Extended Operation of Reactor-Scale Fusion Fuel Loop Under US-Japan Collaboration

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ABSTRACT

Tritium Systems Test Assembly (TSTA) in the Los Alamos National Laboratory is a reactor-scale fusion fuel processing loop and is operated by the Japan Atomic Energy Research Institute (JAERI) and the USDOE under the collaboration. An extended experimental campaign of the TSTA loop was performed with 100 grams of tritium in April-May 1992 in order to simulate a steady-state fusion fuel processing for 25 days. Continuous processing of simulated plasma exhaust (DT and H mixture, He, CH_4 and N_2) was successfully demonstrated. Impurity processing was successfully tested by two different techniques. US developed Fuel Cleanup System (FCU) purifies DT by cryogenic molecular sieve beds and decomposes tritiated water by Magnesium beds. Japanese developed J-FCU is based on purification by permeation through palladium alloy membrane and vapor electrolysis with a ceramic electrolyte cell. Isotope Separation System was stably operated with four interlinked columns and continuously produced pure tritium and deuterium stream while exhausting protium impurity. Real-time analysis in the ISS process was demonstrated with the laser Raman Spectroscopy. The result demonstrated the safe and stable operation of reactor-scale fusion fuel loop in a steady state.

INTRODUCTION

In June 1987, the Japan Atomic Energy Research Institute (JAERI) and the United State Department of Energy (DOE) signed a collaborative agreement regarding development of technology for fusion fuel processing. Under this agreement, JAERI and DOE have continued joint operations and experiments on fusion-fuel processing technology with the Tritium Systems Test Assembly (TSTA) at the Los Alamos National Laboratory. The TSTA is a unique facility that can simulate and test the fusion fuel processing loop with reactor scale tritium inventory and throughput. The objective of the TSTA is to develop, test, evaluate and demonstrate the safe operation of fusion fuel processing loop for future fusion machines. Through the joint operation of the TSTA, it is expected to: develop and demonstrate fusion fuel processing technology, establish safe handling of tritium for personnel and environment, test and operate tritium handling equipments and components in realistic tritium services, and establish safety database, safe procedures and training system for personnel [1,2]. Main subsystems are, Isotope Separation System (ISS), Fuel Cleanup Systems (FCU), Transfer Pump Units (TPU), Uranium Tritide Beds (UTB), Tritium Waste Treatment (TWT), Master Data Acquisition and Control (MDAC), and safety systems and utilities. In 1990, a new plasma exhaust processing system JAERI Fuel Cleanup (JFCU), designed and fabricated by Japan, was installed in the TSTA as an upgrade [3]. During the five year period, a number of tritium tests have been performed in the TSTA and many programmatic and technical milestones were accomplished. Significant progress and improvements on the tritium processing technology were made as the results and valuable data and experiences were provided for the fusion program. In 1992, an experimental campaign of integrated plasma exhaust gas processing loop for 25 days was performed. This paper reports this extended tests.

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EXPERIMENT

The purpose of the extended run were:

1) Operate the integrated TSTA fuel processing loop continuously for 25 days.
2) Operate the ISS in 4-column configuration with Raman spectroscopy for profile and dynamic measurement.
3) Operate FCU for purification by cold molecular-sieve beds and processing impurities using catalytic reactor-DTO freezer-Mg bed chain.
4) Operate the JFCU with various impurities and interface with ISS.
5) Process various hydrogen containing mixtures in a number of gas containers by the processing loop.

Configuration of the major subsystems is shown in the Fig. 1. For the purification of the hydrogen isotopes, FCU and JFCU were alternatively used. DT mixture was fed from the UTB. Simulated impurity gases such as methane and nitrogen were supplied from external source. Many gas containers were connected at the LIO (Load-in/Load out) and emptied so that DT and various impurities were also fed to the loop. The impurity elements were removed by either FCU or JFCU and exhausted to the TWT. The ISS removed H in the

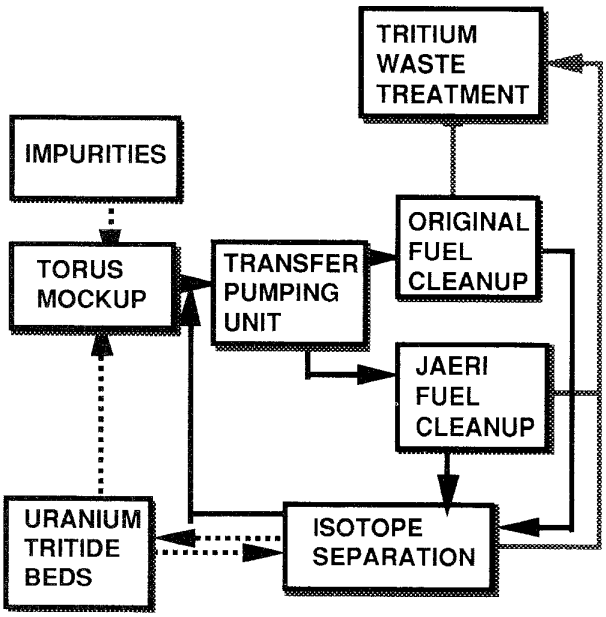

Fig.1 Simplified flow diagram of the TSTA loop.

hydrogen isotope mixture and produced pure tritium that was off-loaded and separately recovered at the end of the run.

Personnel were attached round-the-clock by three shifts during the 25 days experiment. The mid night shift was a "holding" shift where no major change or operation was attempted and system operated stably. Some 20 staffs and operators including 5 Japanese participants were assigned shift responsibilities. The test started on April 20, 1992 and ended on May 14. The ISS was operated continuously throughout the run. Various configurations to test the steady state fusion fuel cycles were investigated during the run.

RESULTS

This extended TSTA loop run was successfully performed for 25 days, that has been the longest continued operation at the TSTA. During the run, ISS was operated and controlled quite stably with 4 interlinked columns as shown in the figure 2, that was not possible in early experiments. Also, behavior in transient operation and interaction with both FCU and JFCU were tested for the first time. About 20 gas containers each has approximately 40 liters of HDT and impurity mixtures were processed in the loop, and impurity elements were separated and exhausted while pure hydrogen was processed in the ISS. Total hydrogen isotope composition during this run was H:D:T = 1:7:2 with ~100 grams of tritium. All safety system such as TWT worked effectively and no major tritium release through stack was detected from the processing loop.

All four ISS distillation columns were interconnected and continuously operated during the run. Column profiled under various conditions were obtained. Laser Raman analysis system that was installed in 1990 and been in operational since then as real time measurement system of ISS composition was used for both measurement of column profiles and monitoring changing purity of products from the columns [4]. Figure 3 shows a typical column profile in a steady state. The distribution of molecular species are compared with the numerical simulation and further studied. Dynamic response to changes in parameter such as flow rates were measured. The response at the column T was approximately 2 hours. H_2 was added as an impurity at the rate of ca. 1-2% of loop flow for 10 days. During that time H containing product was discharged to TWT at an average rate of ca. 200 cc/min. The tritium in this stream was kept lower than 4 Ci/m^3. This result demonstrated the capability of the ISS to continuously separate and discharge H species in the fuel mixture without tritium loss. On the other hand, pure tritium was continuously collected at the bottom of the column T at the purity of 99.8% or higher. Total 12 grams of pure tritium was withdrawn as a product from the loop at the end of the run.

The ISS interfaced with both FCU and JFCU stably and demonstrated integrated fuel loop operation at the steady state. Switch over operations from FCU-ISS loop to JFCU-ISS loop and switch back were tested with acceptable perturbation to the loop stability.

During the extended run, ISS was operated quite stably and smoothly, and little system upset that was

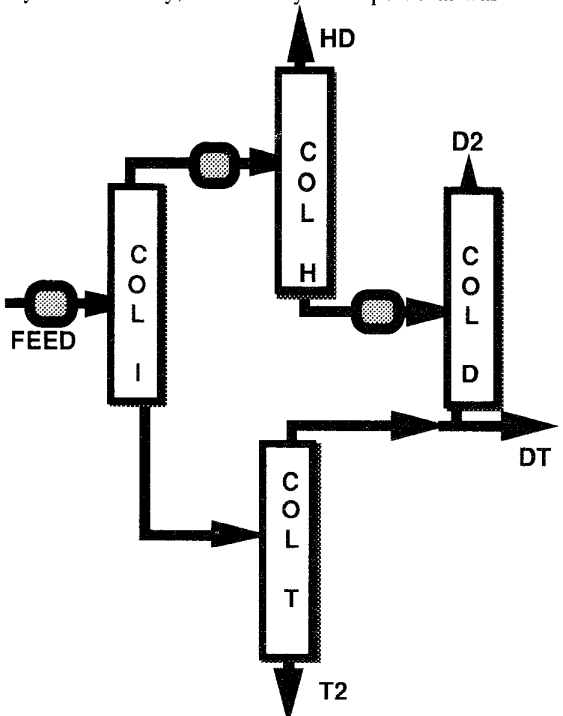

Fig.2 Configuration of 4 ISS Distillation Columns.

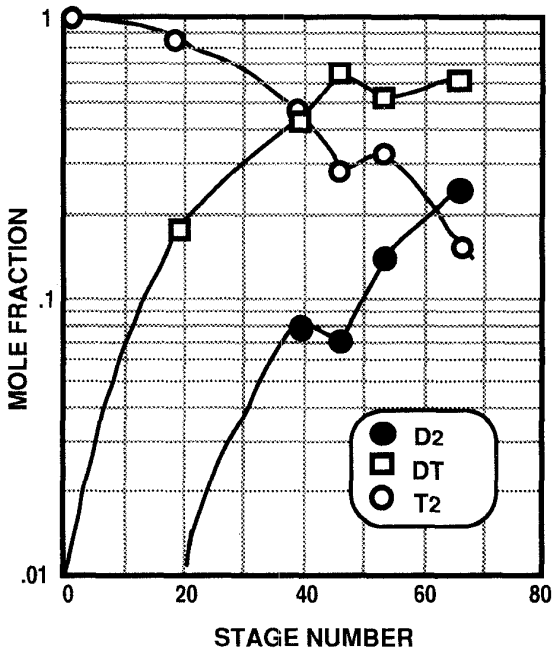

Fig.3 Profile of the column I content in a steady state.

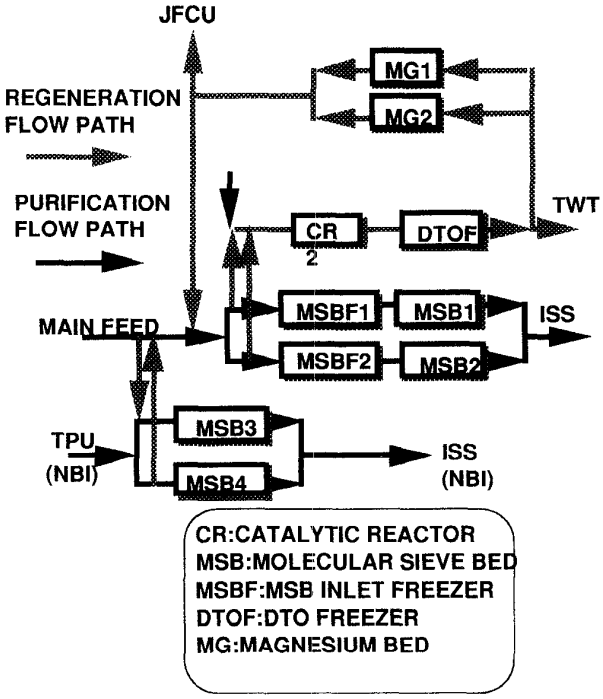

Fig.4 Flow diagram of the FCU based on cold molecularsieve and Mg beds.

occasionally experienced in the past runs were observed. Major reasons were, improved refrigerator operation, experience and skill of operators, and real-time measurement by laser Raman spectroscopy. One of the feed tap was, however plugged with impurities transferred from FCU plumbing, probably due to insufficient purging after switching cold molecular sieve beds.

The FCU successfully demonstrated the complete processing loop as shown in the fig. 4 during the run for the first time. The FCU main flow path molecular sieve beds were both used for about three weeks to remove both artificial impurities from gas cylinder (N_2/CH_4) and "real" impurities from the tritium shipping containers that had significant amount of He-3 and other species. The molecular sieve beds were alternatively used and regeneration train (catalytic oxidation/freezing water /magnesium reduction of water) was demonstrated while the other purification path was on line. The manganese beds replaced the active uranium hot metal beds that have not worked well in previous runs [5]. Switch over of the two magnesium beds was also tested, and both beds were almost completely exhausted. Very small amount of tritiated water passed through the FCU to TWT by the impurity processing. Some of the trapped impurities were transferred to the JFCU for impurity processing and tritium recovery. During the run, FCU also served to purify D_2 stream that simulates NBI deuterium cycle. No impurities was added in this line.

Plugging problem was experienced at the cold molecular sieve beds and freezers before them, probably due to inadequate temperature control. Further improvements

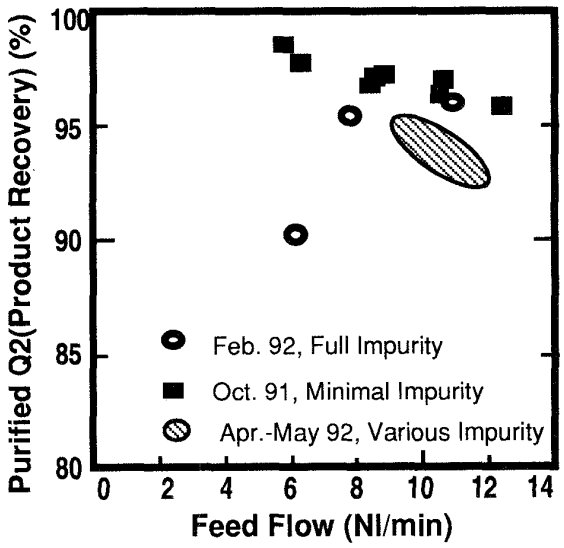

Fig.5 Behavior of the JFCU DT purification in the loop run.

will be needed for cooled components to avoid this plugging problems. One of the possible solution to be attempted is using ambient molecular sieve bed to separately collect water.

The JFCU was operated with all 4 distillation columns of the ISS for the first time in this run. Fuel processing was performed with various impurities, such as continuous artificial impurity of 10% methane and N2 mixture, a regeneration & purging of molecular sieve beds of the FCU, and gases from the Mg bed. The largest load of impurity, however came from a number of gas containers that kept various impurities.

The interaction between the ISS and JFCU was investigated. The main loop flow of DT was processed continuously by the palladium diffuser and approximately 10 Nl/min of pure hydrogen isotopes stream was produced for feed to ISS continuously. Figure 5 shows the fraction of the DT flow rate to the feed flow. This immediate product permeated through the palladium diffuser is fed to the ISS as pure product stream. Approximately 95%of DT fed to the JFCU was sent to the ISS as immediate product. The remained 5% was sent to the processing train for recovery of tritium. As seen in the figure, this ratio was almost stable in the run. Although Loop flow and ISS column pressure fluctuated, little influence was observed in the JFCU and no major operational trouble occurred. It was of concern before this experiment that the product path of the JFCU that has an active vacuum pump that drives pure hydrogen to the distillation column could have possible interaction to cause instability in pressure and/or flow rate between them. The result showed that the active pumping from the JFCU did not disturbed the distillation column at all. However in the case of high pressure in the ISS caused a difficulty to operate the JFCU loop because of the excessive pressure that activates interlocked stop of the process. In the completely passive FCU with cold molecular sieve beds would accept this upset as a back flow and thus more tolerant.

The Ceramic Electrolysis Cell (CEC) decomposed tritiated water well (~1.1 mol/h) beyond the designed capacity of 0.8mol/h. The CEC finally decomposed most of the residual moisture in the entire TSTA loop and recovered tritium from it. This feature would be utilized for better inventory control and decontamination of various kinds of processing loops. However after the cooling down of the cell, it was found to have a major leak across the brazing between the metal and zirconia ceramic. The new cell with improved joints replaced it later.

Small humidity spike at the outlet of the cold traps was detected when each trap was switched over. This problem was uncovered in previous runs and improved the tritium loss to be within the acceptable limit.

Through the run, the JFCU was successfully operated and demonstrated all the major advantages of this process, such as reliable purity of product, removal of helium, small tritium inventory particularly after shut down, and capability to remove residual moisture in the entire loop and recovery of tritium from it.

CONCLUSION

The most important result of this 25 days extended loop run is the demonstrated operation of fusion fuel cycle in a steady state, that also is one of the major objective of the TSTA project. Processing of plasma exhaust, removal of impurity elements, recovery of tritium, separation of isotopes to simultaneously remove H and produce pure D and T, were successfully tested for weeks continuously. The result suggests that the TSTA established, although in a limited and simplified configuration, a technical basis of a fuel circulation loop for the future fusion machines. This accomplishment is a major milestone in the tritium technology for fusion development.

It would be important to note that although the TSTA has simulated the most important mode of the fusion fuel cycle - steady state plasma exhaust processing - , next generation of fusion machine will require rather different operation modes of fuel cycle. For instance, International Thermonuclear Experimental Reactor (ITER) will be operated as a pulse machine. In order to accommodate the requirement to process exhaust from ITER torus and supply fuel to it, fuel cycle should be operated in mainly batch mode. Also, for a completely closed tritium fuel cycle, tritium from breeding blanket, NBI, pellet injector, and primary coolant systems should be recovered and processed as fuel for reuse. Therefore realistic fuel loop for the near future fusion machine, there are many technical issues that has not been covered by the results obtained at the TSTA steady operation. Some of these issues can be investigated at the TSTA with minor modification. The tests for these new objectives were initiated in 1992 under extended collaboration program.

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