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TITLE EXPERIENCE OF TSTA MILESTONE RUNS WITH 100 GRAMS-LEVEL OF TRITIUM

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*EXPERIENCE OF TSTA MILESTONE RUNS WITH 100 GRAMS-LEVEL OF TRITIUM

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ABSTRACT

The first loop operation tests of the Tritium Systems Test Assembly (TSTA)[1] with 100 grams-level of tritium were performed at the Los Alamos National Laboratory (LANL) in June and July, 1987. The July run was resumption of the June run, which was halted because of a loss of cryogenic refrigerant in the hydrogen isotope separation system.

INTRODUCTION

The test was one of the milestones of TSTA established under the framework of Annex IV (Fusion Fuel Technology) to the US/Japan Implementing Arrangement for the Development of Fusion Energy. The objectives of this collaborative program are to establish a fusion fuel processing technology on a practical scale and to demonstrate safety technology for handling large quantities of tritium.

OBJECTIVES OF THE MILESTONE RUNS

The primary objectives were: operate the TSTA process loop with 100 grams of tritium; demonstrate major process functions such as impurity removal in the fuel cleanup system, H-D-T and ^{3}He separation in the hydrogen isotope separation system, and the neutral beam return flow process; and demonstrate functions of the safety systems such as the secondary containment system, tritium waste treatment system, and the process and room monitoring system.

CONFIGURATION

The major process systems (shown in Fig. 1) used were: LIO (tritium load-in/out system); UTB

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(tritium storage and supply system); FCU (fuel cleanup system)[2]: NBI (neutral beam interface for processing gas flows from neutral beam systems); ISS (hydrogen isotope separation system)[3]; TP1 and TP3 (gas transfer system); GAN (gas analysis system); and safety systems such as the TWT (tritium waste treatment system); SEC (secondary containment system; gloveboxes, etc.); TM (tritium monitoring system); MDAC (master data acquisition and control system); and VEN (ventilation system). Other critical systems such as ETC (emergency room cleanup system), emergency power systems, and breathing air systems were available, but were not needed during the experiment.

TEST PROCEDURES

Tritium Loading and ^{3}He Stripping

The loading of tritium into the process loop from several tritium shipping containers (PC's) (approximately 10 g-T and 40% ^{3}He) through the FCU, and from the UTB through the ISS was accomplished. Two methods for helium stripping were tested during the June run. The first was to separate ^{3}He from hydrogen isotopes by absorbing the H-D-T mixture on the uranium beds (UTB) followed by pumping residual gas to a ^{3}He storage gas cylinder. The second was to withdraw ^{3}He from the top of Column H in the ISS during the continuous distillation of H-D-T mixture.

Loop Operation

Full loop operation, using the flow paths through FCU-ISS-TP3-TP1 and through FCU-ISS-TP3-NBI, was initiated after completion of tritium loading and initial testing of the FCU and NBI.

The following tasks were planned to be demonstrated: separation of H-D-T with the ISS under steady state distillation conditions; continuous withdrawal of pure T_2 from the ISS and loading it (approximately 5 g-T_2) into a shipping container; injection of impurities (0.9%N_2 and 0.1%CH_4 in the D-T stream) to the loop and removal of them with the FCU; and withdrawal of ^{3}He and H_2 from the ISS.

Shutdown of the Process Loop

The normal shutdown procedures used were: unloading of hydrogen isotopes in the loop to the UTB during warmup of the ISS; unloading of residual gas in the loop by circulating it through the flow path FCU-ISS-UTB-TP1; and pumping the process gas including impurities injected into the FCU, to gas cylinders during warm up of the cryogenic molecular sieve beds.

RESULTS ON PROCESS SYSTEMS--JUNE RUN

Tritium Inventory

Approximately 91 grams of tritium (44 g-T from the UTB and 47 g-T from five tritium gas cylinders) were loaded into the process loop. It took almost four days to achieve steady state operation of the process loop. This was partially due to several tests of ^{3}He stripping from the H-D-T mixture in the process loop. The ISS, consisting of four interlinked cryogenic distillation columns, was proved to be effective in separating helium from a hydrogen isotope mixture. The stripping of helium with a low level of tritium (less than 1 mCi/liter of gas) was also achieved during the continuous addition of H_2 gas which was expected to enhance ^{3}He separation from the D-T mixture in the distillation system.

Fuel Cleanup System (FCU)

The impurity injection experiment, which was planned to continue for 48 hours using the cryogenic molecular sieve bed front-end, was started after achieving full loop operation. It was halted only 21 minutes after the initiation of impurity injection as the result of an emergency condition in the ISS due to loss of refrigerant caused by a mechanical failure of the helium refrigerator.

Isotope Separation System (ISS)

The ISS, Fig. 2., operated for approximately 38 hours with the 91 g tritium inventory. Most of this time was spent attempting to achieve steady-state operation of the distillation system. The ISS was scrammed without demonstrating H-D-T separation under steady state distillation conditions because of the refrigerator failure.

Uranium Storage Beds (UTB)

Four uranium beds in the UTB were used to supply H-D-T mixtures to the process loop. The heating time from 300 K to 673 K was approximately 3 hrs., and cooling time to 373 K was approximately 1 day. H-D-T from the ISS was dumped successfully to the uranium beds during the emergency scram to hold column pressures below 2.8 atm (290 kPa). If the pressure in the ISS exceeds 5 atm, the gas from the ISS goes to an evacuated surge tank through rupture disks. One of the beds, connected to Column H, which is used to separate light species such as He, H_2, and HD, did not adsorb hydrogen isotopes efficiently during the emergency shutdown. This phenomenon was due to the well known "blanketing effect" from the formation of a boundary layer of inactive gases such as He and N_2 at the uranium powder surface. This effect could easily be counteracted by either pumping out or circulating the residual gases over the uranium bed.

RESULTS ON PROCESS SYSTEM--JULY RUN

Tritium Inventory

Approximately 70g-mols of H-D-T mixture were loaded from the UTB (91g-T) and tritium shipping containers (11g-T). Hydrogen of about 4 at. % of the total H-D-T inventory in the process loop was previously added to the FCU for presaturation of the two cryogenic molecular sieve beds. Hydrogen and ^{3}He in the process loop were withdrawn from the top of Column H several times during this run (maximum flow rate of 500 STP cm^3/min., total time ~ 8 hours). Deuterium (~ 30 STP-l) was also withdrawn from the top of Column D during the full loop operation. The isotopic ratio of D/T in the ISS inlet stream varied from 2.7 to 1.3 during the operation, depending on flow rates out of the ISS. The hydrogen concentration in the inlet stream was less than 0.2% after withdrawal of H_2 and ^{3}He from the top of the Column H (the design value of H_2 is 1%).

Fuel Cleanup System (FCU)

Impurities (60 STP-cm^3/min of 90%N_2-10%CH_4) were injected into the process loop for 53.1 hrs; 26.6 hrs. to one molecular sieve bed and 26.5 hrs. to a second molecular sieve bed, both operating at 77 K. No cryogenic plugging of the ISS or the FCU was observed during the loop operation, but the outlet concentrations of these species measured with off-line Raman Spectroscopy appeared to be 0.04-0.1%N_2 and 0.002-0.004%CH_4, respectively. Blank samples run after the conclusion of the run showed background levels of N_2 and CH_4 in the sample tube comparable to that measured on the process gas exiting the fuel cleanup system.

Isotope Separation System (ISS)

The ISS was operated with the FCU and NBI for 115 hrs. Withdrawal of ^{3}He, H_2, D_2, and T_2 was performed at appropriate times during this milestone run. Most of this time was spent achieving steady state operation of the distillation columns and performing gas analysis for evaluation of the separation characteristics of each column

Demonstration of enriching tritium to purities > 99.99% and withdrawal of H_2, D_2, T_2, and ^{3}He was fully achieved as primary objectives of this milestone run. In future experiments at TSTA, efforts to establish conditions for long-term steady state distillation will be performed following some improvements of the existing control instrumentation and installation of mass flow meters for accurate measurement of hydrogen isotopes loaded from the UTB.

SAFETY SYSTEMS-JUNE RUN

Tritium Waste Treatment System (TWT)

The Tritium waste treatment system (TWT) was operated for the entire period of this run. Increases in the radiation levels at the inlet and outlet of the TWT were observed several times during this run. The major sources of tritium to the inlet of the TWT were FCU-molecular sieve bed regeneration gas, ISS gas analysis, and stripping of helium gas from ISS Column H. Major peaks in the outlet radiation level were related to the regeneration of FCU molecular sieve bed, which had been previously used for methane adsorption. The temperature of the catalyst bed was raised because tritiated methane requires a temperature of at least 810 K for efficient conversion. The temperature of the catalyst bed, however, could not be raised above 780 K because of a possible heater/temperature control problem on the catalyst bed. During high outlet radiation levels, the TWT automatically went into recycle and some operations such as glovebox purging were halted until the TWT had cleaned up the gas adequately. Hence, radiation levels in glovebox increased at those times. During processing of regeneration gas from the FCU molecular sieve bed, approximately 1.5 Ci of tritium were released to the stack. This was due to a design failure in the exhaust tritium monitor. Improper range change information was sent from the radiation monitor to the TSTA control room computer. Thus the control system routed this gas to the stack rather than putting TWT into recycle.

Secondary Containment System (SEC)

Radiation levels in gloveboxes during the run were within acceptable levels. Several boxes indicated small leaks in the process piping. The maximum released into gloveboxes was approximately 300 mCi, with no glovebox level rising above 60 mCi/m^3.

Radiation levels in ISS-GB1

This glovebox contains the valves, pressure transducers, equilibrators, flow controllers, and other noncryogenic components of the ISS. A leak was found during the run in one of the ISS rupture disks attached to the top flow path of the ISS Column I. Because of the inadvisability of fixing the leak during operation, a small covering was placed over the rupture disk and atmospheric gas around the rupture disk was purged directly to the TWT. The off normal increase in ISS-GB1 radiation level was caused by this leak. High radiation levels were observed when both the pressure and tritium concentration at the top of Column I were high. During loading and unloading of tritium, the tritium concentration at the top of the column I was high because no separation had yet occurred in the column. When the TWT was in recycle, the radiation level in the glovebox increased because the glovebox purge was halted. The maximum radiation level was about 60 mCi/m^3 during loading of tritium to the ISS and when the glovebox purge was off. This is the highest radiation level observed in a glovebox in the June and July run.

Radiation levels in ISS-GB2

This glovebox contains the ISS gas analysis system (ISS-GAN). Most of these tritium leaks occurred during the ISS gas analysis. Before starting the gas analysis, a leak to the glovebox was detected. This leak was from a fitting on a pressure regulator and was fixed. During gas analysis, the radiation level in this glovebox was relatively high. However, no marked peaks of radiation level were observed. These facts indicate very small unidentified leaks existed in the ISS-GAN.

Radiation levels in FCU-GB1

This glovebox contains the FCU. The radiation level in this glovebox gradually increased and no marked peaks of radiation levels were observed except during the ISS emergency shutdown. These facts also indicate small unidentified leaks existed in the FCU. The off-normal radiation level at the ISS emergency shutdown is discussed later.

Room Radiation Level

Although several periods of off-normal radiation levels were observed in the gloveboxes, no off-normal increase of radiation levels in the experimental room (TSTA main cell) occurred during this run.

Stack Radiation Level

Off-normal radiation levels at the TSTA stack radiation monitor were found while the TWT was stacking processed gas from the FCU molecular sieve bed as shown in Fig. 3. As mentioned previously, approximately 1.5 Ci of tritium was released to the stack based on the reading of the stack monitor. The stack bubbler, however, did not detect this off-normal tritium release. It was, of course, detected by the continuous-reading stack ionization chamber. These facts show this tritium was released in the form of tritiated methane.

ISS Emergency Shutdown

This tritium run was halted due to the failure of the helium refrigerator followed by loss of refrigerant to the ISS. Before the total failure of the refrigerator, the column pressures were increasing. It was noticed that loss of refrigeration power caused the off-normal pressure increase. It was soon recognized that an emergency shutdown and unloading ISS to UTB should be carried out. Just before unloading ISS to UTB, gas circulation was automatically stopped by the safety program due to high pressure in the loop. The ISS was opened to UTB to dump the gas in ISS to UTB. This occurred about ten minutes after the first detection of increasing pressures. At that time, the highest column pressure was three times as high as that in normal condition. At this time, the helium refrigerator completely stopped. It was found that the shaft which couples the expansion engines to the inlet and exhaust valves was broken.

The gas was absorbed by the uranium beds quickly enough that the backup rupture disks did not release gas into the safety surge tank at ISS. The temperatures of the uranium beds began to increase rapidly because of the exothermic reaction between hydrogen isotopes and uranium. But the temperature of the uranium bed connected to Column H did not increase. This indicates that the bed was not absorbing gas. This would be caused by the helium blanketing effect due to the remaining helium-3 from the top of the column. To overcome the helium blanketing effect, the bed was isolated and the gas over the bed was pumped to to the TWT. This operation was effective and the bed began to effectively absorb hydrogen isotopes.

While the TWT was processing the stagnant gas over an uranium bed, the outlet radiation level increased. The TWT went into recycle three times. The stagnant gas included tritiated hydrocarbons from the rotary pump used in the house vacuum system. The TWT was in the stacking mode a short time, so only small off-normal tritium levels at the stack were observed.

During this emergency shutdown, radiation levels in ISS-GB1 and FCU-GB1 increased. Because the ISS pressures increased from about 100 kPa to 290 kPa at the highest and with the leak in one of the rupture disks, the radiation level in ISS-GB1 increased at this time. Because the FCU pressure increased to over 260 kPa and there were small unidentified leaks, the radiation level in FCU-GB1 also increased. While these radiation levels were decreasing in the latter stage of the emergency shutdown, they increased again due to the TWT recycle. Although off-normal tritium levels were detected in gloveboxes during the emergency shutdown, no increase of room radiation level was detected.

SAFETY SYSTEMS--JULY RUN

Tritium Waste Treatment System

The TWT was operated over the entire period of this run. The TWT removed tritium well even though the temperature of the catalyst bed (730 K) was not as high as desired. There appeared to be little conversion problem. This shows that the chemical form of the tritium was an elemental one and little tritiated hydrocarbon were transferred to TWT.

The inlet radiation level showed many spikes. The major source of the spikes was exhaust gas from the ISS gas analysis. The outlet radiation level gradually increased throughout the run. However, it did not influence the stack radiation level.

Two different methods were used to estimate the amount of tritium exhausted to the TWT. The estimated amounts are between 0.4×10^4 and 1.0×10^4 Ci respectively. On the other hand, the amount of tritium released from the TWT was approximately 0.2 Ci based on the reading of the stack bubbler.

Radiation levels in TPU-GB1

This glovebox contains two transfer pump units. Failure of a bellows in one of the transfer pumps resulted in a rise in radiation level in this glovebox. An off-normal increment in radiation level was observed when the pump was operated. This pump was indispensable for taking analytical samples from the FCU. Hence, after the second off-normal increment in radiation level was observed, the pump was replaced with a new one during the run.

Radiation levels in FCU-GB1

The radiation level in FCU-GB1 increased gradually during the run. Two small leaks were identified which would cause gradual increases in radiation levels. Higher radiation levels were observed in the latter stage of the run. The cause was one of the gas sampling cells for Raman analysis. A rise in the radiation level was observed when the gas samples were taken, and the cell became the source of a rise in the stack radiation level when placed in a hood. The maximum radiation level in FCU-GB1 was approximately 25 mCi/m^3. This was the highest radiation level in the glovebox in the July tritium run.

Radiation Levels in ISS-GB2

The radiation level in this glovebox increased during ISS gas analysis. This is due to unidentified small leaks as mentioned in the June tritium run.

Room Radiation Level

No off-normal radiation levels in the experimental room were detected during the run, though off-normal radiation levels were observed in gloveboxes.

Stack Radiation Level

Stack radiation levels above background were detected for approximately four hours in the run. This off-normal level was caused by the tritium leakage from the gas sampling cell placed in a hood. Exhaust gas from the hood is routed directly to the stack without detritiation. The cell was transferred to one of the gloveboxes after the detection of off-normal high radiation level in stack. Figure * shows the variation of radiation level at the stack when the cell was placed in the hood. The amount released to the environment from the cell was evaluated to be about 450 mCi based on the increment of radiation level in the stack.

It is important to remember that the stack releases of tritium at TSTA during four years of operations (including those discussed here) have totaled less than 35 Ci, far below the self-imposed limit of 200 Ci/yr., which, in turn, is well below any regulatory limit.

CONCLUSIONS

All of the objectives of the 100 gram milestone run were met or exceeded during the June and July tests. The demonstration of the ability to process continuously the exhaust gas stream at a flow rate (~ 1 kg/day tritium) comparable to that required for ITER or INTOR shows that the tritium technology development at TSTA will not be a pacing item for future fusion systems. The production and collection of the very high purity (> 99.99%) tritium was an important demonstration of the total system capability. The response of the TSTA system, equipment and personnel, to the emergency created by the failure of the helium refrigerator was near ideal. At the time of the refrigerator failure there were approximately 91 g of tritium in the system, much of it as liquid in the ISS. This liquid began vaporizing and generating gas at a significant rate. However, due to the rapid response of the TSTA system, no tritium was released to the environment or to the room. Rupture disks connected to the ISS safety surge tank did not reach pressures sufficient to release gas to this backup system. No personnel exposures resulted from this event. One of the long-term objectives at TSTA is to determine the system response to off-normal and emergency situations. This was our first, unplanned, test under these conditions.

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TSTA

Present Configuration

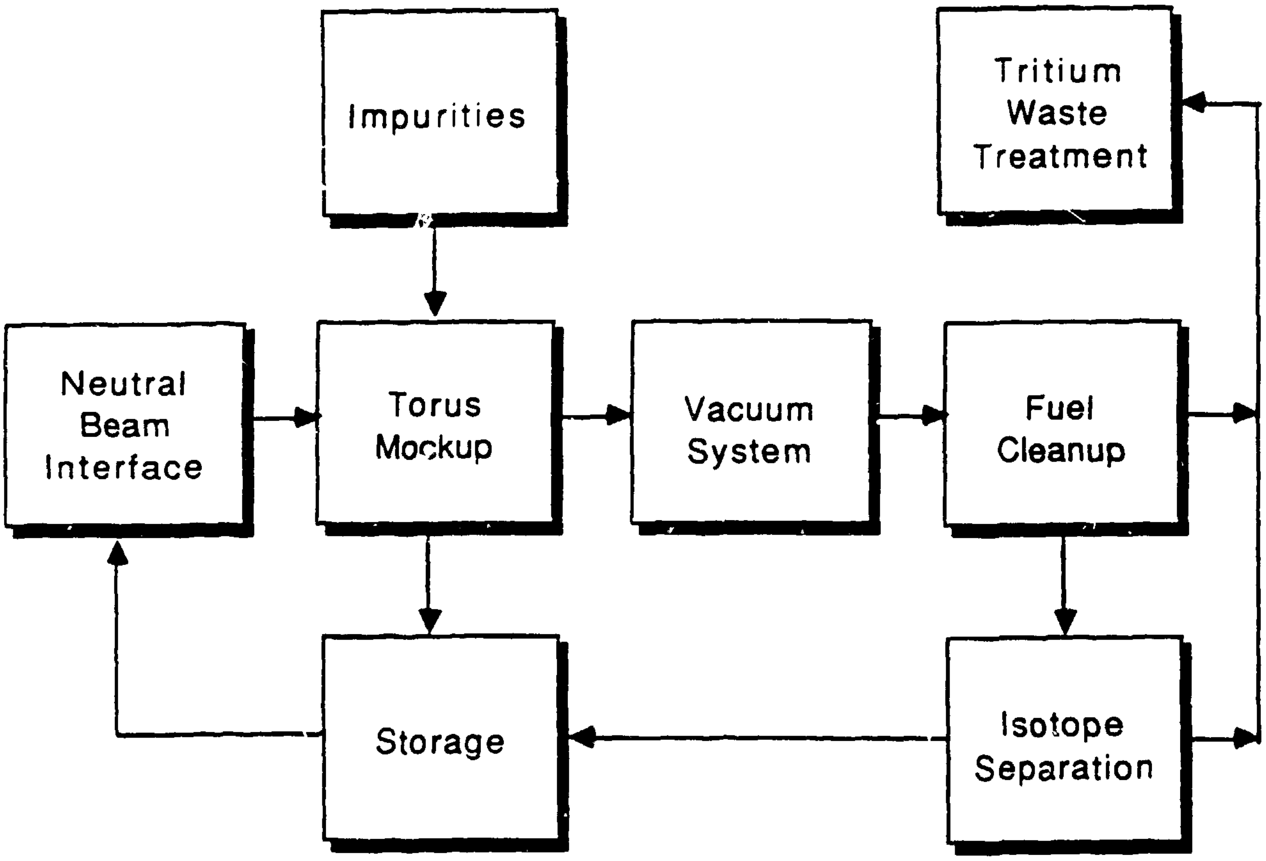

Fig. 1

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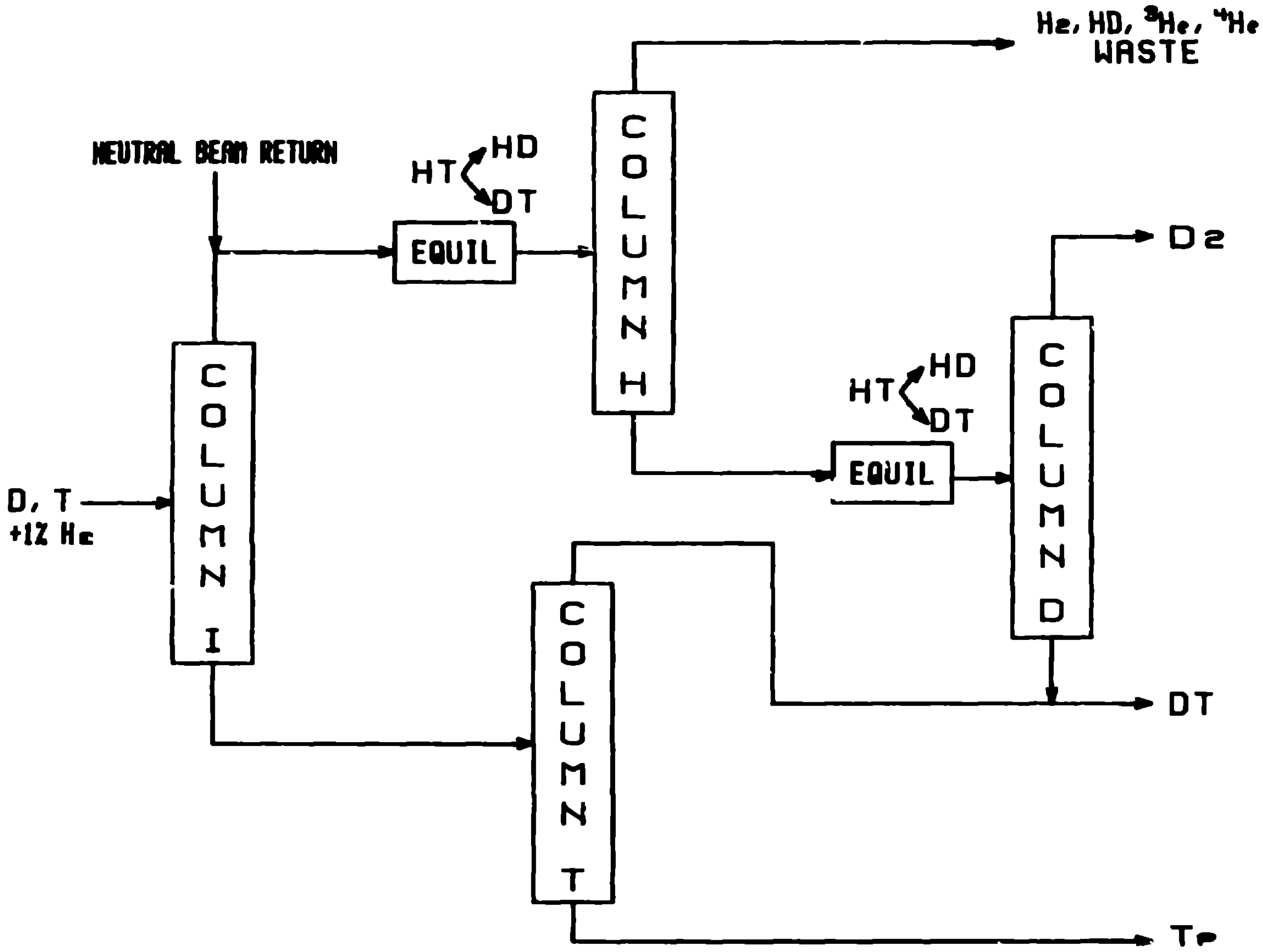
Fig. 2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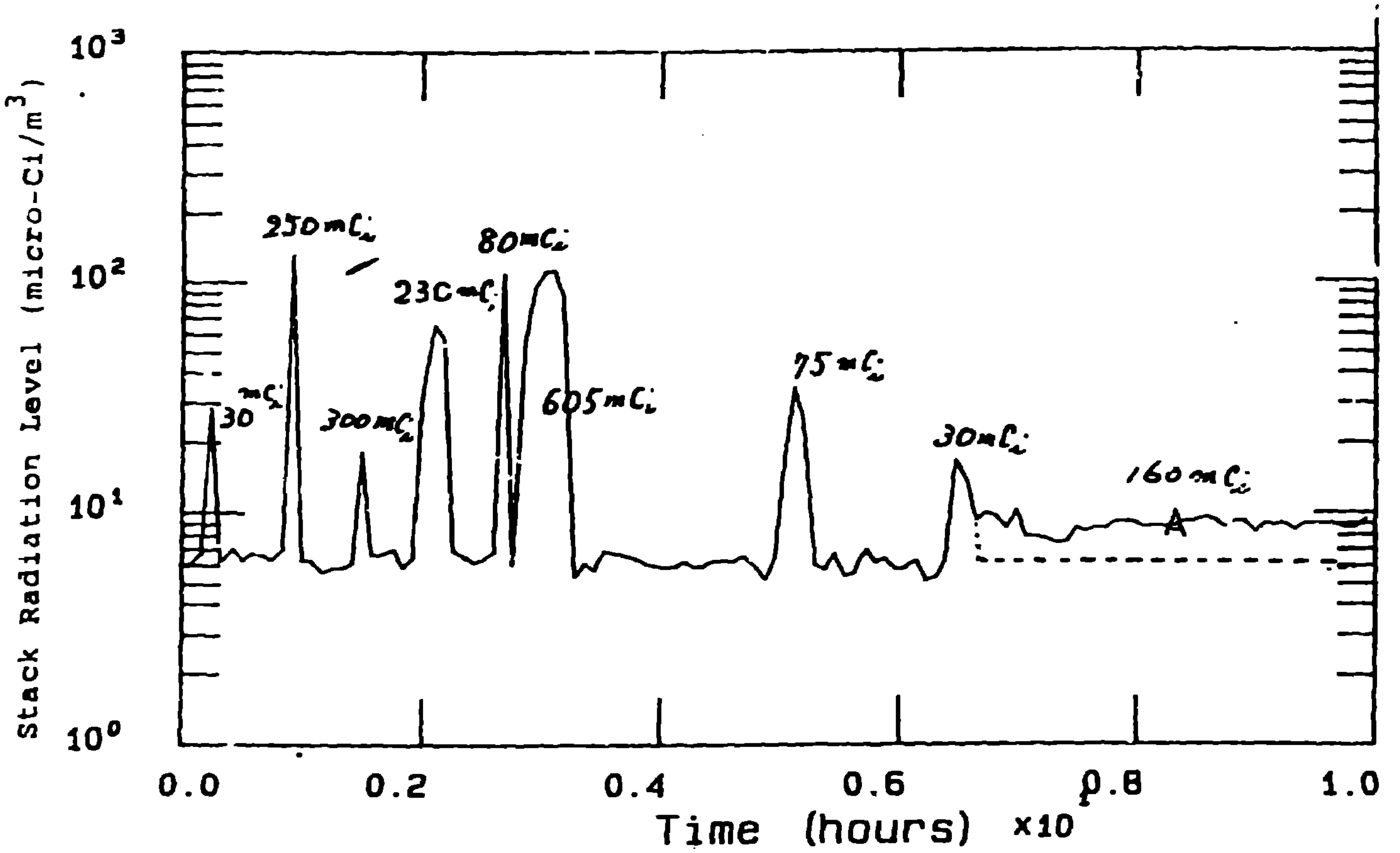

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Fig 3

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