with nitrogen at this point. Methane, of course, remains tightly bound in the initial portion of the bed. The peak above the inlet nitrogen concentration is caused by nitrogen being pushed off the initial part of the bed by the addition of the more tightly captured methane.

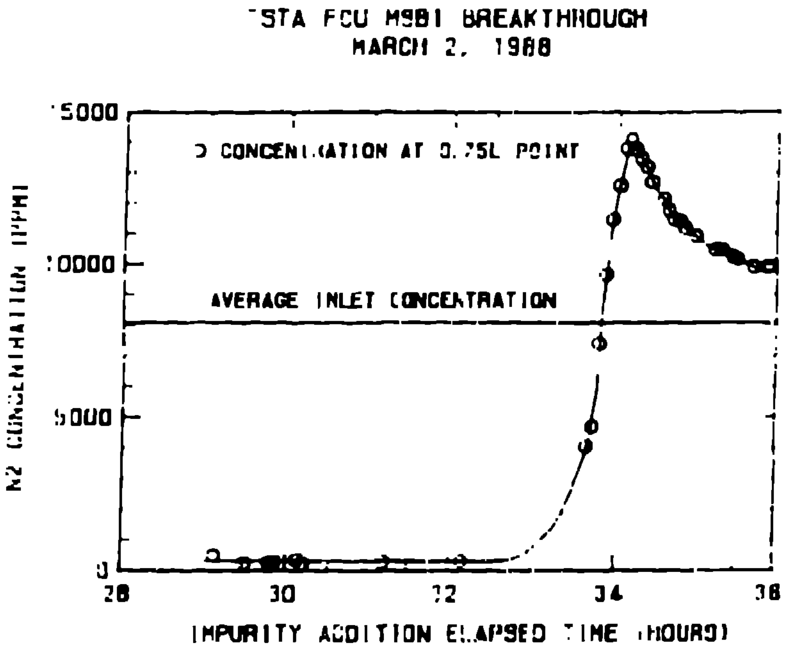

FIGURE 1.
Impurity Addition Elapsed Time (Hours)

2.5 May/June 1988

The most recent integrated loop operation was a seven-day run that took place in late May and early June. This run involved for the first time the integration of all TSTA subsystems. A compound cryopump was included in the flow loop for the first time.

This run included continuous injection of fuel impurities (nitrogen and methane), cryopumping of the fuel mix of deuterium and tritium plus impurities, on line regeneration of the cryopumps, removal of the impurities and recovery of the contained D T, and continuous separation of the hydrogen isotopes by fractional cryogenic distillation. All operations were successful. Cryopump results are included below.

Several weeks of tests on the cryopumps (VAC) without tritium were necessary to prepare for the integrated run in May. Though not without minor problems, the tests achieved the calibration and readiness of VAC needed for system integration.

Two pumps were tested one designed by Brookhaven National Laboratory (BNL) and one by Lawrence Livermore National Laboratory (LLNL). Torus pumping tests with these pumps were performed with D T, D_2, H_2, He, N_2, and their mixtures.

The nominal pumping surface areas are:

	BNL	LLNL
DT condensing chevron	2400 cm^2	9000 cm^2
He sorbing panel (charcoal)	1300 cm^2	11000 cm^2

The principal results were the following:

a) Pumping speeds for the two pumps for pumping D-T at the Torus were similar despite large differences between the pumps in the areas of the cryopumping surfaces (see Figure 2).

b) The BNL pumping speeds (in loop operation) were in the range of 2-10% of the full plasma exhaust gas flow rate for an ITER-size reactor. If three trains (pumping, regenerating, and recooling trains) of the VAC system are needed, 30-150 pumps will be needed.

c) Impurity effects on the pumping speed for D-T (and D_2) were investigated with 1% N_2 and 1-25% He. Little effect was seen.

d) The effectiveness of separating He/DT on both panels of the BNL pump was measured: DT gas regenerated from the condensing chevron showed no He contamination; He gas regenerated from the charcoal panel showed an acceptable level of DT contamination (10-25% DT).

e) A Monte Carlo simulation code to evaluate the BNL pump performance was developed. Detailed analysis of these test results are ongoing.

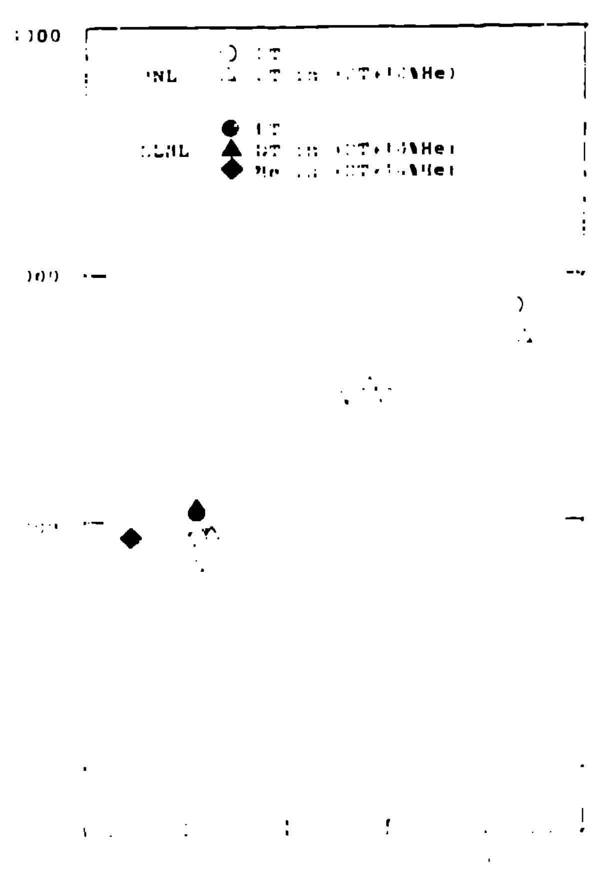

FIGURE 2.
Cryopump Performance

3. PERFORMANCE TESTS AND MAINTENANCE OF THE ISOTOPE SEPARATION SYSTEM

Isotope separation at TSTA is done by means of an interlinked, four-column cryogenic distillation system. Individual columns of the four-column isotope separation system were operated in five-day, round-the-clock runs in October and December of 1987 and April of 1988. The purpose of these tests was to measure fundamental design parameters, such as liquid holdup in columns and the height equivalent to a theoretical plate (HETP).[2]

Repairs were made on instrumentation external to the columns, but inside the vacuum jacket. This was done successfully by lowering the vacuum jacket. Tritium contamination inside the jacket was negligible.

4. TRITIUM TESTS OF NEW COMPONENTS

Five new components of potential benefit to the fusion program have been evaluated for performance and tritium compatibility in individual testing. The first four components, and organizations with whom TSTA collaborated on each, were:

a) a commercial zirconium-iron getter material for detritiation of inert glovebox atmospheres (Ontario Hydro Research Division);
b) a piezoelectric valve for fuel gas injection at the Tokamak Fusion Test Reactor (TFTR) at Princeton;
c) a ceramic electrolysis cell for recovering D-T in the reprocessing of plasma exhaust gas (Japan Atomic Energy Research Institute); and
d) a palladium-alloy membrane diffuser for purification of plasma exhaust gases (JAERI).

All four proved to be attractive and tritium-compatible components for their intended uses. Detailed results are available in the literature.[3, 4, 5]

The fifth component tested has been more recent and only preliminary results are available. This is a tritium-proof-of-principle pellet injection designed and built by Oak Ridge National Laboratory. Over 80 tritium pellets have been produced to date and accelerated with hydrogen propellant to speeds up to 1.4 kilometers per second. Work is continuing.

5. TESTS IN THE EXPERIMENTAL CONTAMINATION STUDIES LABORATORY (XCS)

Associated with the TSTA is a small laboratory dedicated to studies on the contamination and decontamination of equipment, surfaces, and atmospheres exposed to tritium. In collaboration with outside programs, two areas of work have been started since our last reporting.

1. With personnel from TFTR and the Idaho National Engineering Laboratory (INEL), studies are in progress on the effect of catalyst temperature and moisture pre-loading in the driers on the efficiency of a gas detritiation system.
2. With personnel from the Joint European Torus (JET), studies are in progress on the

contamination effects and residual contamination of remote maintenance tools (welders and cutters) after use in the torus. Both studies are incomplete at this writing.

6. JAPAN ATOMIC ENERGY RESEARCH INSTITUTE JOINS TSTA

In June 1987, an international collaborative agreement was signed by the Japan Atomic Energy Research Institute (JAERI) and the U. S. Department of Energy. This agreement, Annex IV to the U. S./Japan Agreement on Fusion Energy, calls for the joint funding and joint operation of TSTA by DOE and JAERI for the next five years (till 1992), thereby doubling the size of the program. Under the agreement, JAERI will attach a four-person staff to TSTA during the five-year life of the collaboration. The JAERI staff arrived at TSTA in mid June, 1987, in time to participate in the integrated loop operations of June/July.

7. FUTURE PLANS

7.1 JAERI-Designed Fuel Cleanup System

As part of the broad collaboration of TSTA with JAERI, a JAERI-designed Fuel Cleanup System will be fabricated in Japan and installed in the TSTA integrated fuel reprocessing loop. The design will be based on palladium diffuser technology for producing a stream of hydrogen isotopes free of impurities. The new equipment is scheduled for installation in 1989.

7.2 Breeding Blanket Interface

Since the inception of TSTA in 1976, long term plans have included the eventual addition of a breeding blanket interface at the facility. In 1987, the initial steps to define and develop this process interface were taken in collaboration with blanket design experts at Argonne National Laboratory.[6]

The work includes examining several leading blanket concepts (liquid lithium, solid lithium oxides, and aqueous lithium salt) to define the composition and flowrate of the tritium-bearing product stream from the tritium recovery process in the blanket. In a fusion power reactor, this fluid product stream, after appropriate initial processing, will join the plasma exhaust stream to make up the full reactor fueling stream.

The long term goal is to install the appropriate initial processing technology at TSTA and to demonstrate breeding blanket product processing in conjunction with plasma exhaust gas processing. The definition of stream compositions, flowrates, and processing technologies is proceeding now. The schedule for process installation at TSTA is uncertain, though at least several years away, and may depend on developments with the International Thermonuclear Experimental Reactor (ITER).

8. SUMMARY

The fusion program in the U. S. in tritium research, development, and demonstration has its focus at the integrated fusion fuel processing facility at TSTA. The overall TSTA program is multi-faceted, including integrated fuel reprocessing loop operations, new component testing, contamination experiments, and personnel training. The program is characterized by increasingly closer ties among elements within the U. S. and with programs abroad.

ACKNOWLEDGMENTS

The list of contributors to this work is too large and wide-ranging to include here. Organizational involvements have been indicated in the text. Thanks to all.

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