JAERI-M 88-242

TSTA Loop Operation with 100 Grams-Level of Tritium
- Full Components Milestone Run in June, 1988 -

Hiroshi YOSHIDA, Hiroshi FUKUI, Shingo HIRATA*[1]
Toshihiko YAMANISHI, Taisei NAITO*[2], J.L. ANDERSON*[3]
J.R. BARTLIT*[3], C.R. WALTHERS*[3], R.H. SHERMAN*[3]
D.O. COFFIN*[3], R.V. CARLSON*[3], R.S. WILLMS*[3]
J.E. NASISE*[3]

Department of thermonuclear Fusion Research
Naka Fusion Rsearch Establishment
Japan Atomic energy Research Institute
Naka-machi, Naka-gun, Ibaraki-ken

(Received November 7, 1988)

A fully integrated loop operation test of Tritium systems Test Assembly (TSTA) with 107 grams of tritium was completed at Los Alamos National Laboratory (LANL) in June, 1988. In this test, a compound cryopump with a charcoal panel was incorporated into the main process loop for the first time.

The objectives were (i) to demonstrate the compound cryopump system with different flow rates and impurities, (ii) to demonstrate the regeneration of the compound cryopump system, (iii) to accumulate operating experience with other process systems such as the fuel cleanup system, the isotope separation system, the tritium supply and recovery system, etc. and (iv) to improve the data-base on TSTA safety systems such as the secondary containment system, tritium waste treatment system and tritium monitoring system.

This report briefly describes characteristics of the main subsystems observed during the milestone run.

Keywords: Fusion Reactor, Tritium Technology, Fusion Fuel Cycle, Plasma Exhaust Gas, Compound Cryopump, Fuel Cleanup, Isotope Separation, Secondary Containment, Tritium Monitoring

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*1 Kawasaki Heavy Industries, Ltd.
*2 Mitsubishi Atomic Power Industries, Inc.
*3 Los Alamos National Laboratory

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1. INTRODUCTION

1.1 LAYOUT OF JAERI/TSTA-LANL COLLABORATION

The joint work of the TSTA Loop Operation in the first Annex IV year (June 11, 1987 - June 10, 1988) defined by the JAERI/TSTA-LANL collaboration program under Japan/US Fusion Cooperation Program was successfully completed, while producing many scientific and technological advances.

Table 1.1 summarizes the TSTA activities achieved in this period.

The loop tests in June and July, 1987 were the first loop operation of the TSTA process systems and safety systems with 100 grams-level of tritium. An emergency situation due to the loss of helium refrigeration of the cryogenic hydrogen isotope separation system, which was one of the most serious scenarios in the TSTA failure mode and effects analysis, happened during the June run. The test eventually had to be halted. There were, however, no offnormal environmental tritium releases or personnel exposures, and no resulting damage to TSTA systems which might have impacts on the Annex IV first year program. The second loop operation was successfully resumed, only one month after this unexpected event.

Hydrogen isotope separation experiments on a single column with H-D system (October, 1987) and D-T system (December, 1987), and with a two-column cascade configuration with H-D-T system (April, 1988) were performed to study isotope separation characteristics of full-scale cryogenic distillation columns.

Demonstration experiments on the fuel cleanup system, FCU (Front-end: impurity removal process consisted of catalytic oxidizer and cryogenic molecular sieve beds; Regeneration process: D-T recovery process of catalytic oxidizer, DTO freezer and hot metal beds) were carried out from January through March, 1988. The March run was the first complete functional test of the FCU under a full loop operating condition using impurities of 0.099%N_2 and 0.019%CH_4 in the D-T stream.

Compound cryopump experiments of TSTA-VAC system (composed of the torus mockup, two different compound cryopumps having D-T condensing chevrons and a He adsorbing charcoal panel, and a regeneration train) had been done with D_2, H_2, D-T, He, N_2 and their mixtures in the period from March, 1988 through July, 1988. The D-T experiments were done in both operating modes of non-loop flow and full loop flow with FCU, ISS and TPU (gas circulation system in the compound cryopump regeneration train). The loop operation of May-June, 1988 was the first test of all components of a fusion fuel cycle on an engineering scale. The pumping speed of D-T, D-T-He (10 - 25%), D-T-N_2 (1%), and the He/D-T separation performance of both chevrons and a charcoal panel, and the regeneration back to the TSTA process loop were successfully demonstrated during a series of VAC system experiments.

This report briefly describes the results of this integrated operation of the full fuel processing loop test.

1.2 BRIEF DESCRIPTION OF TSTA [Ref. 1,2 and 3]

The detailed description of the above systems is given in previous reports "TSTA Loop Operation with 100 grams-level of Tritium - Milestone Run in June, 1987 - " and "TSTA Loop Operation with 100 grams-level of Tritium -Milestone Run in July, 1987 - ".[Ref. 1 and 2]

1.2.1 PROCESS SYSTEMS

Figure 1.1 shows the conceptual process loop which was used during this run. The current TSTA process loop, which is shown in Figure 1.2, is composed of the following subsystems.

(1) VAC

The Vacuum Facility (VAC) with a torus mock-up, two different designs of compound cryopumps, and a turbopump for regeneration of cryopumps (Figure 1.3).

(2) UTB

Tritium and other hydrogen isotopes storage /supply system with five large uranium beds (UTB-1, 2, 3, 4 and 5). Figure 1.4 shows the general arrangement of UTB.

(3) ISS

Hydrogen isotope separation system with four interlinked cryogenic distillation columns (I, H, D and T) and two hydrogen isotope equilibrators (EQ).

(4) TP1

Transfer pump system with a scroll pump (S) and metal bellows pumps (MBPA and MBPB).

(5) TP3

Transfer pump system with metal bellows pumps (MBPA and MBPB), a gas mixer (MX) and a hydrogen isotope equilibrator (EQ).

(6) FCU

Fuel cleanup system with catalytic reactors (CR1 and 2), cryogenic molecular sieve beds (MSB1, 2, 3 and 4), uranium beds (HMB4 and 5) and a tritiated water vapor freezer (DTOF). This system includes a NBI front end composed of MSB3 and 4.

(7) LIO

Load-in/Load-out system for tritium using T_2 gas shipping containers.

1.2.2 SAFETY SYSTEMS

The major environmental and safety subsystems of the TSTA facility are as follows;

(1) SEC

The primary process equipment and process lines are doubly contained with secondary containment consisting of gloveboxes and plastic tubing, with nitrogen gas purge and control of their atmospheric pressures. Figure 1.5 shows the concept of the instrumentation of a typical glovebox. Purge gas (N_2) is supplied to the glovebox at a preset tritium level.

(2) TWT

The tritium waste treatment system (Figure 1.6) processes all tritium-bearing gaseous effluents generated in various subsystems in TSTA. This system is operated either in once-through or recirculation mode as necessary, and routes the effluents to the TSTA stack after detritiation and monitoring the tritium release level.

The capacities of the TWT compressors are 90 and 25 STP-m^3/h.

(3) TM

A number of tritium monitors (Stack, Duct, Room, Glovebox and Process) have been installed in the TSTA facility. Figure 1.7 shows the location of the room-tritium-monitors. The monitors perform the following functions; (i) quantitative determination of stack releases, (ii) monitoring tritium concentrations in room and room-exhaust air, secondary containment atmosphere, and process system lines, (iii) initiation of local alarms and computer-directed signals (in secondary containment and room or room exhaust ducts) and (iv) initiation of room air isolation and an evacuation alarm and computer-directed signals.

(4) ETC

The TSTA main cell contains approximately 3000 m^3 of building atmosphere which would be contaminated with tritium in the event of an accidental release from a secondary containment. This system, the emergency tritium cleanup system (Figure 1.8), has the primary function to reduce the probability and amount of a tritium release to the environment from the TSTA main cell after such an accident.

The free air capacity of the primary compressor is 2500 m^3/h at 585 Torr (0.77 atm) and 293 K.

(5) VEN

The ventilation system is divided into two zones. The Zone I system provides heating and ventilation for areas (rooms for non-tritium handling) from which tritium will be excluded and is maintained at a slight positive pressure (0.23 Torr) with respect to atmospheric pressure. The Zone II system (shown in Figure 1.9) for the main cell and other tritium handling rooms is maintained at a slight negative pressure (0.23 Torr) with respect to atmospheric pressure to minimize possible diffusion of tritium to Zone I or to the environment.

The ventilation capacity of the Zone II system is 15291 m^3/h.

(6) MDAC

The TSTA is designed to be a computer controlled system. This system, master data acquisition and control, contains two computers (shown in Figure 1.10); the process computer and an interface, and the backup computer.

1.2.3 TSTA DESIGN DOSE

For TSTA to handle tritium the following subsystems must be on line: SEC, TM, TWT, ETC, VEN, MDAC, Power and Utilities. Most safety system operations are under total computer control. Table 1.2 shows the TSTA design dose. In addition, actions are taken to reduce radiation exposure from tritium to As Low As Reasonably Achievable (ALARA).

The value for occupational exposure is one-fifth of the guide level (5 rem/year) in DOE manual (DOE Order 5480.1A Chapter XI). The nonoccupational dose will be less than 1 mrem/year for the routine environmental tritium release rate of 200 Ci/year (selected as a design goal for TSTA). The dose for personnel in adjacent buildings will be less than 500 mrem/year.

1.2.4 ACCIDENT CONSIDERATIONS

(1) Failure Modes and Effects Analysis

TSTA subsystems have been analyzed with Failure Modes and Effects Analysis to evaluate the safety features of the design, identify critical failure modes, and recommend alternatives or precautions that will mitigate the effect of failures.

Table 1.3 gives a summary of the effects resulting from representative accidents which have been postulated for TSTA. Table 1.4 shows an expected tritium inventory in TSTA.

Analysis and discussions of the postulated accident and failures for TSTA are described in the TSTA Final Safety Analysis Report.[Ref.3]

(2) Accident Scenarios

(i) A single failure in any secondarily contained subsystem, i.e., a release into a glovebox, will not result in exposures to individuals or release to the environment, since the TWT will process the secondary containment atmosphere.

(ii) Double failures in systems which have secondary containment or a single failure in a single containment containing low levels of tritium may result in a tritium release into the experimental area. The extent of personnel exposures depends on the tritium concentration in the area, the tritium form (oxide or elemental), and the time required to exit from the area. The exposures for all credible accidents are within the TSTA design goal (25 rem) for accident situations.

Examples of accident scenarios are:

- glove rupture plus a release in that glovebox,
- rupture of ISS system,
- TWT low pressure receiver failure.

The release to the environment for the above type of accident is very small because the ETC is designed to process the contaminated room air. For a postulated release of 100 grams (10^6 Ci) of tritium into the facility only 10 Ci would be released from ETC to the environment (design).

(3) Emergency Evacuation Procedures

Evacuation procedures for a TSTA emergency have been established in accordance with the TSTA Emergency Plan. Any tritium release to the room atmosphere is quickly picked up by the room monitor. Local alarms will be given at each of three levels of tritium concentrations measured.

- Low (20×10^{-6} Ci/m^3) ;amber light
- Mid (100×10^{-6} Ci/m^3) ;red light, steady sonalert (mutable)
- High(10000×10^{-6} Ci/m^3);flashing red light, pulsing sonalert

The evacuation alarm is automatically triggered by the high level.

The stay time in the contaminated room to keep the committed dose below 50 mrem is:

(i) without protective clothing;
stay time (min) = 6000/tritium level (10^{-6} Ci/m^3),
(ii) with bubble suits and supplied air;
stay time (min) = 1200000/tritium level (10^{-6} Ci/m^3).

Re-entry at a concentration over 10^{-3} Ci/m^3 requires full protective clothing (bubble suits) and may only be made if accompanied by a second person who is also suited up. Self-contained supplied air suits also be used for re-entry with permission of TSTA management and HSE-1 (branch of the LANL health physics group).

Table 1.1 Schedule of TSTA Operations

MAJOR EXPERIMENTS & OPERATIONS AT TSTA, FIRST YEAR OF ANNEX IV

	Date	Operation	Description
1.	June 22-26, 1987	loop test of FCU/ISS	with continuous impurity flow
2.	July 23-27, 1987	loop test of FCU/ISS	with continuous impurity flow
3.	September 1987	maintenance on ISS	lower ISS vacuum jacket after tritium use
4.	October 4-9, 1987	non-loop ISS (UTB,TPU)	single column experiments of ISS
5.	October 1987	FCU-related testing	begin assembly/tests (w/o tritium) of high temperature metal beds
6.	December 6-11, 1987	non-loop ISS (UTB,TPU)	single column experiments of ISS
7.	January 1988	non-loop FCU	non-tritium test of FCU operation
8.	February 7-9, 1988	loop test of FCU/ISS	preparatory for first full integration of FCU/ISS with continuous impurity flow
9.	February 21-24, 1988	loop test of FCU/ISS	--same as item 8 above--
10.	February 28-- March 4, 1988	loop test of FCU/ISS	first full integration of FCU/ISS with continuous impurity flow
11.	March-May 1988	non-loop VAC tests	without tritium
12.	April 4-8, 1988	non-loop ISS (UTB,TPU)	ISS experiments, 2 column
13.	May 31-June 6, 1988	loop test of VAC/FCU/ISS	first integrated operation of full fuel processing loop

Table 1.2 TSTA Design Dose Commitments

Condition	Design Objectives	
	Radiation Workers	Public
[b]Normal Operation (mrem/yr)	1000	170
[c]Accident (rem)	25	5

[a]Design dose commitment is the exposure which, under the given conditions, shall not be exceeded in design. These dose commitments are less than specified in DOE 5480.1A.

[b]Examples:

(1) Normal component operation including shutdown, repair, maintenance, and checkout

(2) Operational occurrences such as leaks, loss of power, and component malfunctions likely to occur once or more during the life of the facility

[c]Examples:

(1) Very low probability events such as "most intense predicted" natural phenomena

(2) Major component failure events which are not likely to occur during the life of the facility

Table 1.3 Summary of Postulated Accidents

Failure	Releasable Inventory		Mitigation Method[1]	Release to Stack	Boundary[2] Site Whole Body Dose (mrem)	Whole Body Worker Dose Rate[3] (mrem/min)	Freq
	Ci	Form		Ci			
1. a) Rupture or large leak from torus plus loss of SEC	100	DT	A B	100 1×10^{-3}	1×10^{-6} 7×10^{-7}	1×10^{-3} 1×10^{-3}	E E
b) Same as 1a, accompanied by a fire	100	DTO/HTO/T_2O	A B	100 1×10^{-3}	7×10^{-2} 7×10^{-7}	67 67	E E
2. a) Rupture of cryopump plus loss of SEC	5.8×10^{4}	DT	A B	5.8×10^{4} 5.8×10^{-1}	7×10^{-4} 4×10^{-4}	0.8 0.8	E E
b) Same as 2a, accompanied by a fire	5.8×10^{4}	HTO/T_2O	A B	5.8×10^{4} 5.8×10^{-1}	38 4×10^{-4}	3.9×10^{4} 3.9×10^{4}	E E
3. a) Rupture of distillation columns to vacuum jacket	9.7×10^{5}	DT,T_2	C	1	7×10^{-4}	0	E
b) Same as 3a followed by a breach of the vacuum jacket	9.7×10^{5}	DT,T_2	A B	9.7×10^{5} 9.7	1×10^{-2} 6×10^{-3}	13 13	E E
c) Same as 3b, accompanied by a fire, release at 50 m	9.7×10^{5}	D_2O,DTO,T_2O	A B	9.7×10^{5} 9.7	6×10^{2} 6×10^{-3}	6.5×10^{5} 6.5×10^{5}	E E
4. a) Leakage of transfer lines from NBI and IMS to FCU into secondary containment.	3000	DT,T_2	C	3×10^{-2}	2×10^{-5}	0	E
b) Same as 4a, followed by breach of secondary containment	3000	DT,T_2	A B	3000 3×10^{-2}	4×10^{-5} 2×10^{-5}	4.0×10^{-2} 4.0×10^{-2}	E E
c) Same as 4b, accompanied by a fire	3000	DTO,D_2O,T_2O	A B	3000 3×10^{-2}	2 2×10^{-5}	2.0×10^{3} 2.0×10^{-3}	E E
5. Aircraft crash into facility	9.7×10^{5}	HTO	NA	NA	4.7×10^{3}	NA	E
6. Earthquake total destruction	1.45×10^{6}	HT HTO	NA NA	NA NA	0.23 11×10^{3}	NA NA	E E

[1] Mitigation Method

A - Ventilate Experimental Room

B - Process Room Air with Emergency Cleanup System. Release form is tritiated water vapor.

C - Process Contaminated Air with Tritium Waste Treatment System

NA - Not Applicable

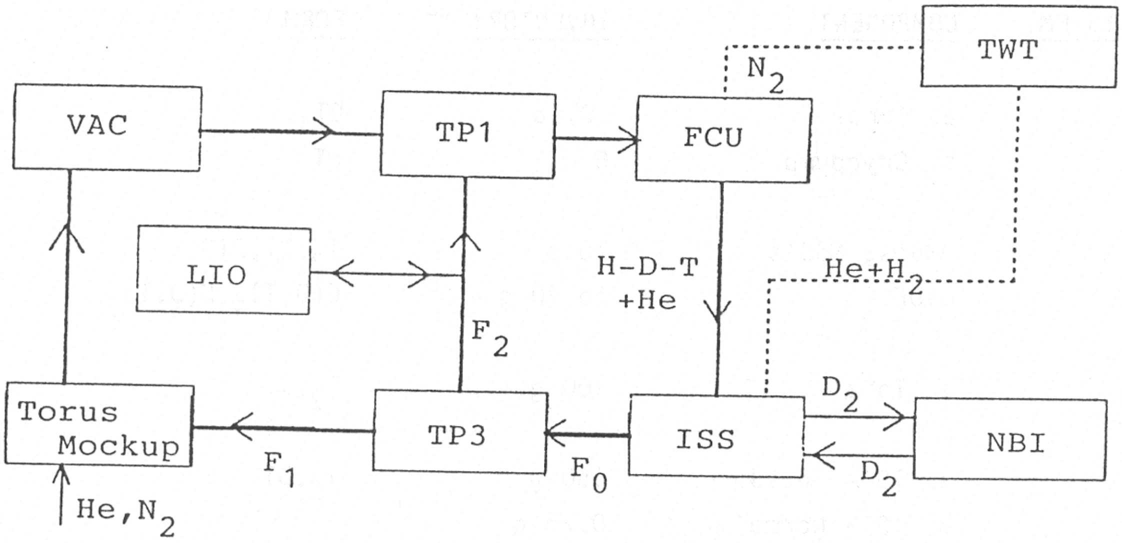
[2] This is maximum dose comitment and includes the skin intake. The dose is determined from Fig. B-1. The dose to the skin itself is discussed in Sec. 6.1. Site boundary is 400 m from TSTA. The dose from any tritium which escapes before the room is isolated has been neglected.

[3] Worker dose per minute of exposure. It is expected that personnel will exit from the room in less than 30 seconds. The calculations also assume uniform mixing in the room.

Table 1.4 Expected Tritium Inventory

SUBSYSTEM	COMPONENT	INVENTORY[1,2]	FORM
VAC	a. Torus	.01 g	DT
	b. Cryopump	6 g	DT
FCU	HMB's, MSB's DTOF	10 g to 30 g	T_2,DT,DTO $C(D,T)_4$,$N(D,T)_3$
ISS	a. Total	100 g	T_2,DT
UTB	a. TSTA Shutdown	150 g	T_2,DT
	b. TSTA Normal	0.25 g	
TWT	a. Low Pressure Receiver	0.1 g	DT,T_2,HTO,C_xT_y,H_2
	b. Molecular Sieve Drier	4-6 g	HTO
XCS		0.1 g	T_2, HTO
ETC	a. Normal Operation	small or none	
	b. After Spill of X g	X g	HTO,T_2O,DTO

1. The inventory in the piping of TSTA is estimated at 1 g.
2. In some cases the amount of tritium is at its maximum in the system before regeneration or removal for disposal.



Main flow rate : F_0=15 - 19 mol-DT/h

VAC flow rate : F_1=2 - 10 % of F_0

Circulating flow rate : F_2=90 - 98 % of F_0

Fig. 1.1 TSTA Conceptual Block Diagram

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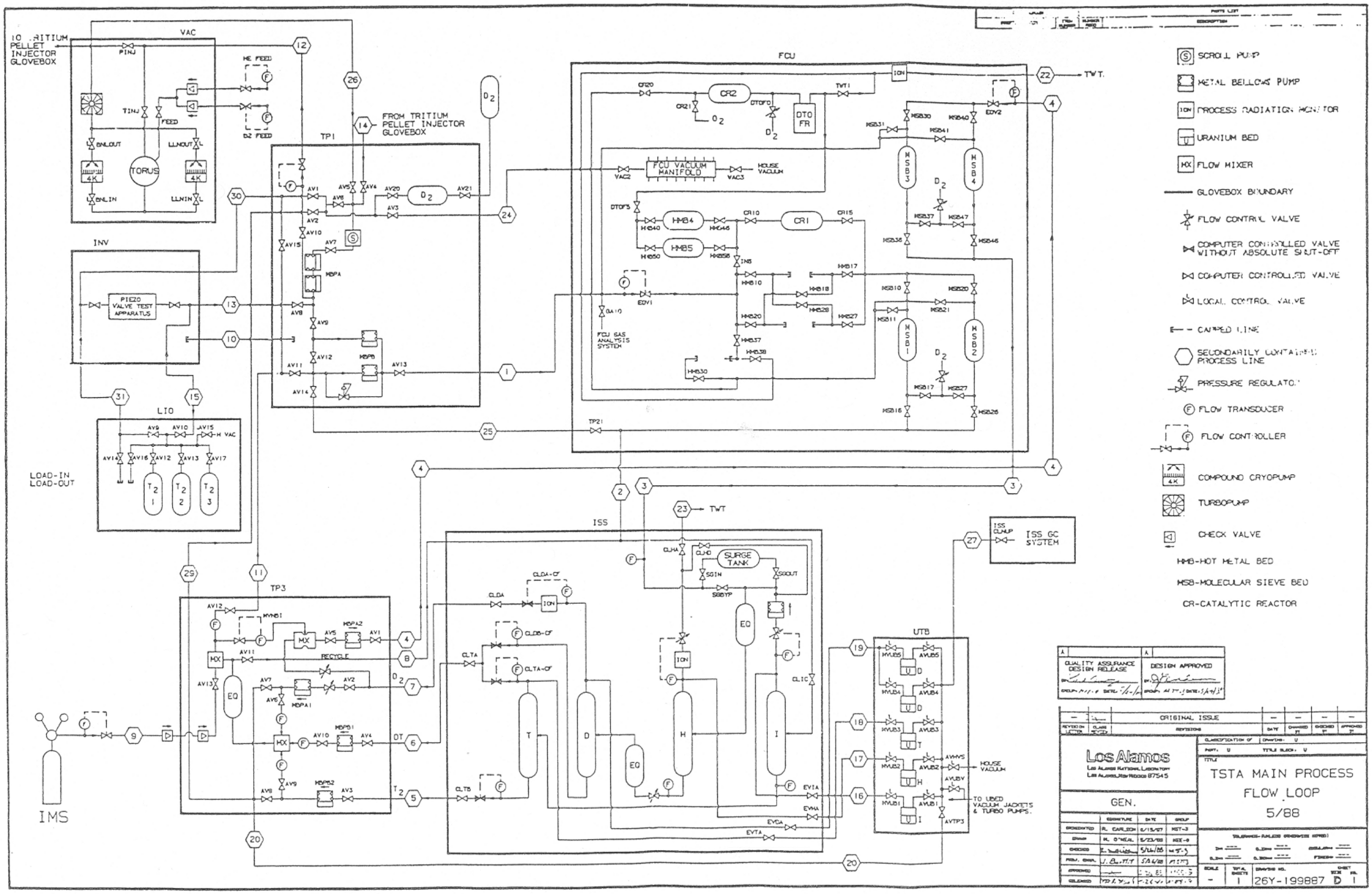
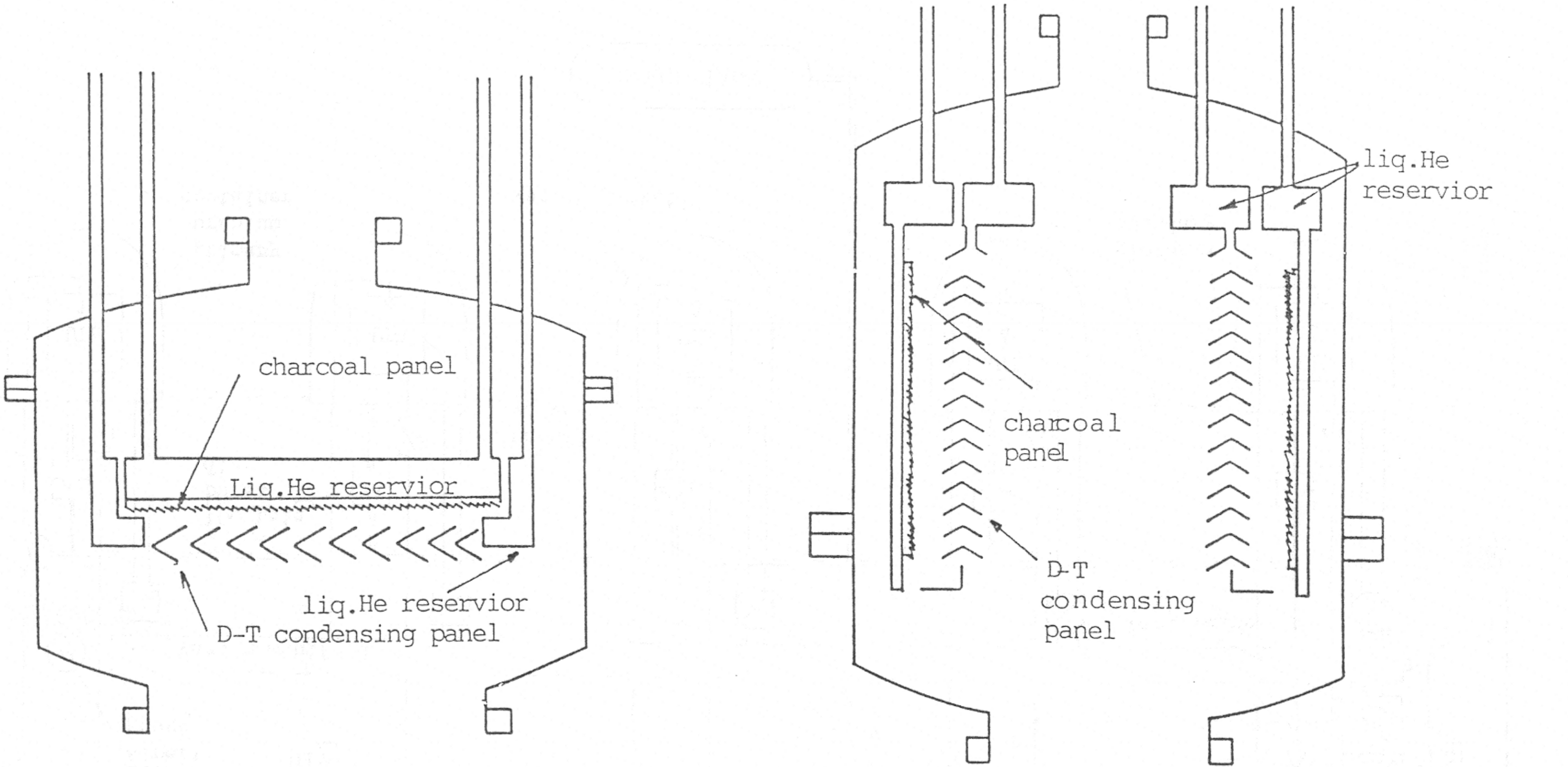


Fig. 1.2 TSTA Main Process Flow Loop



BNL compound cryopump
Cryocondensing area = 2400 cm^2
Charcoal cryosorbing area = 1300 cm^2

Lawrence Livermore National Laboratory compound pump
Cryocondensing area = 900 cm^2
Cryosorbing area = 11000 cm^2
LHe reservoirs

Fig. 1.3 BNL and LLNL Compound Cryopumps

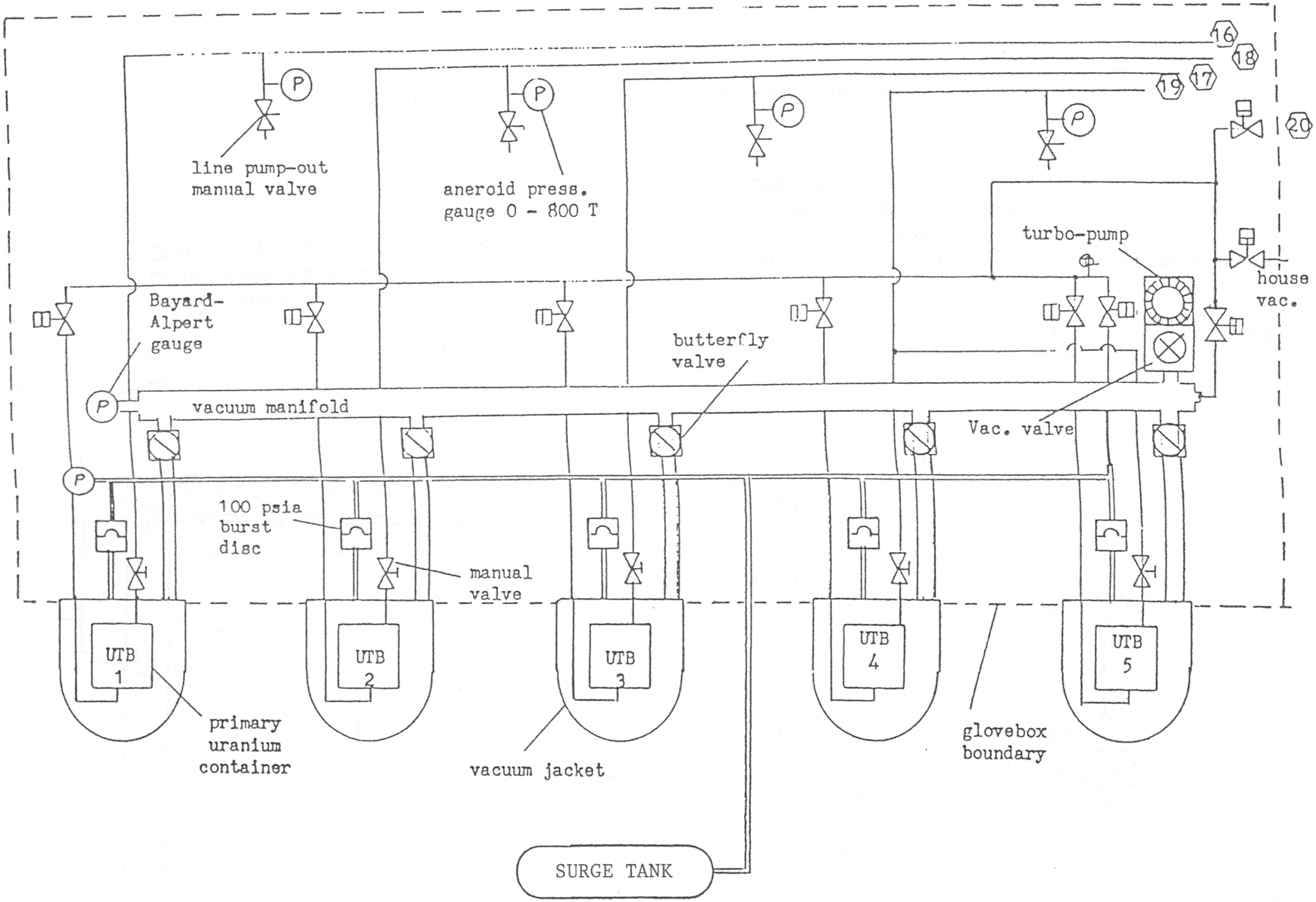


Fig. 1.4 Schematic Configuration of UTB system

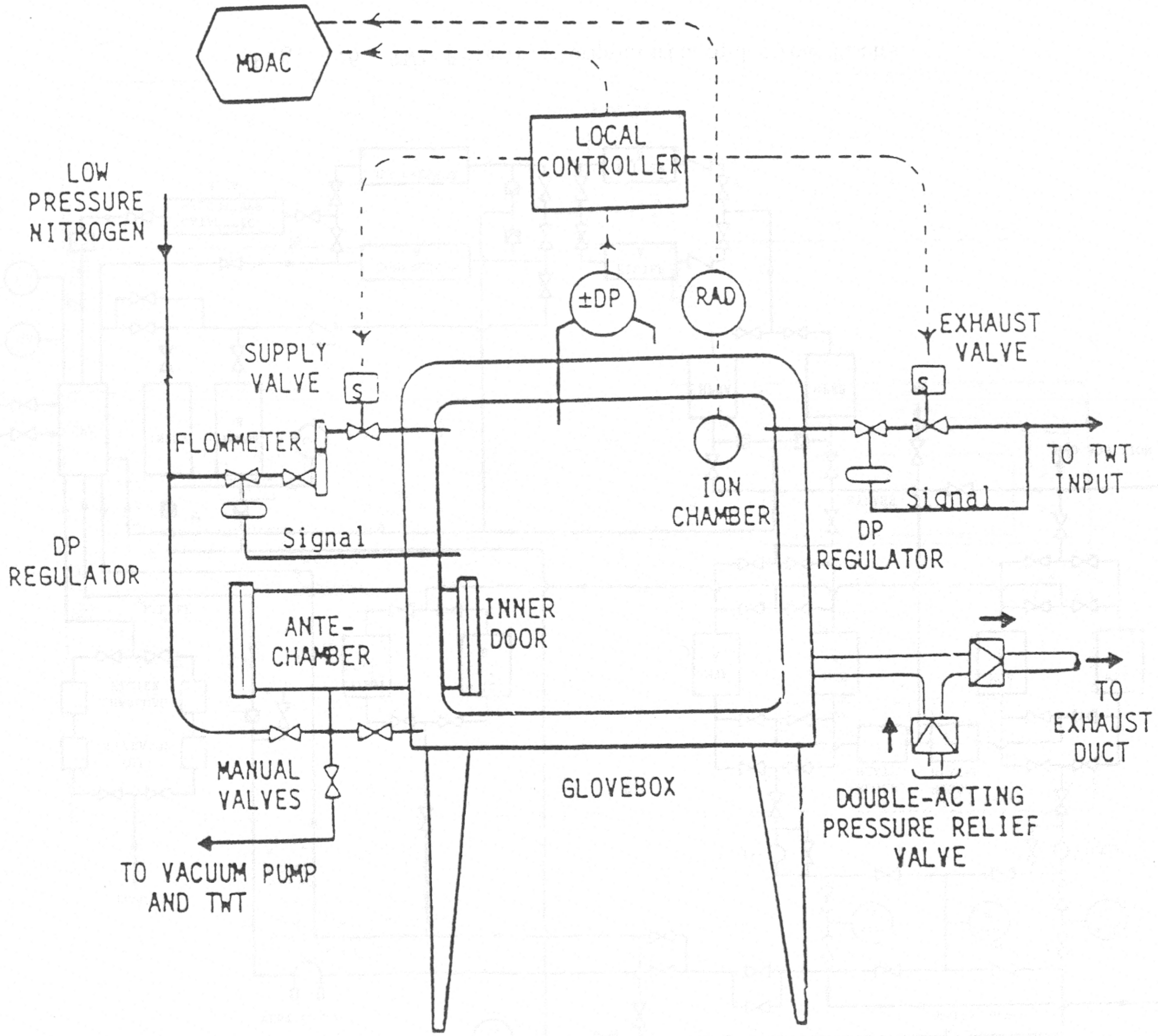


Fig. 1.5 Instrumentation of a Typical Glovebox

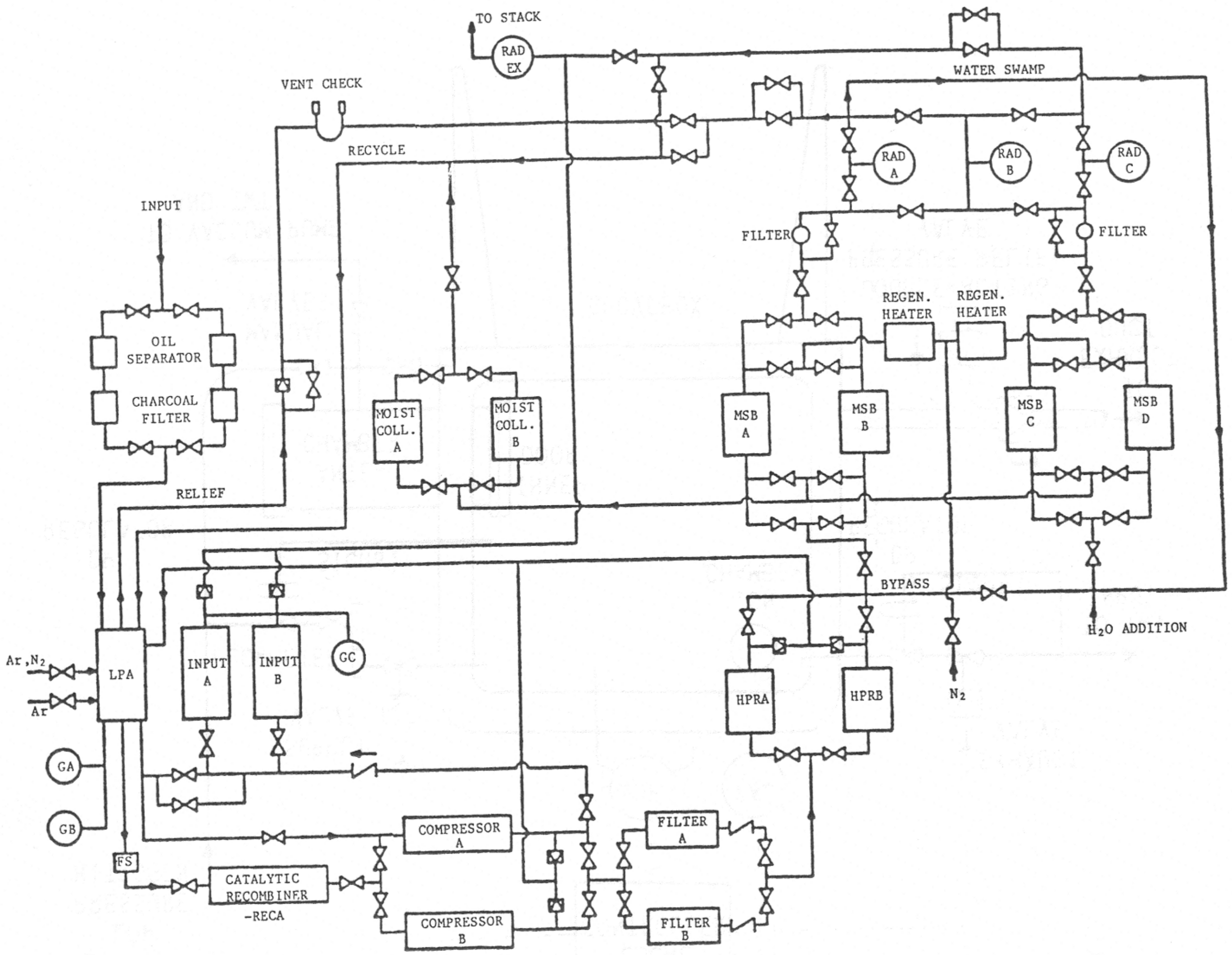


Fig. 1.6 TWT Primary Components and Flow Paths

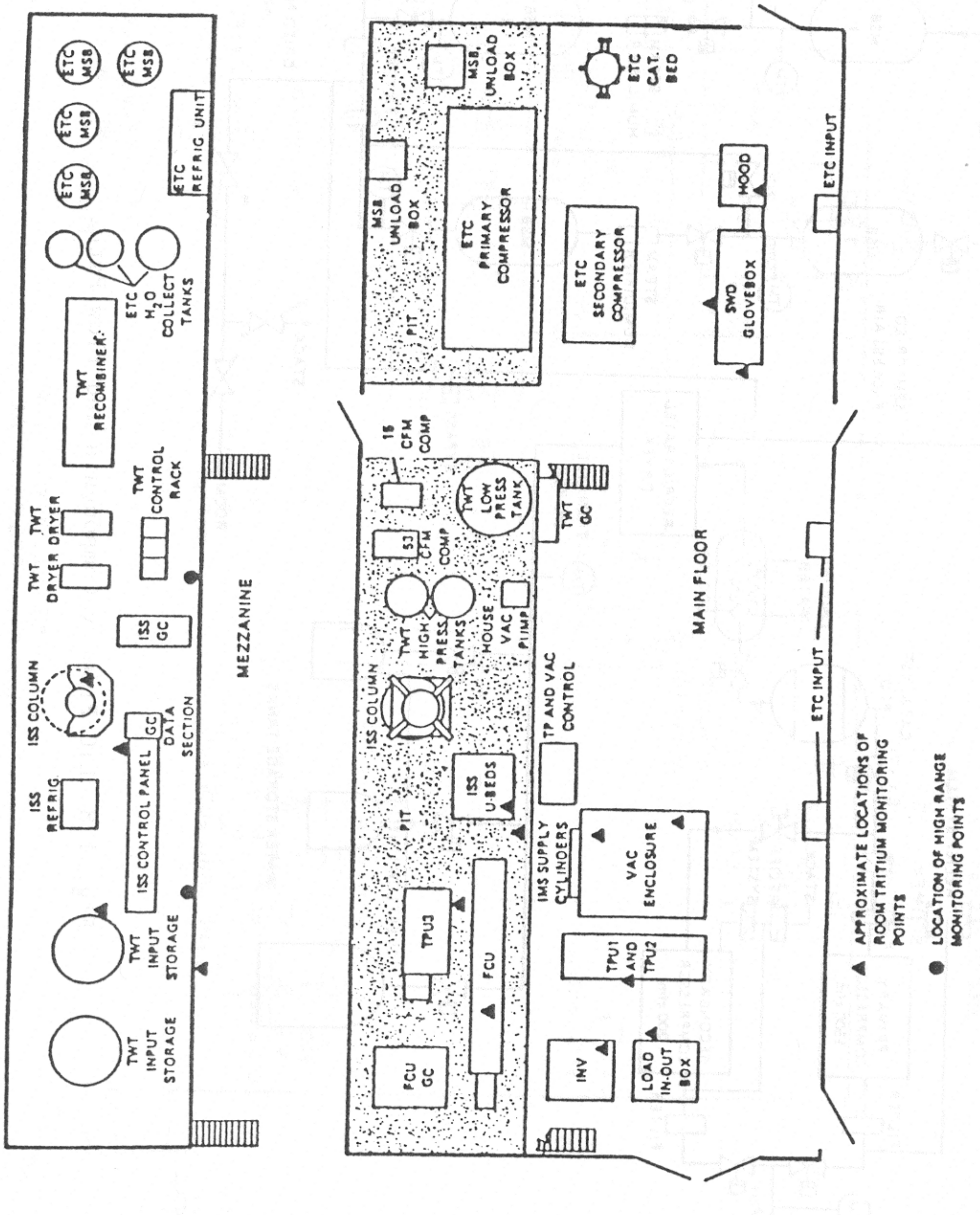


Fig. 1.7 Tritium Monitoring Points

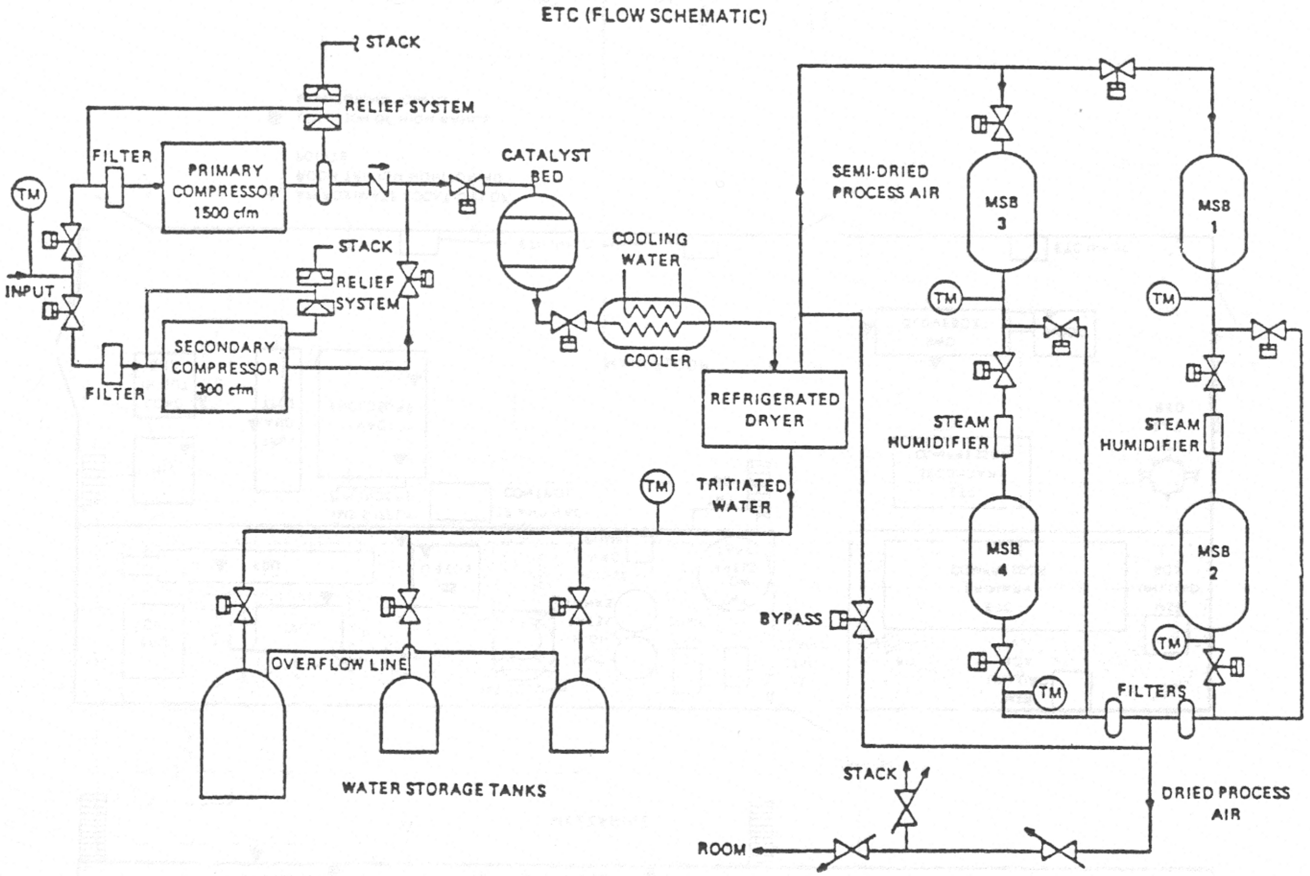


Fig. 1.8 ETC Primary Components and Flow Paths

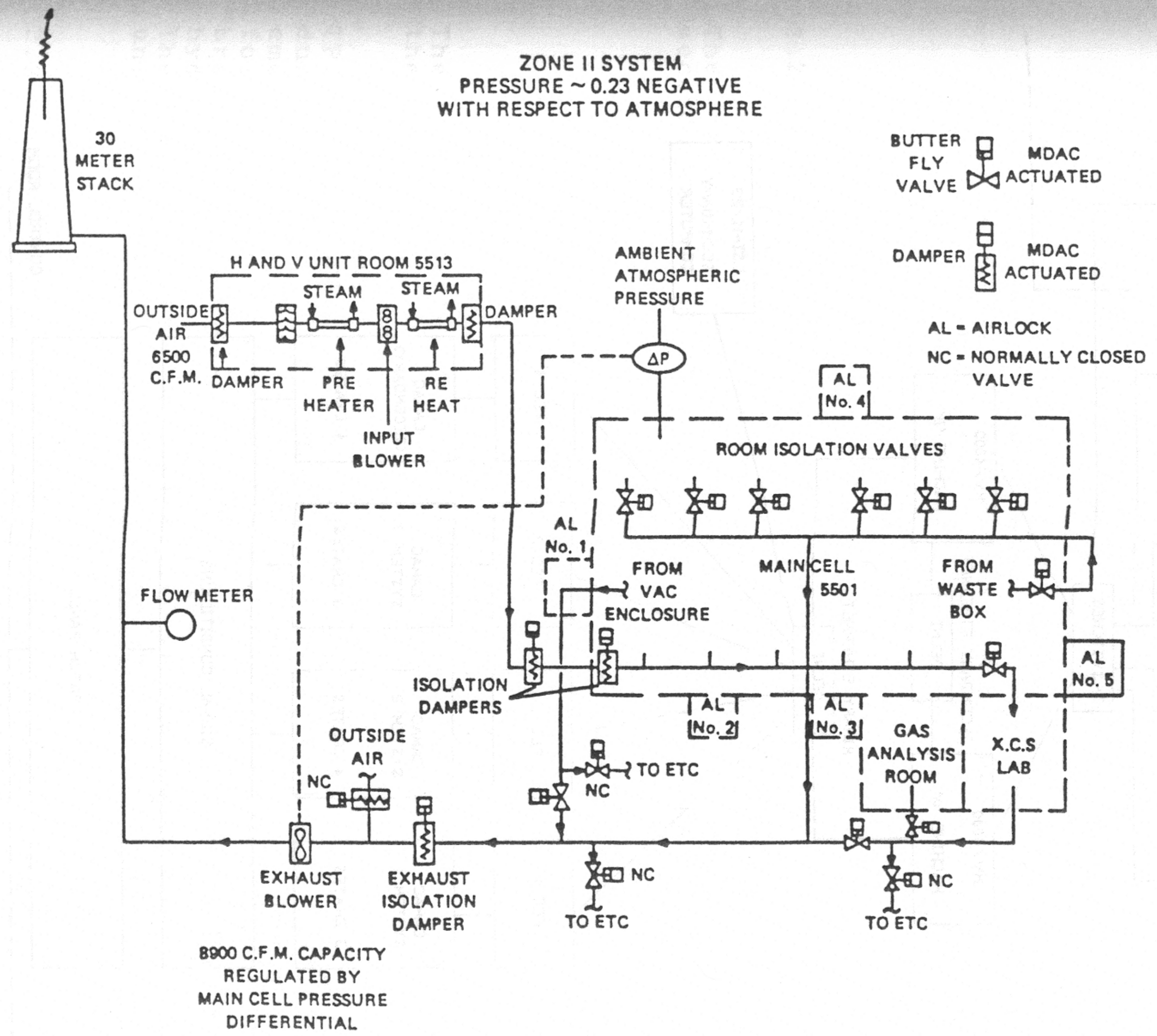


Fig. 1.9 Ventilation System of TSTA Facility (Zone II)

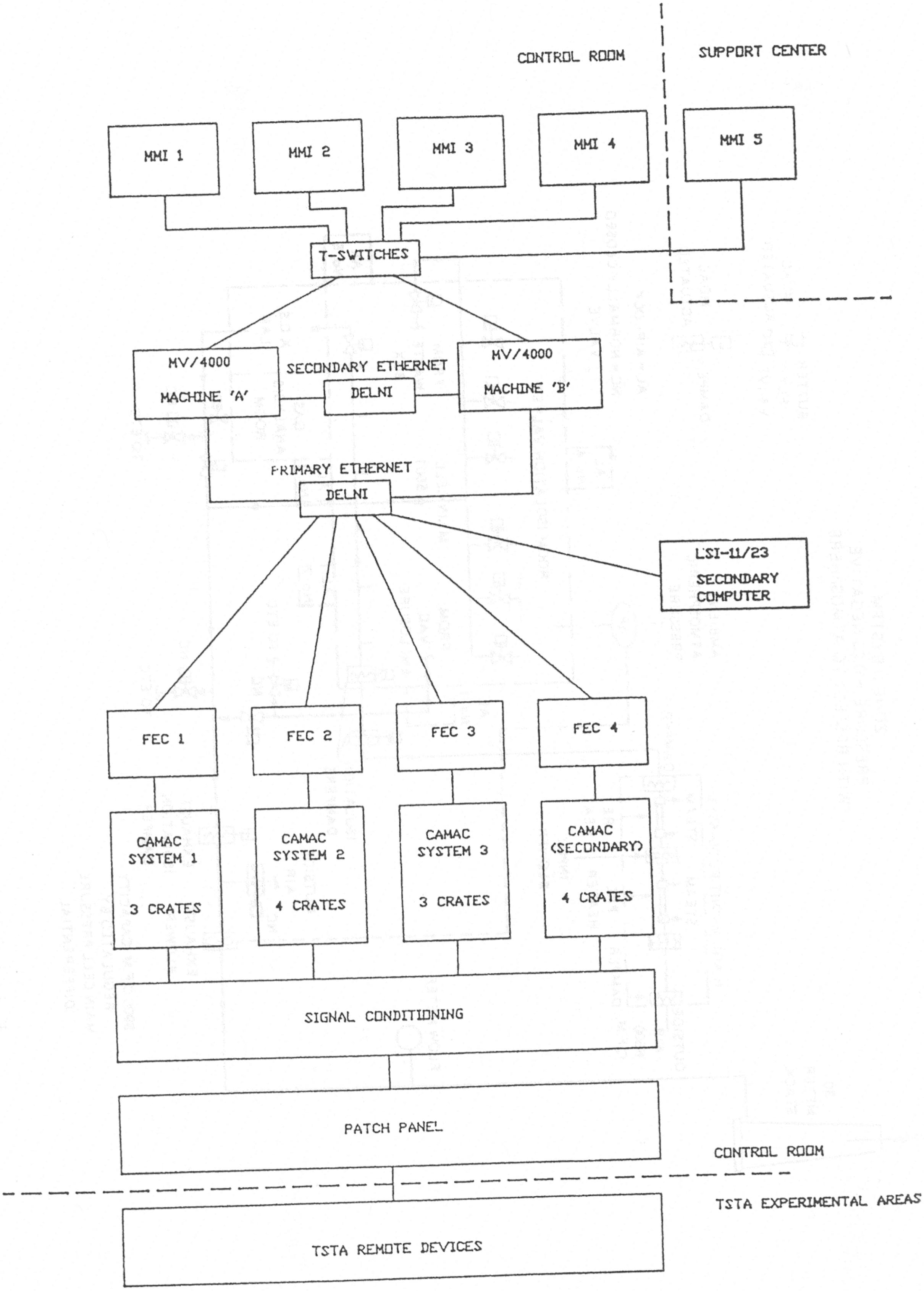


Fig. 1.10 General Block Diagram of MDAC

2. TEST PLAN

2.1 OBJECTIVES

The primary objectives of this milestone run were:

- to integrate the VAC system into the TSTA main process loop,
- to measure pumping speeds of a compound cryopump under different flow rates and impurity compositions (N_2, He),
- to measure D-T/He separation performance of a compound cryopump and demonstrate He and D-T regeneration from cryopanels to the process main loop,
- to improve the data-base and operating experience on both process systems (UTB, ISS, FCU, etc.) and safety systems (SEC, TM, TWT, etc.).

2.2 CONFIGURATION

The TSTA process loop is configured as shown in Figure 1.2. The new subsystem VAC for this test is enclosed within a secondary containment (2.4x2.7x3.6 mH) backed up by ETC.

The system is able to operate in any of the following modes:

- Local,
- Computer manual,
- Computer macro,
- Full computer control.

The hydrogen isotope separation system however, was operated in the local and computer manual mode during this run.

Process systems used were: VAC, LIO, UTB, IMS, FCU, ISS, TP1, TP3 and GAN. All safety systems were required or available during the run, these were SEC, TM, TWT, VEN, ETC, MDAC, and the emergency generator and uninterruptible power supply. The following utility systems were required; the house vacuum system, breathing air, helium, nitrogen (liquid and gaseous) and hydrogen-argon. Liquid helium was supplied to the VAC system. The supplied breathing air system was available for use in the unlikely event of a tritium release into the main cell.

2.3 PROCEDURES

(1) Start up operation

Major steps for the start up of the process systems were:

- low level tritium leak checking of the main process system,

- evacuation of the ISS vacuum jacket, pre-cooling of the ISS thermal shield with liquid nitrogen and cooling down of the columns with the cryogenic He refrigerator,
- evacuation of the vacuum jackets of FCU process components, and cooling down of cryogenic molecular sieve beds (no-heating the catalytic reactor because there was no impurity except N_2 in the main process loop),
- supply hydrogen isotopes to the FCU to pre-saturate the cryogenic molecular sieves (MSB1),
- evacuation of the vacuum jackets and cooling down of NBI return process component (cryogenic molecular sieve bed, MSB4),
- evacuation of the UTB vacuum jackets and pre-heating UTB.

(2) Tritium loading and He stripping

The loading of tritium into the process loop was performed from the UTB (except UTB-2) and from the tritium gas shipping containers attached to the LIO. Approximately 84.4 g-mole of H-D-T mixture(18.1g-H, 230.1g-D, 107.0g-T) was supplied from the UTB and tritium gas shipping containers in this run. The stripping of He and excessive H_2 was performed by using the ISS column H during the full loop operation.

(3) Loop operation

Full loop operation through the flow paths FCU-ISS-TP3-TP1-FCU (DT main flow) and ISS-TP3-FCU(NBI)-ISS (NBI D_2 flow) was started after the completion of the tritium loading from the UTB and tritium gas shipping containers. Additional loading of tritium from an another gas shipping container was carried out after achieving a steady state conditions in the loop. Pumping tests of a compound cryopump were started when steady stat was reached.

The major tasks performed during loop operation were:

- to measure the characteristics of compound cryopumps of VAC (Table 2.1 shows the experimental condition of VAC),
- to measure H-D-T separation characteristics under steady state distillation,
- withdrawal of He, H_2-HD, D_2, DT and pure T_2 from the ISS under continuous distillation conditions.

(4) Shutdown of the process loop

The ordinary shutdown procedures of the process loop are:

- stop process gas circulation through flow paths FCU-ISS-TP3-TP1-FCU and ISS-TP3-FCU(NBI)-ISS,
- offload the H-D-T mixture in the process loop to the UTB,
- warm up the ISS by stopping He refrigerant and liquid nitrogen supply, and continue offloading of H-D-T mixture to the UTB,
- warm up cryogenic molecular sieve beds in the FCU and NBI return process by stopping liquid nitrogen supply,
- if blanketing effect occurs over the uranium beds in the UTB, circulate process gas through the flow path FCU-ISS-UTB-TP3-TP1,
- evacuate process residual gas(including impurities) in the process loop to empty tritium gas shipping containers by using the TP1,
- turn off all electrical heaters of process components and heaters in the ISS.

- stop process gas circulation through flow paths FCU-ISS-TP3-TP1-FCU and ISS-TP3-FCU(NBI)-ISS,
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- warm up cryogenic molecular sieve beds in the FCU and NBI return process by stopping liquid nitrogen supply,
- if blanketing effect occurs over the uranium beds in the UTB, circulate process gas through the flow path FCU-ISS-UTB-TP3-TP1,
- evacuate process residual gas(including impurities) in the process loop to empty tritium gas shipping containers by using the TP1,
- turn off all electrical heaters of process components and heaters in the ISS.

Table 2.1 Set Values for VAC Operation in the Integrated Run

DATE	RUN	EXPERIMENTS	TOTAL THROUGHPUT	F-DT			F-He	
			TORR.L/S	SCCM	V-DC	COUNTs	SCCM	DIV.
2 June, Thu	1	* D-T + N_2 : 1%N_2	1x10min	78.95	0.801	53.5		
		* Regen. to FCU	3 "	236.85	2.191	59		
			5x30min	394.75	3.581	65		
			3x10min	236.85	2.191	59		
			1 "	78.95	0.801	53.5		
3 June, Fri	2	* Pure D-T	1x10min	78.95	0.801	53		
		* Regen. to FCU	3 "	236.84	2.191	59		
			5x30min	394.74	3.581	65		
			3x10min	236.84	2.191	59		
			1 "	78.95	0.801	53		
3 June, Fri	3	* D-T/He : 2%He	5x10min	386.86	3.511	64	7.90	5.44
		5%He	5 "	375.01	3.407	64.5	19.74	13.61
		* Regen. 10%He	5 "	355.28	3.233	64	39.48	27.22
		to FCU 20%He	5 "	315.80	2.886	62	78.95	54.45
		30%He	5 "	276.33	2.538	60.5	118.43	81.67
4 June, Sat	4	* D-T/He : 10%He	1x10min	71.06	0.731	53	7.90	5.44
		10%He	3 "	213.17	1.982	58	23.69	27.43
		* Regen. 10%He	5x60min	355.28	3.233	64	39.48	27.43
		to LIO 10%He	3x10min	213.17	1.982	58	23.69	27.43
		10%He	1 "	71.06	0.731	53	7.90	5.44
5 June, Sun	5	* D-T/He : 10%He * Regen. to LIO	1.5x120min	106.58	1.044	54.5	11.84	8.17
6 June, Mon	SHUTDOWN LOOP OPERATION							
7-9 June, Tue-Thu		* Ion gauges(on TORUS, BNL, LLNL)Calibration with D-T * D-T will be supplyed from UTB * Complementary runs will be performed with UTB and TP1.						

3. RESULTS OF LOOP OPERATION

Loop operation began at 9:23 AM on June 1, 1988. The following is the results of main subsystems during loop operation.

3.1 PROCESS SYSTEMS

3.1.1 VACUUM SYSTEM (VAC)

Torus pumping tests with the compound cryopump (BNL) were performed with D-T, N_2, and He. The pump employed a charcoal panel as the helium sorbing media. The nominal pumping surface areas are 2400 cm^2 for DT condensing chevrons and 1300 cm^2 for the He sorbing panel.

The principal results were the following:

- the BNL compound cryopump was successfully integrated into the TSTA process loop and demonstrated with a D-T flow rate of 1 - 7% of D-T main stream,
- impurity effects on the pumping speed with a D-T stream was investigated with 1% N_2 and 1-25% He, demonstrating little effect,
- He/DT separation performance on both panels of BNL pump was measured : DT gas regenerated from the condensing chevron revealed no He contained, He gas from the charcoal panel showed the level of DT of 10-25% DT ($8x10^{-4}$ - $4x10^{-3}$ g-mol/h).

The detailed results and discussion of this system will be described in a separate report.

3.1.2 TRITIUM STORAGE AND SUPPLY SYSTEM (UTB)

Approximately 84.4 g-mole of H-D-T mixture(18.1 g-H, 230.1 g-D, 107.0 g-T) was loaded to the process system from four uranium beds (UTB-1, -3, -4, and -5) in the UTB and from tritium gas shipping containers. Hydrogen isotopes from UTB were loaded directly to ISS during cooling down with the cryogenic He refrigerator, and tritium gas from gas shipping containers was supplied through the FCU.

Figures 3.1 and 3.2 show temperatures of the uranium beds (each contains 6 kg-U). Figure 3.3 shows the pressure of column I in the ISS during offloading of the UTB. The required time periods to heat the UTB from 473 K to 700 K were approximately 4 hrs, and two days to cool to ambient temperature.

3.1.3 FUEL CLEANUP SYSTEM (FCU)

No impurity except N_2 was added into the main loop in this run, so the catalytic reactors of FCU were not heated (Figure 3.4).

Figure 3.5 shows the temperatures of molecular sieve beds MSB1 in the FCU and MSB4 in the FCU (NBI). Nitrogen gas used for the VAC experiments was removed by this molecular sieve bed (MSB1) during the regeneration of the BNL cryopump.

Figures 3.6(a) and 3.6(b) show the pressures in the main process line of FCU during this run.

3.1.4 ISOTOPE SEPARATION SYSTEM (ISS)

This system (Figure 3.7) was operated with the FCU and NBI for 140 hrs. Withdrawals of He, H_2 and HD from the top of column H, D_2 from the top of column D, and T_2 from the bottom of column T were performed under full loop operation.

Figures 3.8(a) and 3.8(b) show typical distillation conditions of four interlinked columns during the removal of He to TWT and steady state, respectively. The concentration profile was calculated under the condition of steady state shown in Figure 3.8(b), using 5 cm of HETP (Height Equivalent to a Theoretical Plate). Figures 3.9(a) and 3.9(b) show the profile of column I in vapor and liquid phase, respectively.

The mixture of He, H_2 and HD was withdrawn four times from the top of ISS column H to the TWT. The following is the log of these withdrawals.

First time : Time 13:10 - 17:30
(6/1/88) Flow rate 280.0 scc/min
Total 72.8 l-STP
No tritium was detected by GC analyses.

Second time: Time 19:52 - 21:56
(6/3/88) Flow rate 282.0 scc/min
Total 35.0 l-STP
No tritium was detected by GC analyses.

Third time : Time 19:10 - 21:50
(6/4/88) Flow rate 280.0 scc/min
Total 44.8 l-STP
No tritium was detected by GC analyses.

Forth time : Time 20:19 - 20:50; 20:50 - 21:56
(6/5/88) Flow rate 280.0 ; 309.0 scc/min
Total 29.1 l-STP
No tritium was detected by GC analyses.

During these withdrawals, no increase of tritium level in the TWT-LPR was observed except the forth withdrawal (maximum level: 1 Ci/m^3) in which period ISS was not in a good steady state conditions.

Approximately 60 samples of gas analysis were performed with the on-line gas chromatograph system to certify a steady state condition of each column. Tables 3.1(a)-(c) show the results of the analysis.

Figures 3.10(a), 3.10(b), 3.11(a) and 3.11(b) show the pressures and the liquid levels of ISS, respectively.

Figure 3.12 shows the inlet flow rate of column I and compositions at the top of column H. No tritium was detected by gas chromatograph at the top of column H during the entire period of this run.

Figure 3.13 shows the temperatures of columns during cool-down. The required time periods of cooling down to 20K from ambient temperature were approximately 9.5hrs for columns I and T (the packed section of both columns is equipped with He looping coils), 11hrs for column D and 26hrs for column H. It took much time to cool down column H because the concentration of He in column H was high.

Figures 3.14(a) and 3.14(b) show the temperatures of columns during warm-up. The required time to warm up from 20 K to ambient temperature was approximately 50 hrs.

3.2 SAFETY SYSTEMS

3.2.1 SECONDARY CONTAINMENT SYSTEM (SEC)

Notable increments of the radiation levels in gloveboxes were observed at ISS (GB1 and GB2) and LIO. The following are the characteristics of these tritium releases in each glovebox.

(1) Radiation levels of ISS gloveboxes

Figure 3.15 shows the radiation levels of two ISS gloveboxes and UTB glovebox.

The GB1 radiation level (on 31 May) started to increase (from 1.0×10^{-3} Ci/m^3 to 2.5×10^{-2} Ci/m^3) with the increase of ISS column I pressure during loading tritium from two uranium beds (UTB1 and 3). In the previous loop experiments [Refs.1 and 2], this typical increase has been identified as due to a leak through a rupture disc assembly on the top of column I. The radiation levels decreased gradually with the progress of isotopic separation between light elements and tritium in the column I (decrease of tritium concentration in the top of this column). Purge of this glovebox had automatically been performed at a level higher than 1×10^{-3} Ci/m^3. The second peak (maximum 4.0×10^{-2} Ci/m^3) shown in this Figure, was also caused by the increase of tritium at the top of column I due to the disturbance of distillation conditions of the four columns.

Figure 3.16 shows a relationship among radiation levels of ISS gloveboxes and the pressure of ISS. A relationship between radiation levels and pressure of the column H can be seen from this Figure.

Most peaks on the ISS-GB2 were caused by ISS gas analysis (approximately 60 samples were withdrawn from columns to ISS.GAN during this run). The increase of the GB2 radiation level with an increase of the ISS pressure occurred from unidentified small leaks in the plumbing of the ISS gas analysis system (sampling manifold for two gas chromatographs). This glovebox was always purged with nitrogen during this run, since the tightness of isolating valve sheets between the sampling manifold and the ISS columns has deteriorated.

(2) Radiation levels of FCU glovebox

There were no leaks in the glovebox of FCU during this run.

(3) Radiation levels of LIO and INV gloveboxes

As shown in Figure 3.17, five peaks (maximum; 8×10^{-3} Ci/m^3) on the level of LIO-GB were observed. This normal release occurred when a tritium gas shipping container was attached to the LIO manifold. The source of tritium might be some residual gas in a short connecting tube on the gas cylinder. Successive leaks did not occur during loading and offloading.

(4) Radiation levels of TPU glovebox

There appeared no notable radiation peak in TPU-GB1 and GB2 (Figure 3.18). They contain the TP1 and TP3 systems composed of two sets of double-headed metal bellows pumps, a scroll pump (in TP1) and a hydrogen isotope equilibrator (in TP3).

3.2.2 ROOM RADIATION LEVELS

No offnormal radiation levels were detected with tritium monitors placed at several key places in the TSTA experimental room (main cell) during this run. Figures 3.19, 3.20 and 3.21 show the radiation levels in main cell. The sharp peaks were due to the daily check of detectors.

3.2.3 STACK RADIATION LEVELS

No offnormal release were detected during this run (Figure 3.22).

The total environmental release measured with the stack monitor (bubbler system)[Ref.1] was evaluated as follows:

5/30/88 - 6/5/88	HTO :	973.0 mCi
	HT :	62.5 mCi

3.2.4 TRITIUM WASTE TREATMENT SYSTEM (TWT)

The tritium waste treatment system operated the entire period of this run without any problems. Figure 3.22 shows the radiation levels at the exit of TWT and the stack. During this run, two peaks were detected on the radiation level at the exit of TWT. No off-normal release to the environment was observed, because the TWT system went into recycle mode from stack mode, automatically. The evacuation of the main loop caused the first peak on the radiation level of TWT shown in Figure 3.22. The main remaining gas was hydrocarbon.

Figure 3.23 shows the radiation level in the low pressure receiver (LPR) of TWT. Although there are many tritium sources contributing to the LPR radiation level, most peaks observed in Figure 3.23 were due to exhaust gas from the ISS gas analysis system (ISS.GAN).

Figure 3.24 shows the temperatures of the TWT recombiner during this run. The temperature of about 760 K was reached under recycle mode and about 720 K was reached under stack mode.

It is important to keep the pressure in the LPR between set points because the LPR receives the exhaust gases from process systems and safety systems. During this run, the pressure in the LPR was successfully kept between 0.27 atm and 0.54 atm (Figure 3.25).

It is possible to estimate the total amount of tritium transferred to the TWT. The following is the breakdown of tritium exhausted from the ISS-GAN based on the composition, pressures and number of samples analyzed with the ISS gas analysis system, and holdup of its sampling manifold (40 cm^3):

Gas composition	:	Table 3.1(a)-(c)
Gas pressures	:	600 torr for sampled gas 300 torr for flushing
Number of sampling	:	60 times
Number of flushing	:	2 times in each sampling
Total tritium amount	:	1871 Ci

The integrated amount of tritium was determined from the system flow rate (0.425 m^3/min) and the reading of the LPR radiation monitor every minute. The total amount of tritium was 5.8×10^3 Ci, which includes a background contribution (1×10^3 Ci) of the LPR tritium monitor (background radiation level ; 2.7×10^{-4} Ci/m^3).

Table 3.1(a) Results of GC Analysis for This Run (I)
(Experiments have been performed in June '88.)

day/time	position	composition (%)						
		He	H_2	HD	HT	D_2	DT	T_2
1/16:38	H-T	11.75	52.08	35.64	-	0.53	-	-
1/17:15	H-T	8.88	48.23	42.13	-	0.76	-	-
1/17:53	H-T	5.02	53.45	37.61	-	3.92	-	-
1/19:13	I-F	0.12	1.42	12.39	5.60	32.92	38.35	9.20
1/20:54	H-T	2.61	64.62	32.36	-	0.41	-	-
1/21:29	H-T	1.29	72.90	25.51	-	0.31	-	-
1/22:07	I-F	-	0.26	6.89	2.03	48.83	36.58	5.42
2/15:16	I-F	-	-	-	-	38.71	48.47	12.72
2/16:29	I-T	-	-	2.90	0.24	96.85	-	-
2/17:14	I-S(S1)	-	0.82	11.61	2.35	54.74	28.59	1.88
2/18:10	I-S(A2S)	-	-	0.72	0.12	69.85	29.11	0.11
2/18:16	I-S(S1A)	-	-	-	-	52.14	44.53	3.33
2/18:51	I-B	-	-	-	-	19.15	61.72	19.13
2/19:07	T-T	-	-	-	-	26.96	60.45	12.60
2/19:16	T-S(S3)	-	-	-	-	7.91	44.80	47.29
2/19:41	T-S(S3A)	-	-	-	-	0.24	6.73	93.02
2/20:03	T-S(S3B)	-	-	-	-	-	0.18	99.82
2/20:08	T-B	-	-	-	-	-	-	99.99

Table 3.1(b) Results of GC Analysis for This Run (II)
(Experiments have been performed in June '88.)

day/time	position	composition (%)						
		He	H_2	HD	HT	D_2	DT	T_2
2/20:34	H-T	6.10	38.49	53.91	-	1.45	-	-
2/21:04	H-S(S2)	-	0.42	10.21	2.63	80.79	5.93	-
2/21:08	H-S(S2A)	1.12	5.71	22.96	7.08	31.24	28.15	3.74
2/21:31	H-B	-	-	-	-	91.93	7.89	0.19
2/21:58	D-F	-	-	0.09	-	91.46	8.30	0.16
2/22:05	D-T	-	-	0.12	-	99.83	-	-
2/22:34	D-S(S4)	-	0.07	3.82	-	79.95	15.50	0.66
2/23:06	D-B	-	-	-	-	18.63	55.75	25.62
2/23:25	H-F	0.07	0.19	2.24	-	89.49	7.79	0.22
3/00:03	T-T	-	-	-	-	46.13	51.30	2.57
3/00:35	T-T	-	-	-	-	50.59	48.10	1.31
3/01:12	T-T	-	-	-	-	39.03	57.69	3.29
3/01:36	T-T	-	-	-	-	32.34	62.61	5.06
3/02:09	T-T	-	-	-	-	25.17	67.58	7.24
3/02:36	T-T	-	-	-	-	23.12	63.07	7.81
3/03:09	T-T	-	-	-	-	23.30	67.81	6.89
3/03:42	T-T	-	-	-	-	30.57	63.69	5.74
3/04:15	T-T	-	-	-	-	35.84	59.78	4.38

Table 3.1(c) Results of GC Analysis for This Run (III)
(Experiments have been performed in June '88.)

day/time	position	composition (%)						
		He	H_2	HD	HT	D_2	DT	T_2
3/17:37	H-T	2.10	97.33	0.57	-	-	-	-
3/18:10	H-T	6.68	93.32	-	-	-	-	-
3/20:57	H-T	4.35	95.23	0.41	-	-	-	-
3/21:30	T-T	-	-	-	-	27.85	65.85	6.30
3/22:00	T-T	-	-	-	-	23.39	70.05	6.56
3/22:30	T-T	-	-	-	-	25.08	67.69	7.23
3/22:56	T-T	-	-	-	-	29.54	65.42	5.04
3/23:50	T-T	-	-	-	-	35.79	56.77	7.44
4/08:00	I-F	-	-	-	-	54.07	39.44	6.49
4/09:11	I-F	-	-	-	-	52.44	40.70	6.86
4/10:12	H-T	3.42	34.57	59.92	-	2.10	-	-
4/19:00	H-T	15.03	35.92	48.01	-	1.05	-	-
4/20:34	H-T	4.49	37.69	56.68	-	1.13	-	-
4/21:14	H-T	3.15	30.93	64.62	-	1.30	-	-
4/22:01	H-T	2.19	25.03	70.81	-	1.97	-	-
5/08:39	I-F	-	-	-	-	44.95	45.06	9.99
5/18:34	H-T	2.43	9.17	83.11	-	5.28	-	-
5/20:20	H-T	2.79	12.72	77.66	-	6.84	-	-
5/21:02	H-T	4.57	7.47	85.57	-	2.38	-	-
5/21:42	H-T	4.22	3.98	89.35	-	2.45	-	-

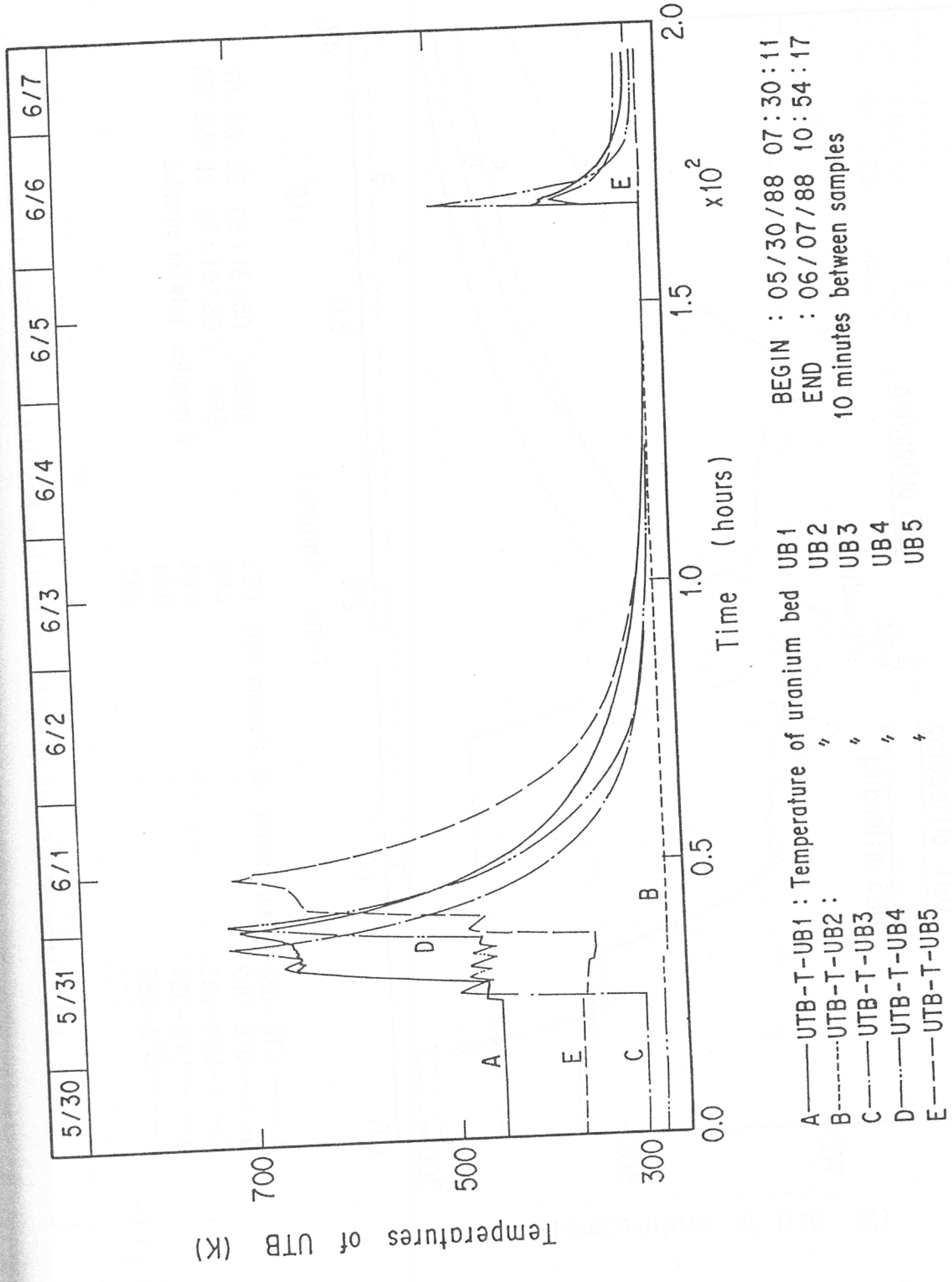


Fig. 3.1 Temperatures of UTB (1) at Tritium Loading to the TSTA Loop

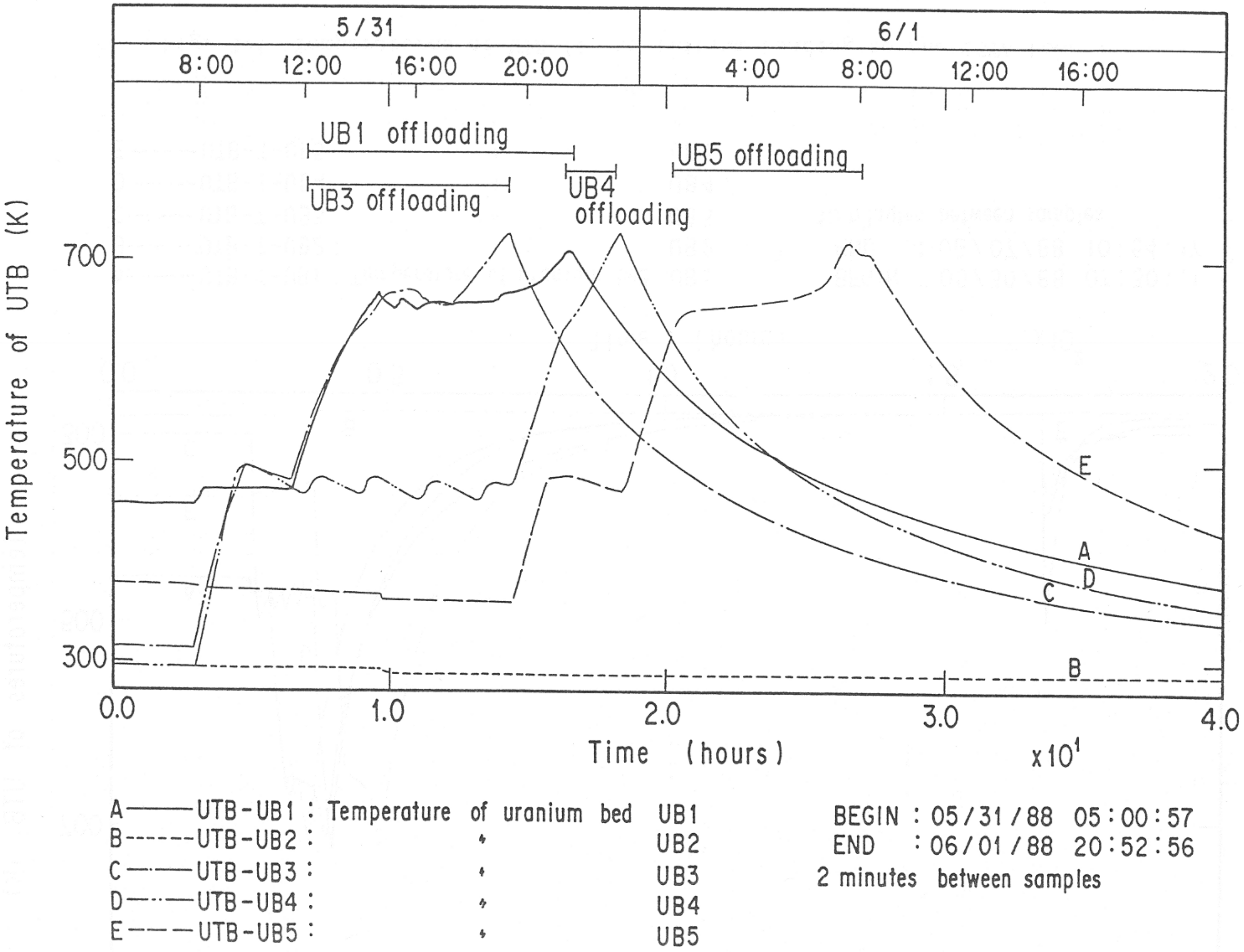


Fig. 3.2 Temperatures of UTB (2) at Tritium Loading to the TSTA Loop

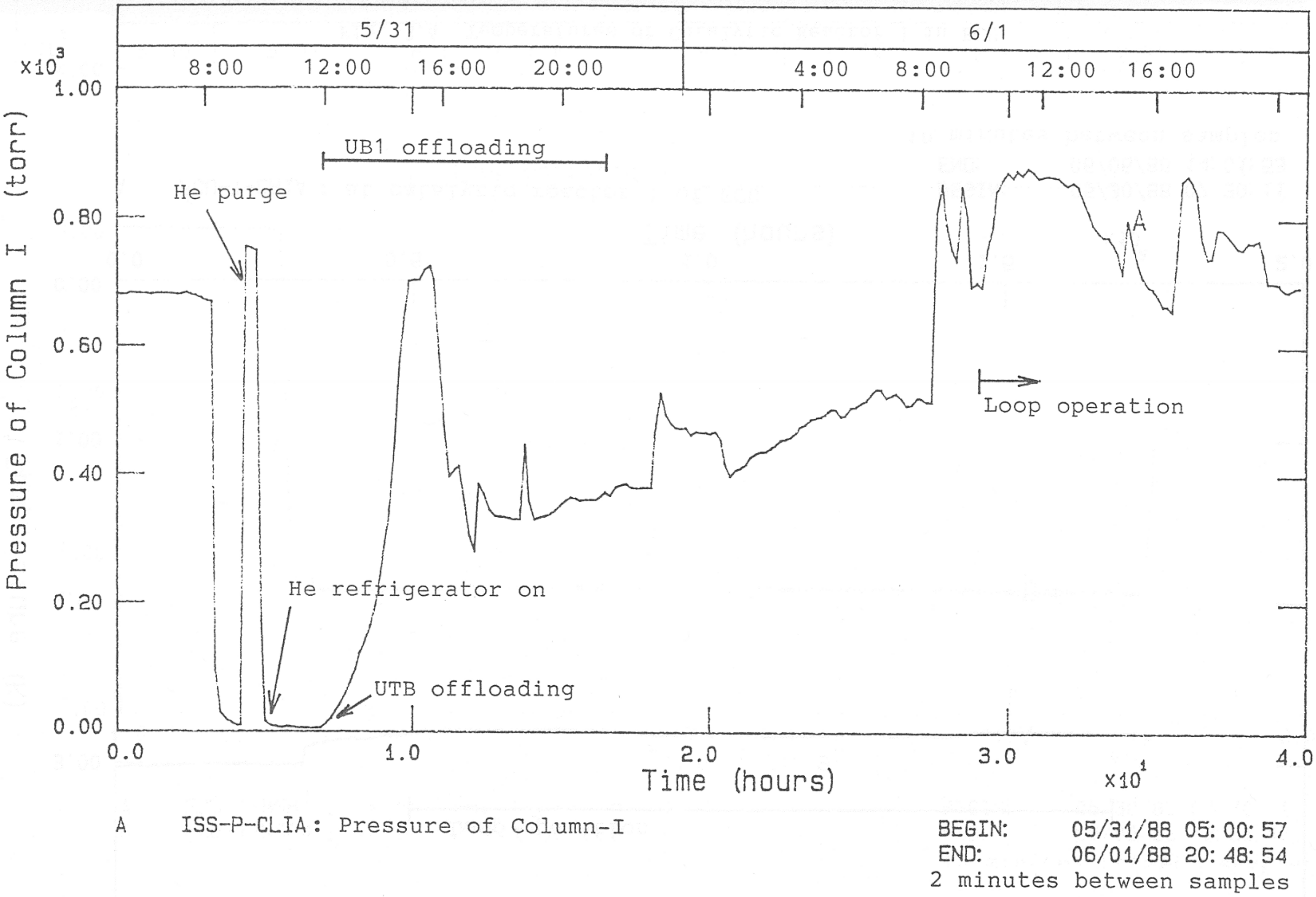


Fig. 3.3 Pressure of Column I during UTB Offloading

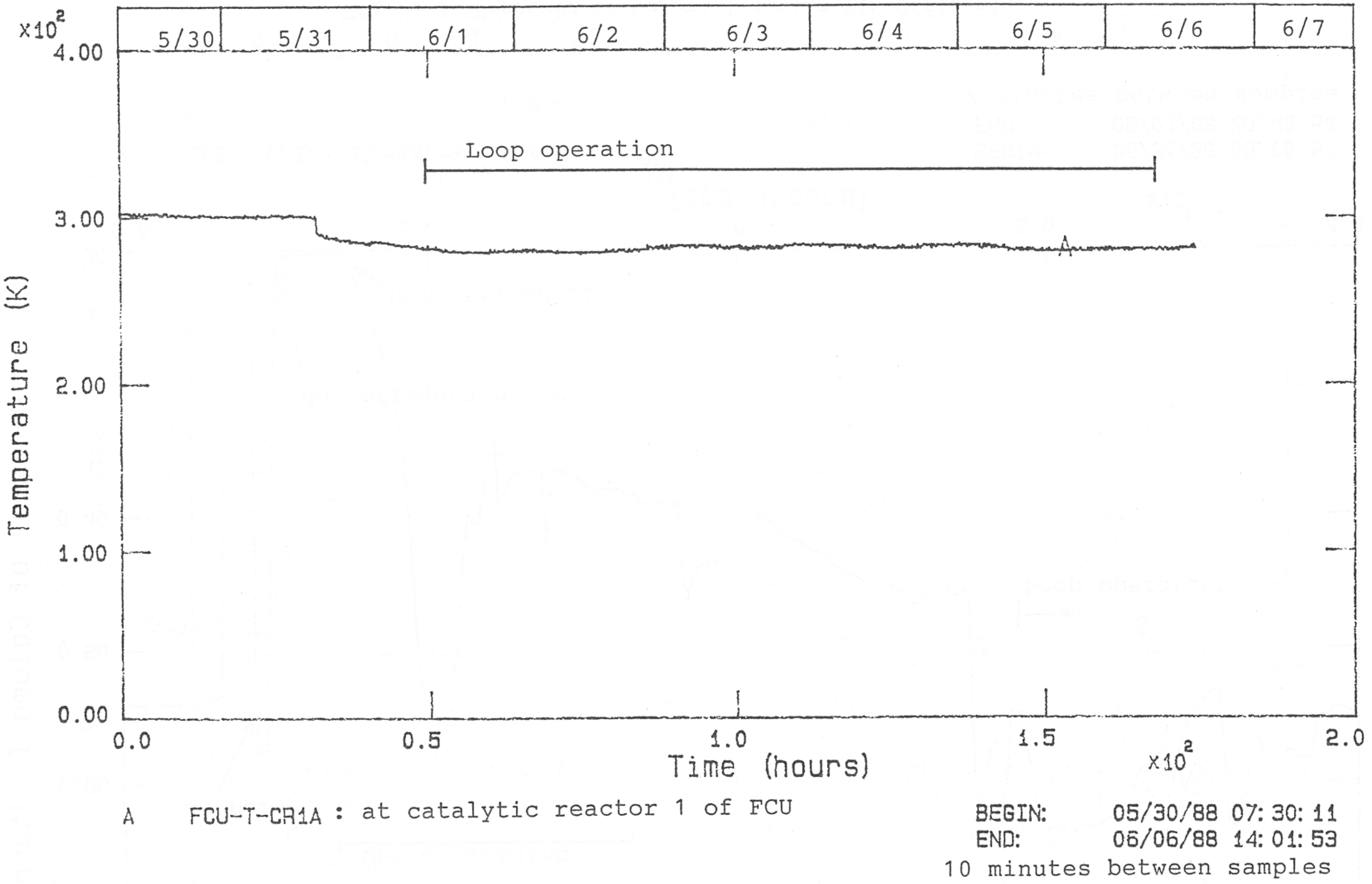


Fig. 3.4 Temperatures of Catalytic Reactor 1 in FCU

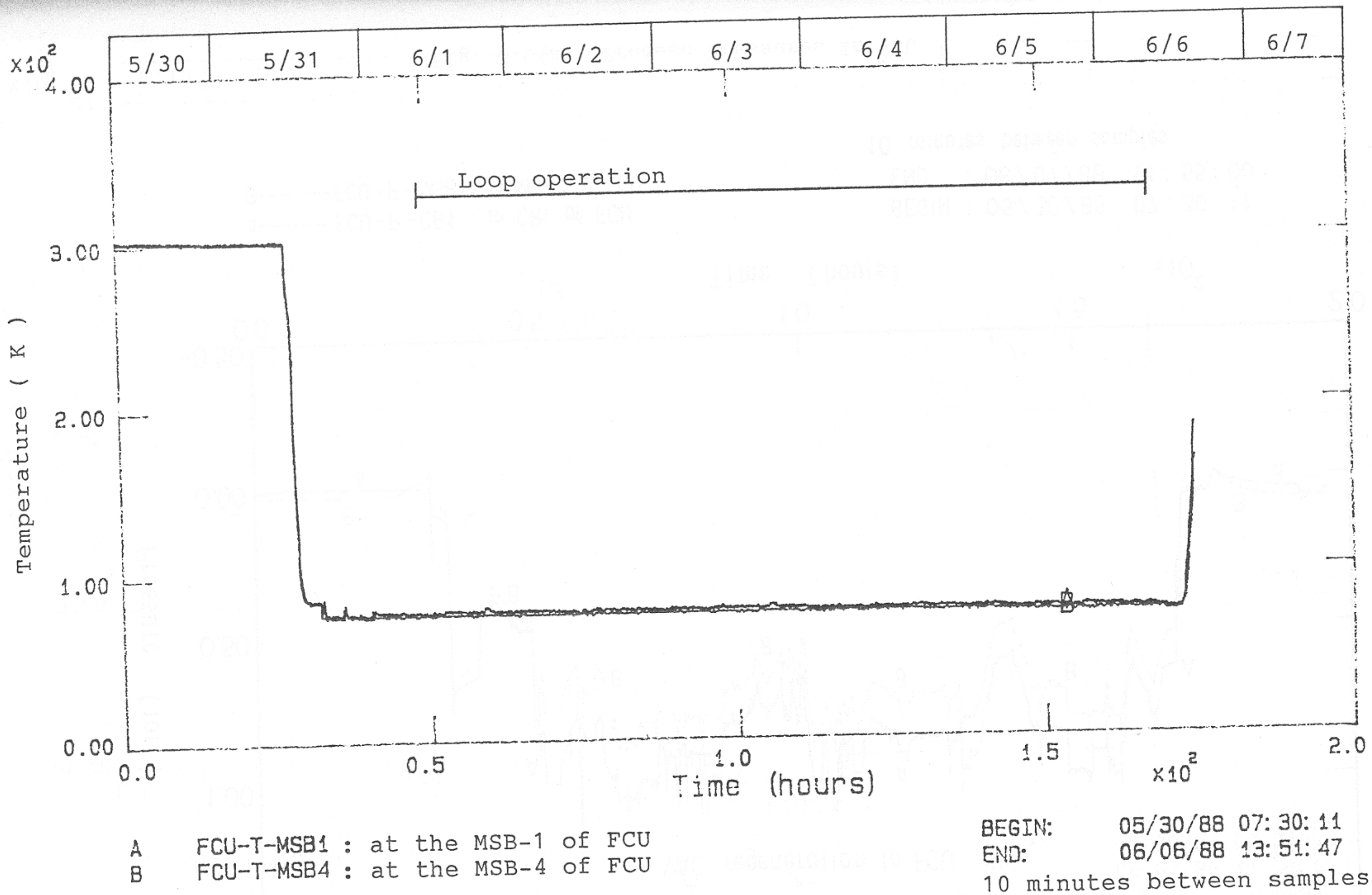


Fig. 3.5 Temperatures of Molecular Sieve Beds in FCU and NBI

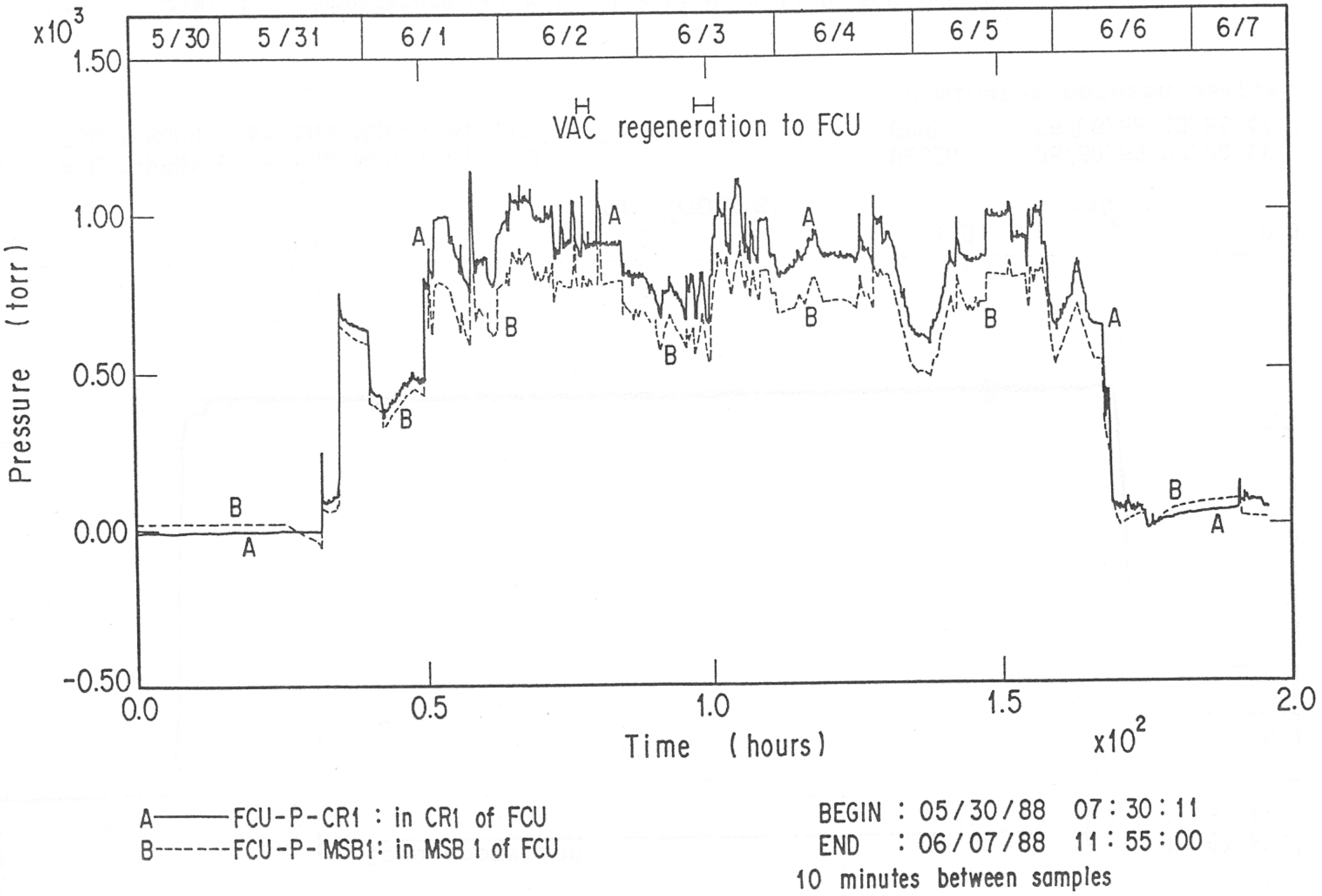


Fig. 3.6(a) Process Pressures in FCU

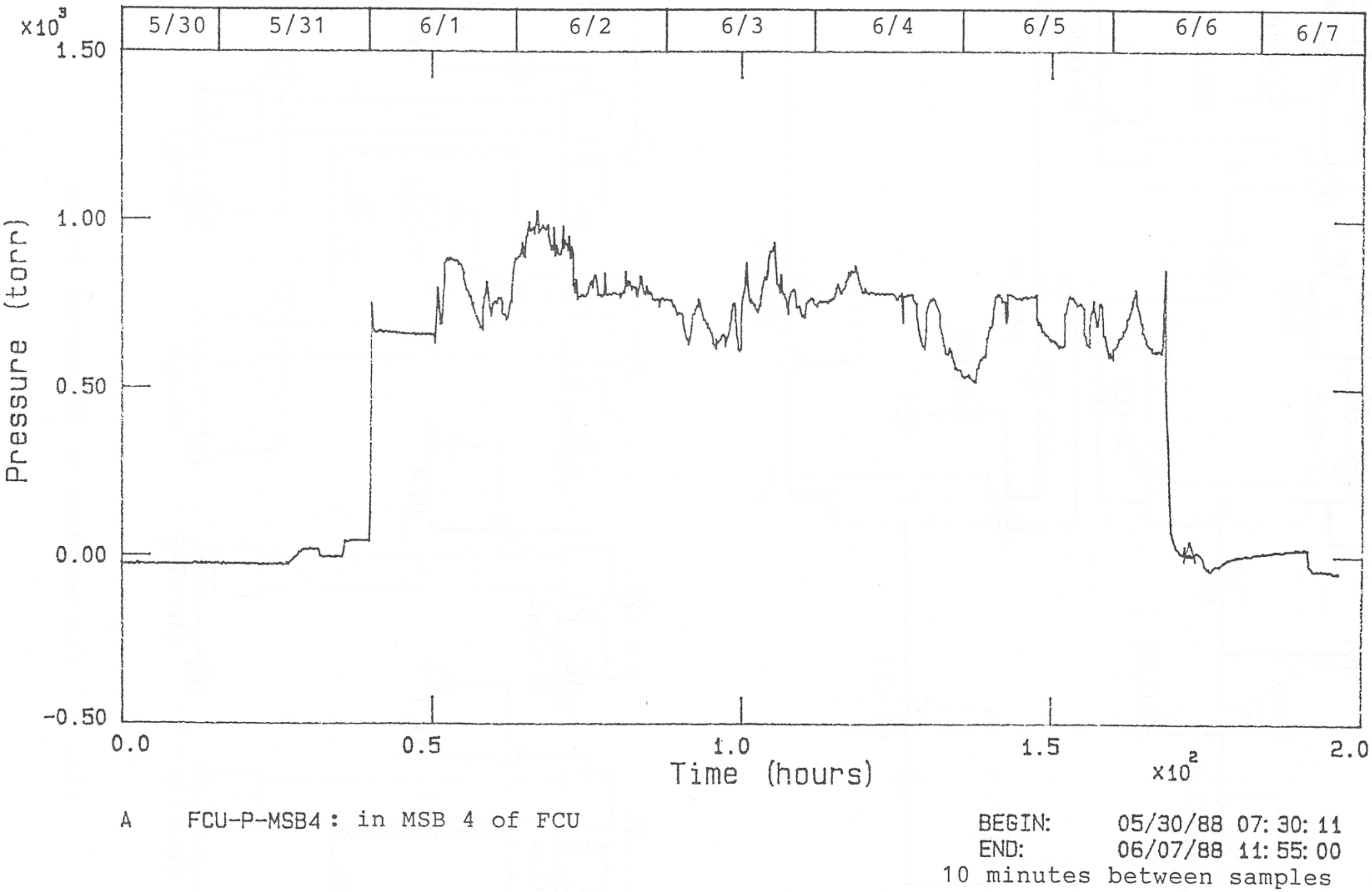


Fig. 3.6(b) Process Pressures in NBI

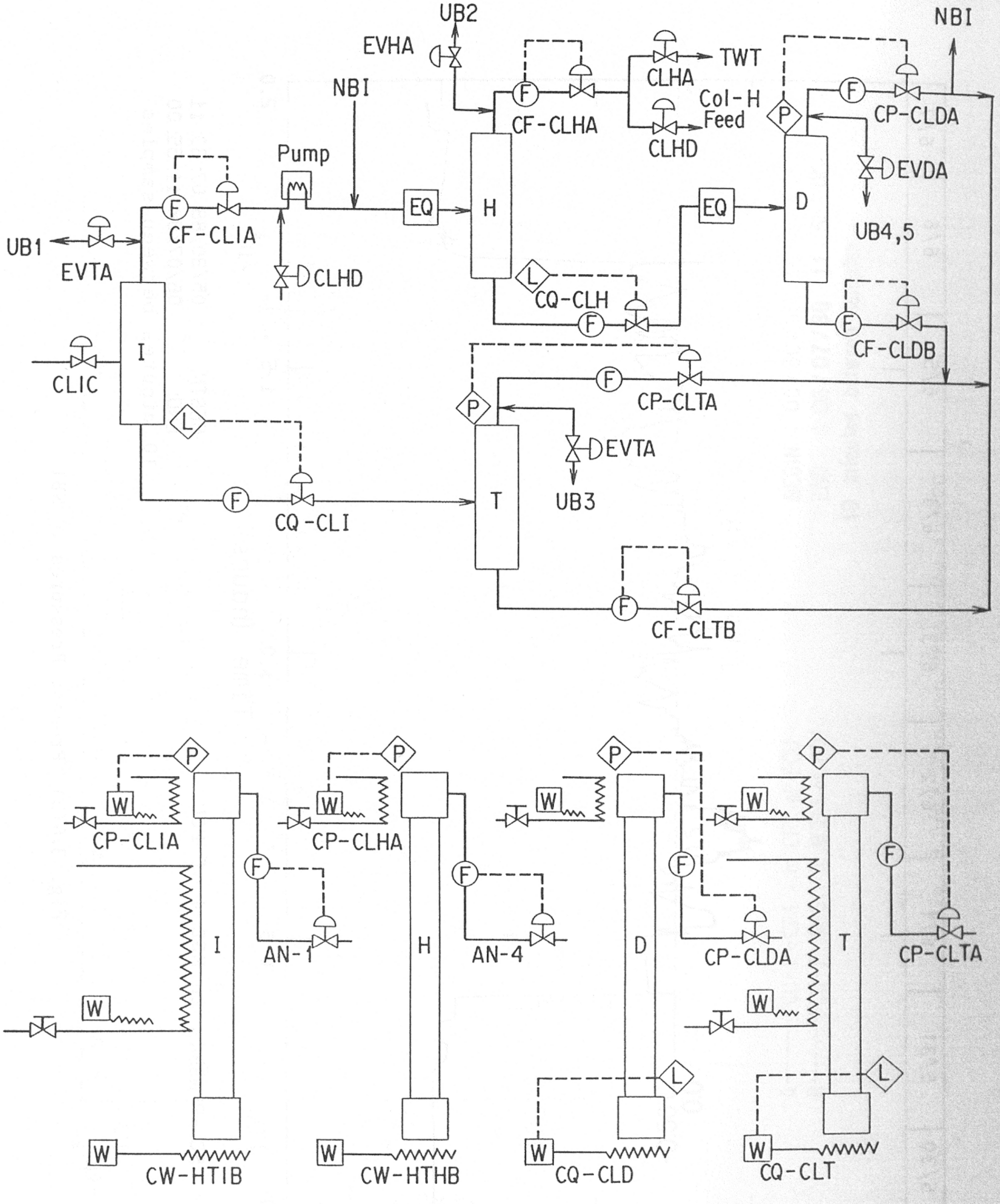


Fig. 3.7 Configuration of ISS Control System

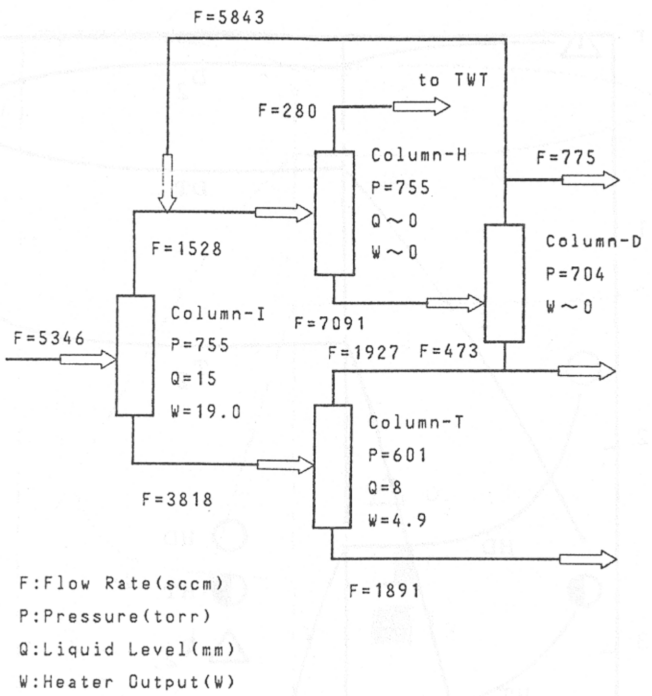


Fig. 3.8(a) Flow Balances in ISS (1)

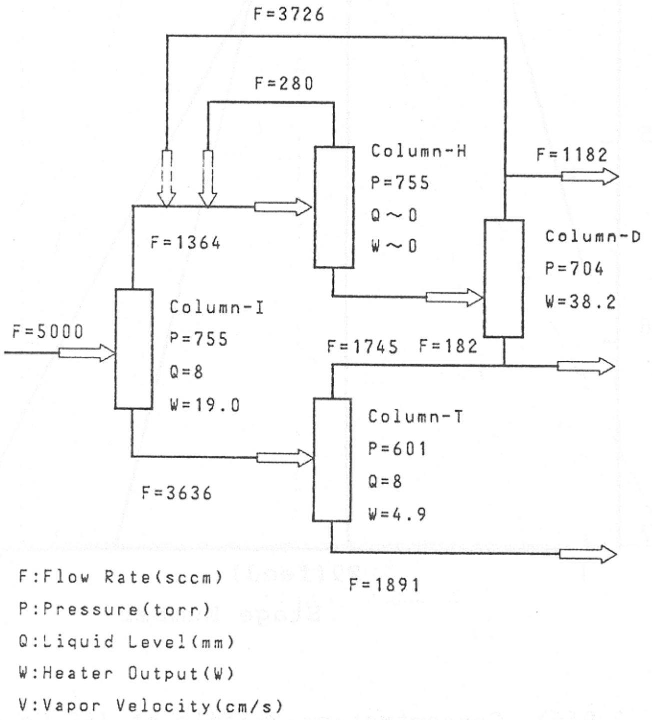


Fig. 3.8(b) Flow Balances in ISS (2)

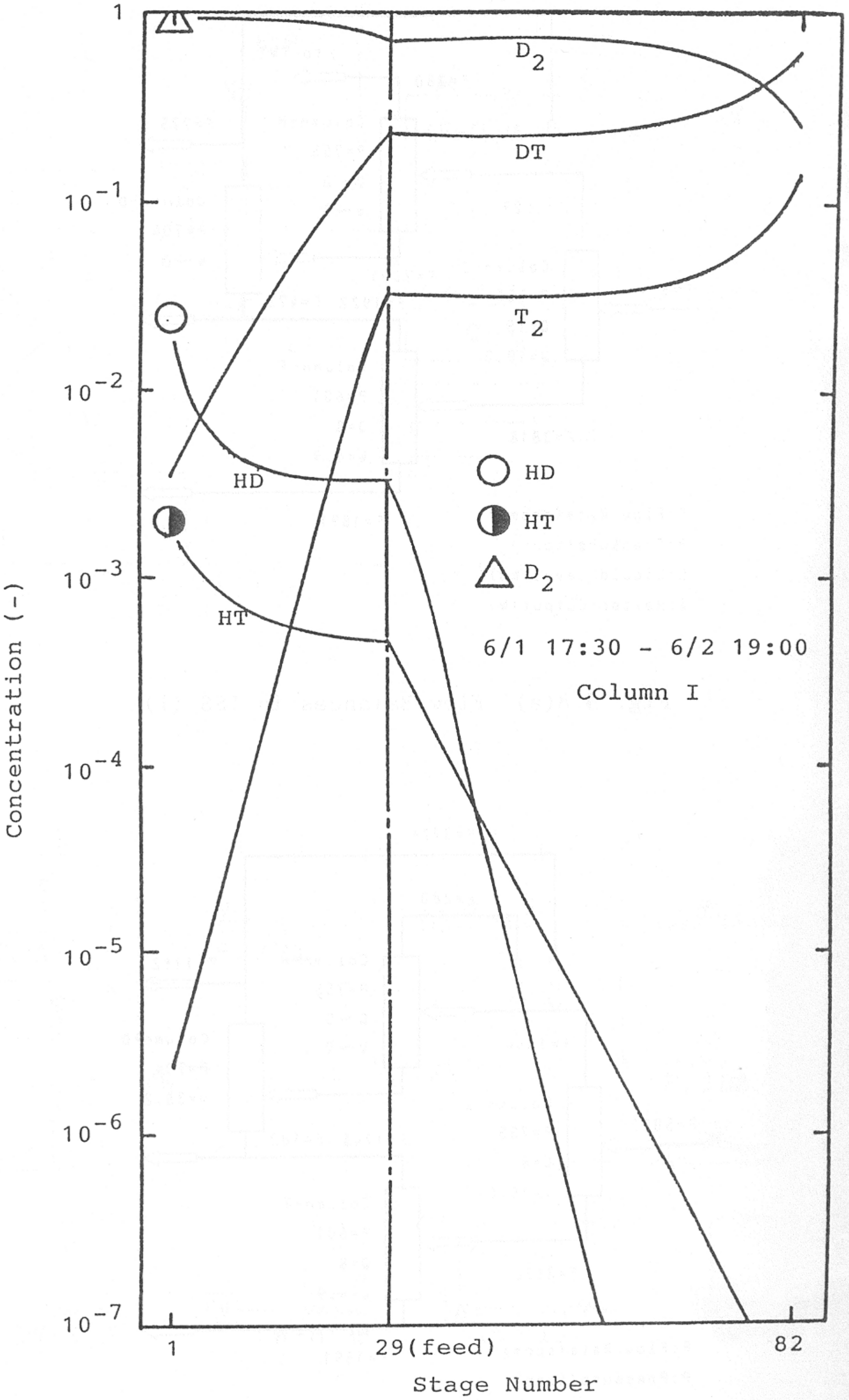


Fig. 3.9(a) Concentration Profile of ISS Column I (in Vapor Phase)

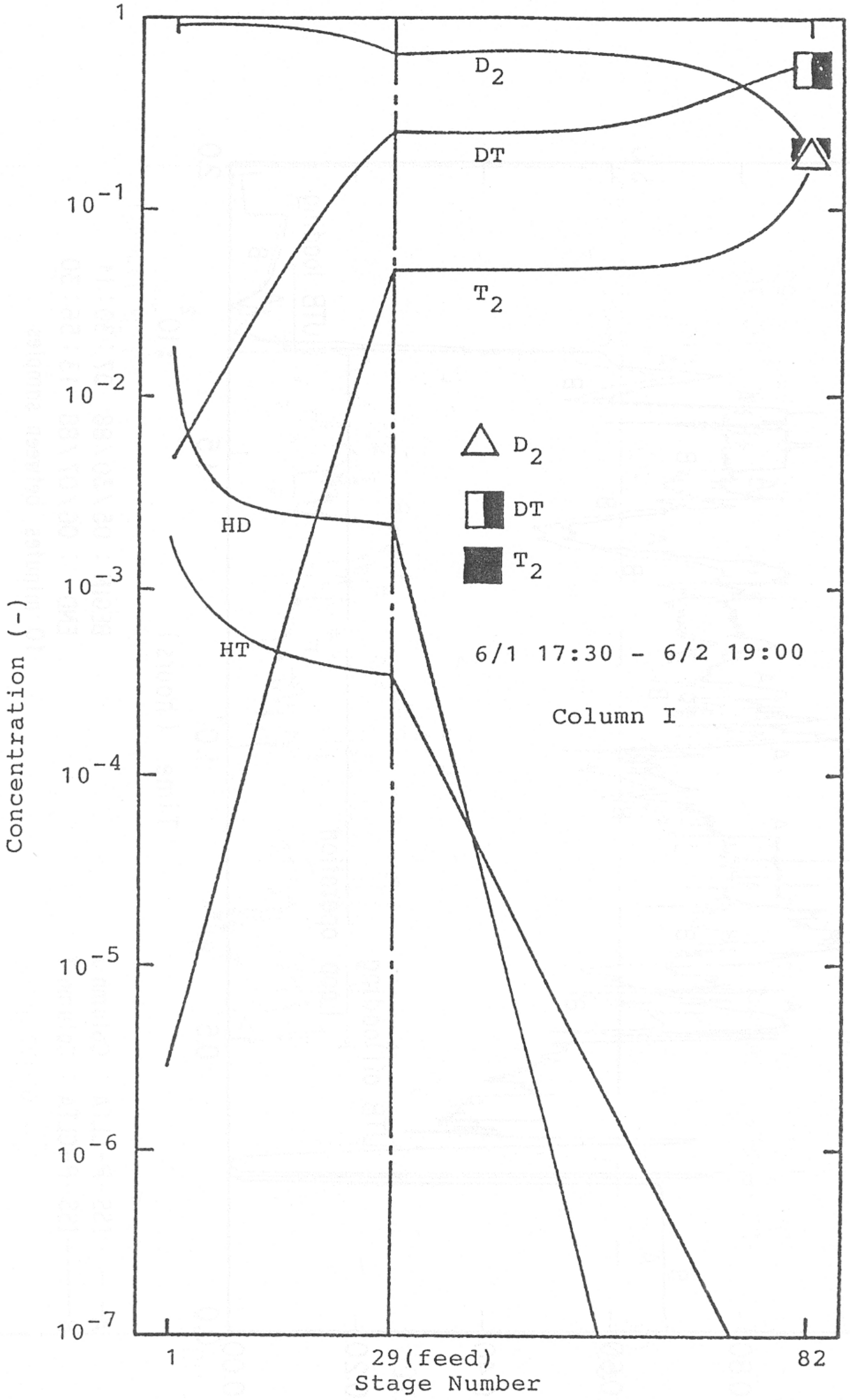


Fig. 3.9(b) Concentration Profile of ISS Column I (in Liquid Phase)

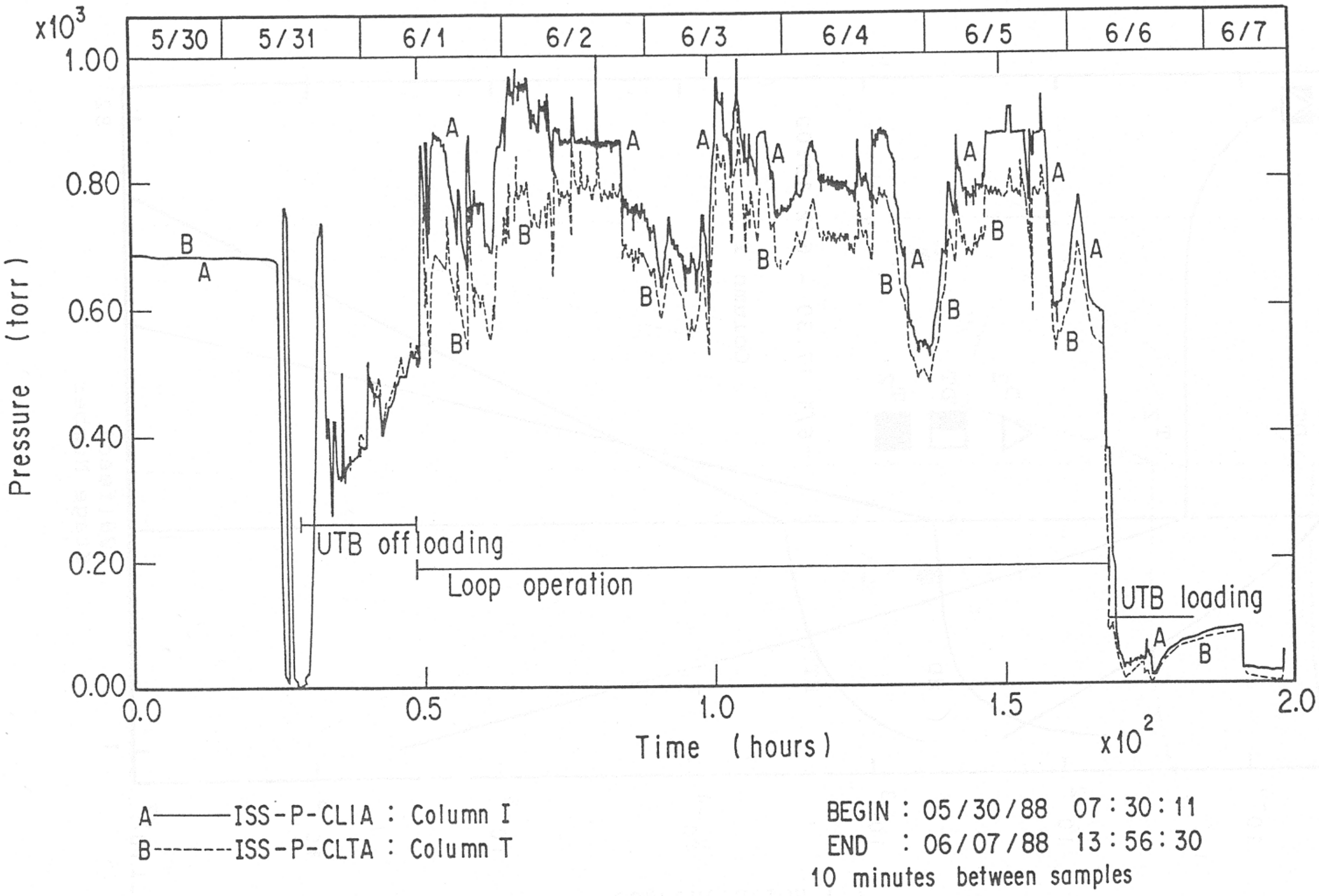


Fig. 3.10(a) Pressures of ISS Columns

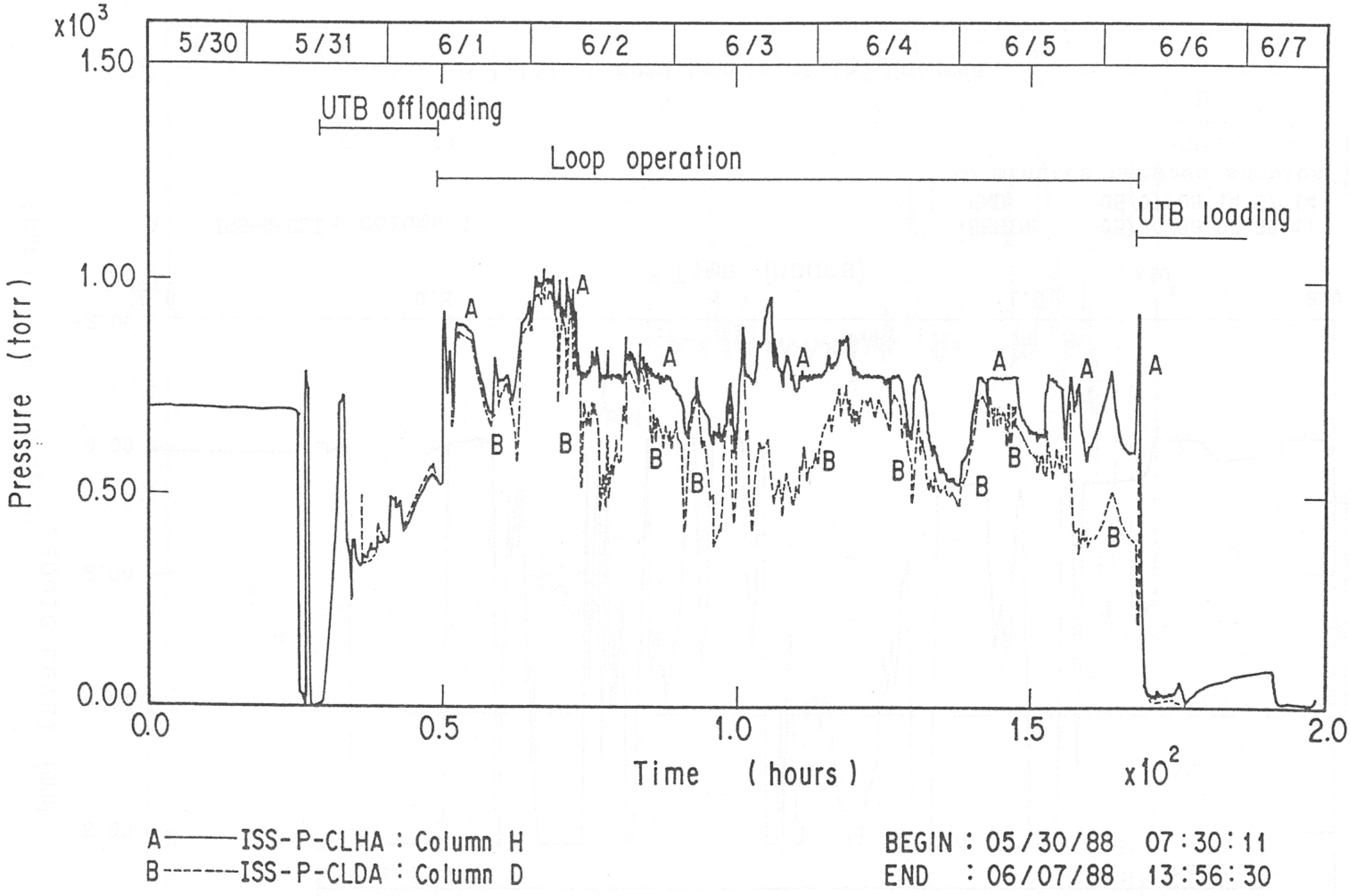


Fig. 3.10(b) Pressures of ISS Columns

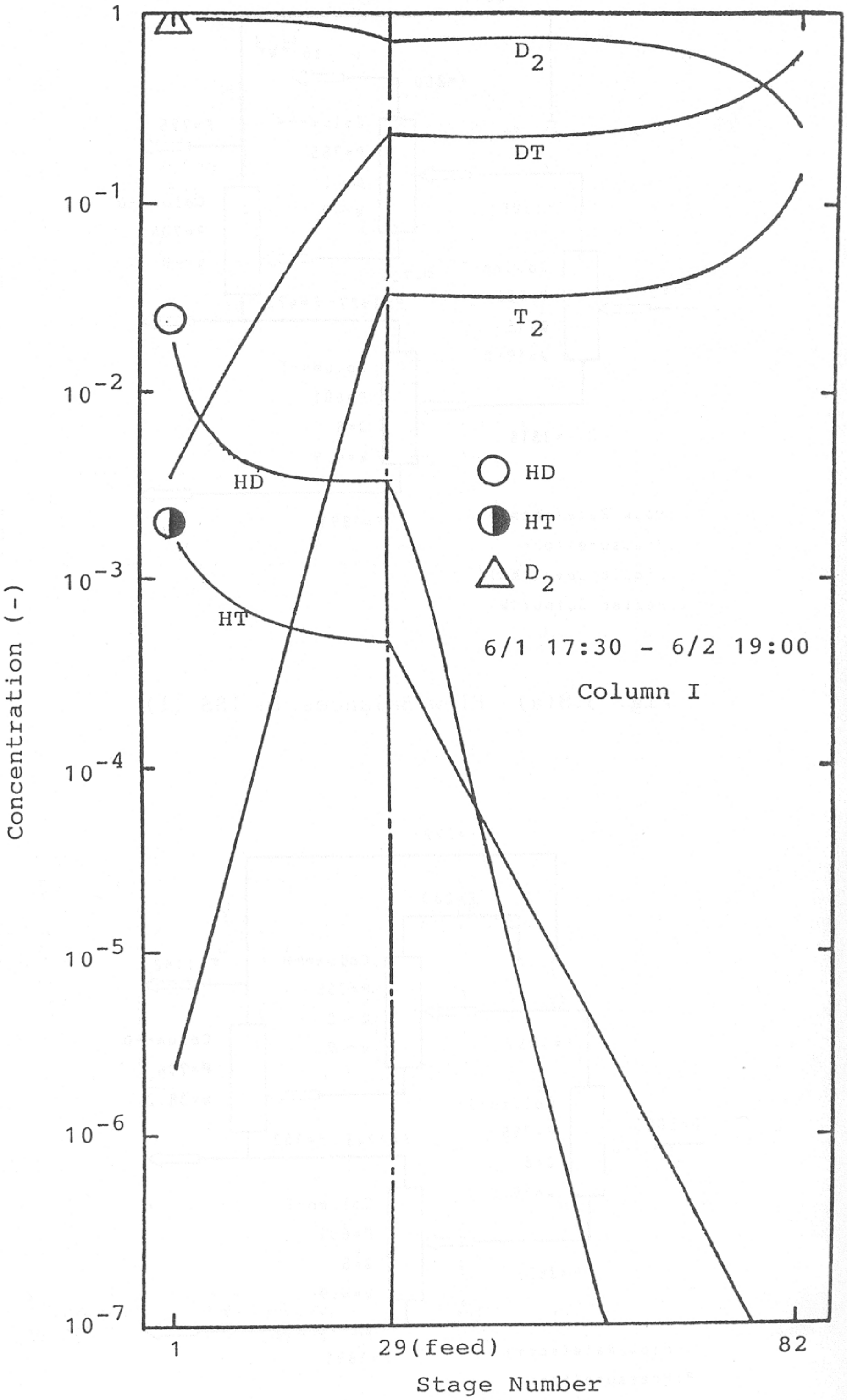


Fig. 3.9(a) Concentration Profile of ISS Column I (in Vapor Phase)

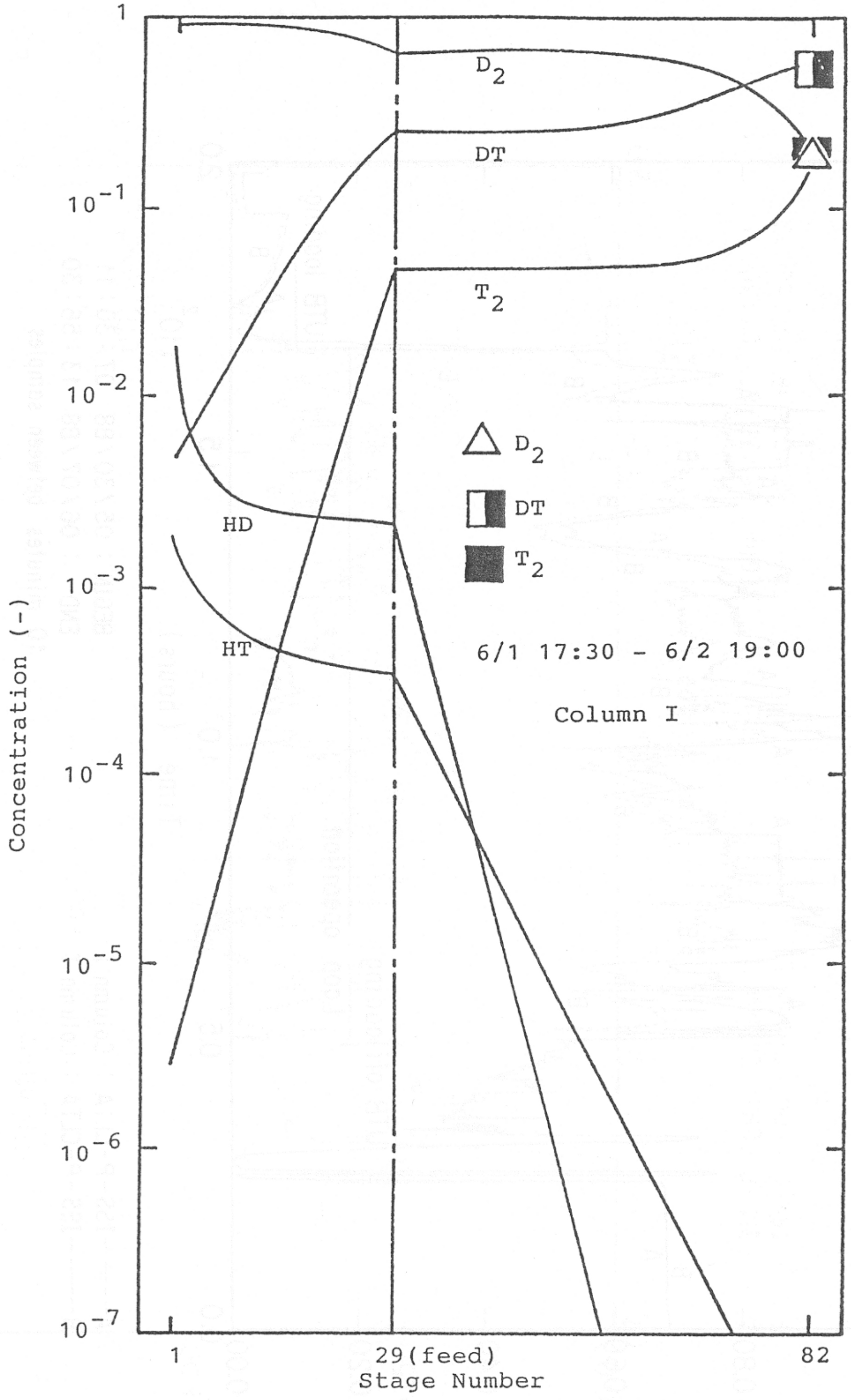


Fig. 3.9(b) Concentration Profile of ISS Column I (in Liquid Phase)

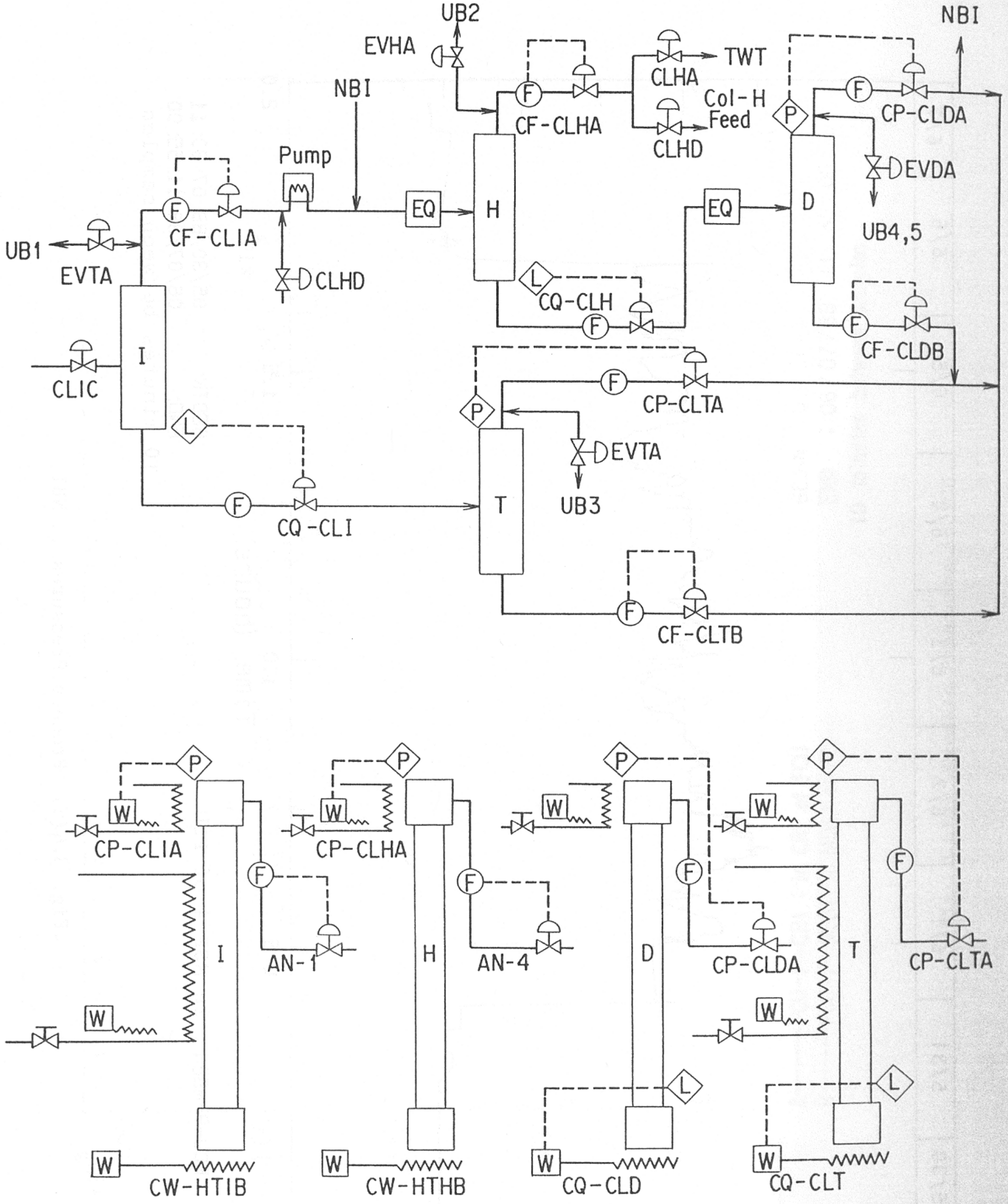


Fig. 3.7 Configuration of ISS Control System

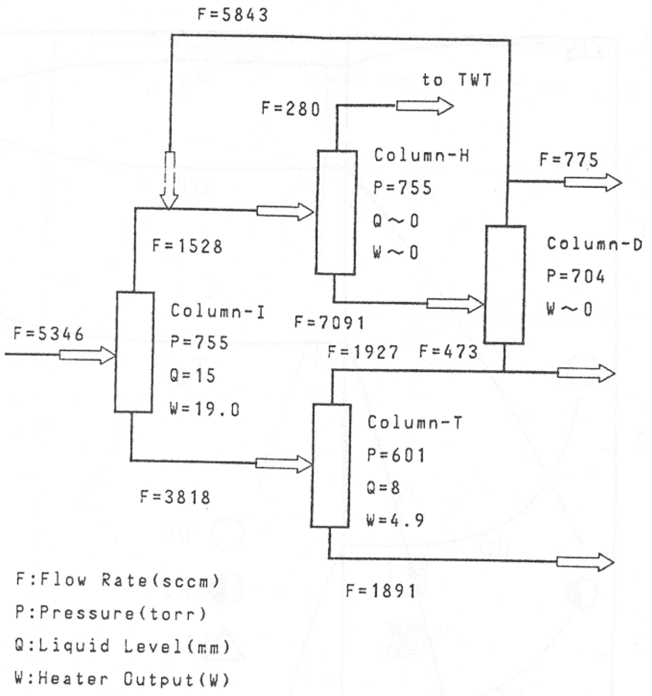


Fig. 3.8(a) Flow Balances in ISS (1)

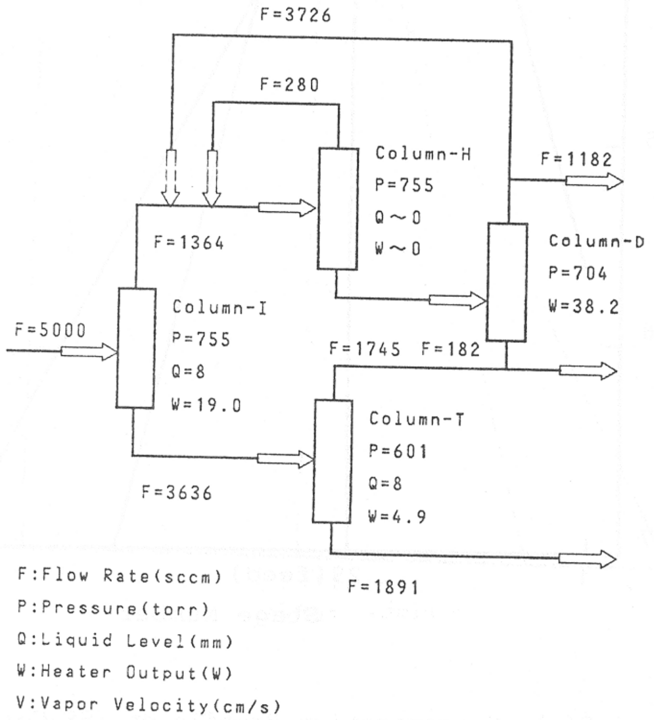


Fig. 3.8(b) Flow Balances in ISS (2)

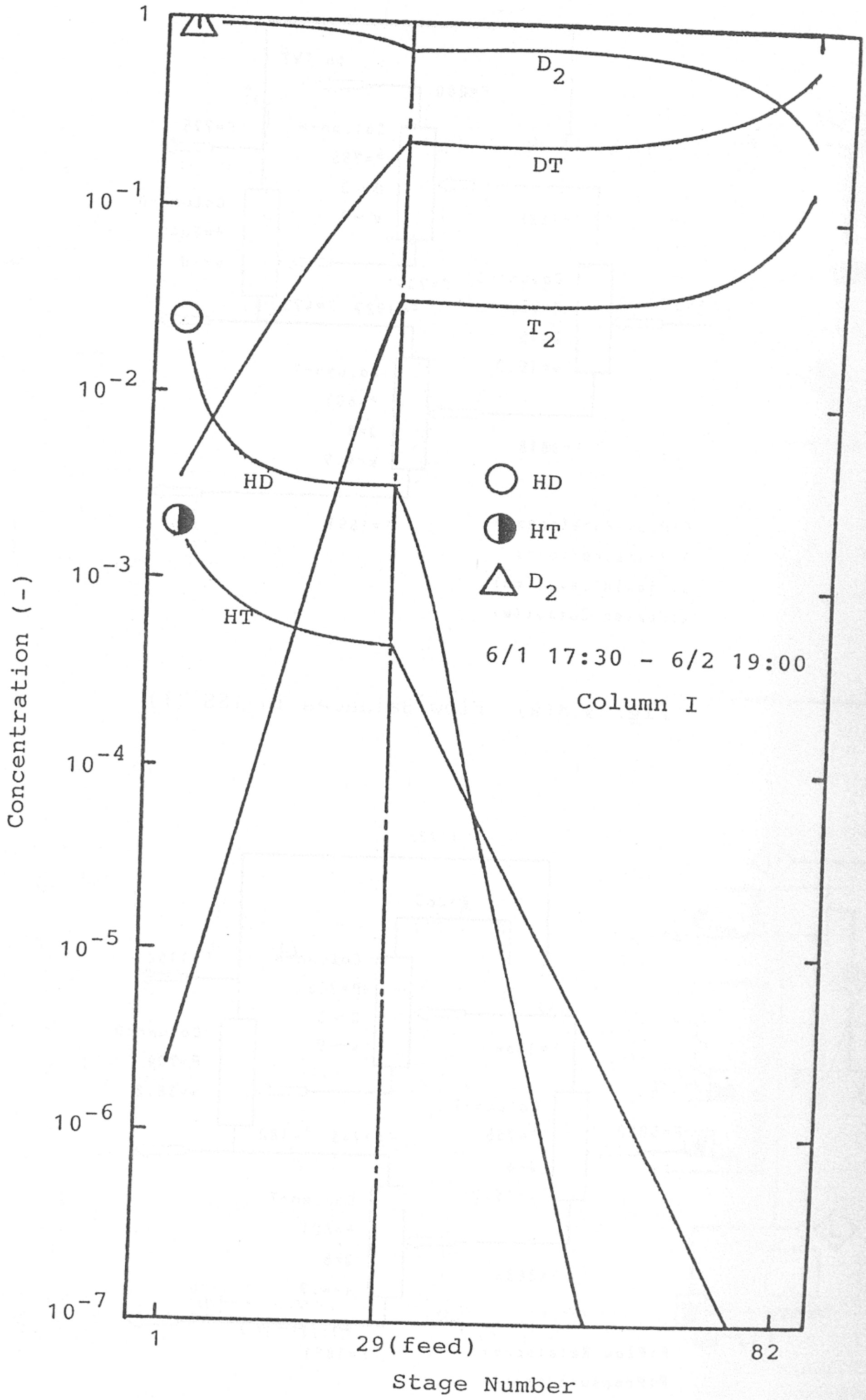


Fig. 3.9(a) Concentration Profile of ISS Column I (in Vapor Phase)

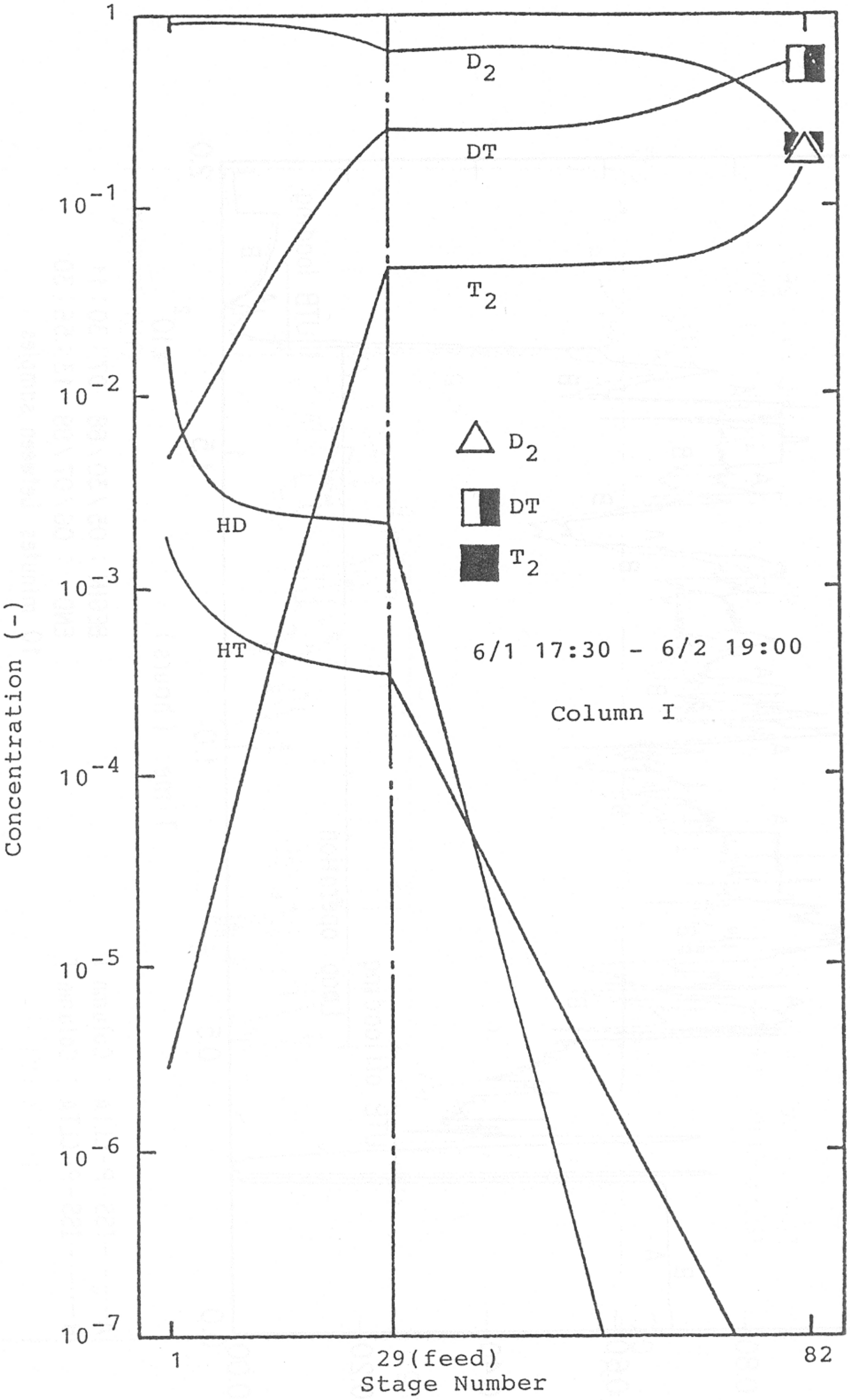


Fig. 3.9(b) Concentration Profile of ISS Column I (in Liquid Phase)

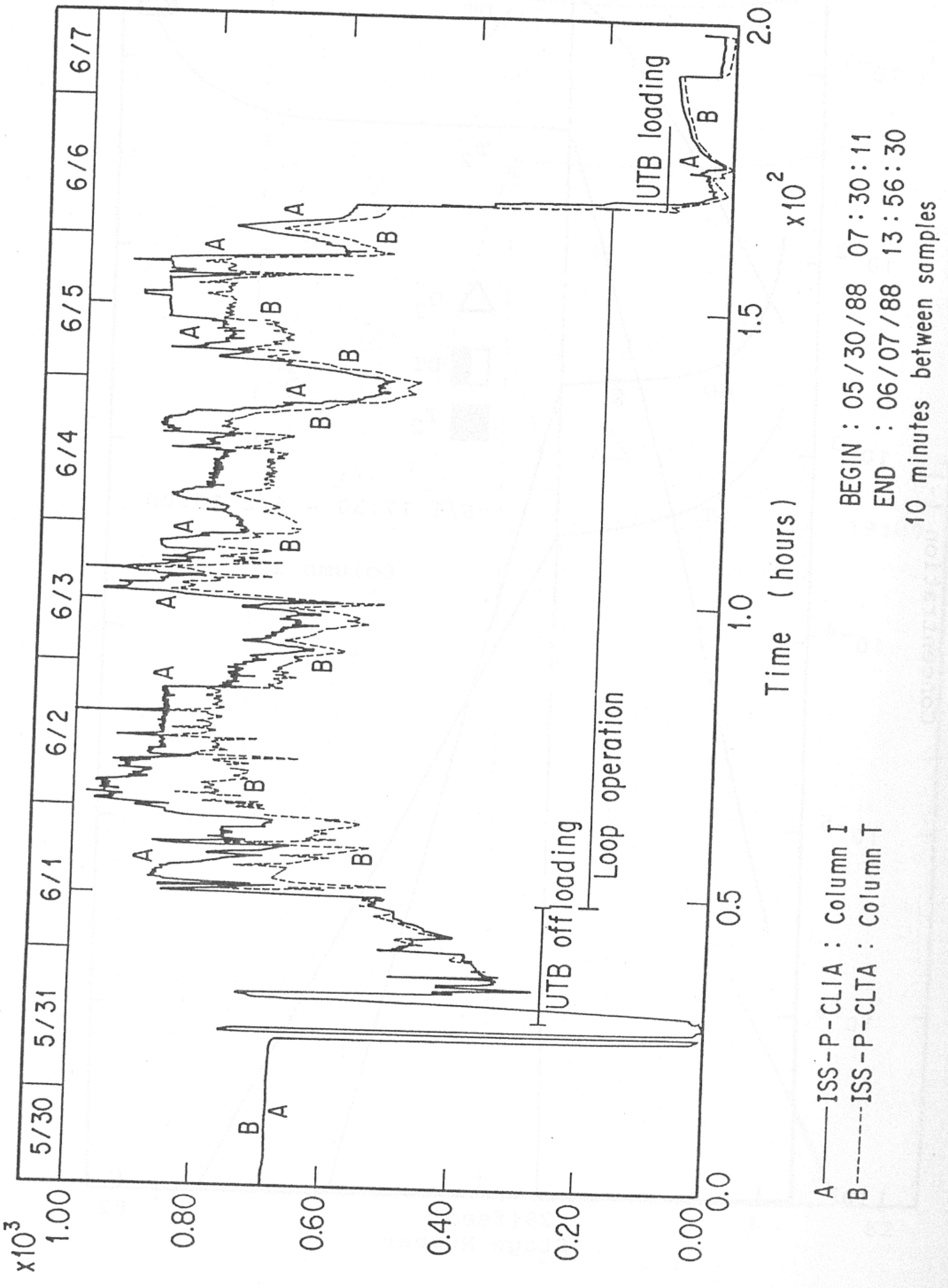


Fig. 3.10(a) Pressures of ISS Columns

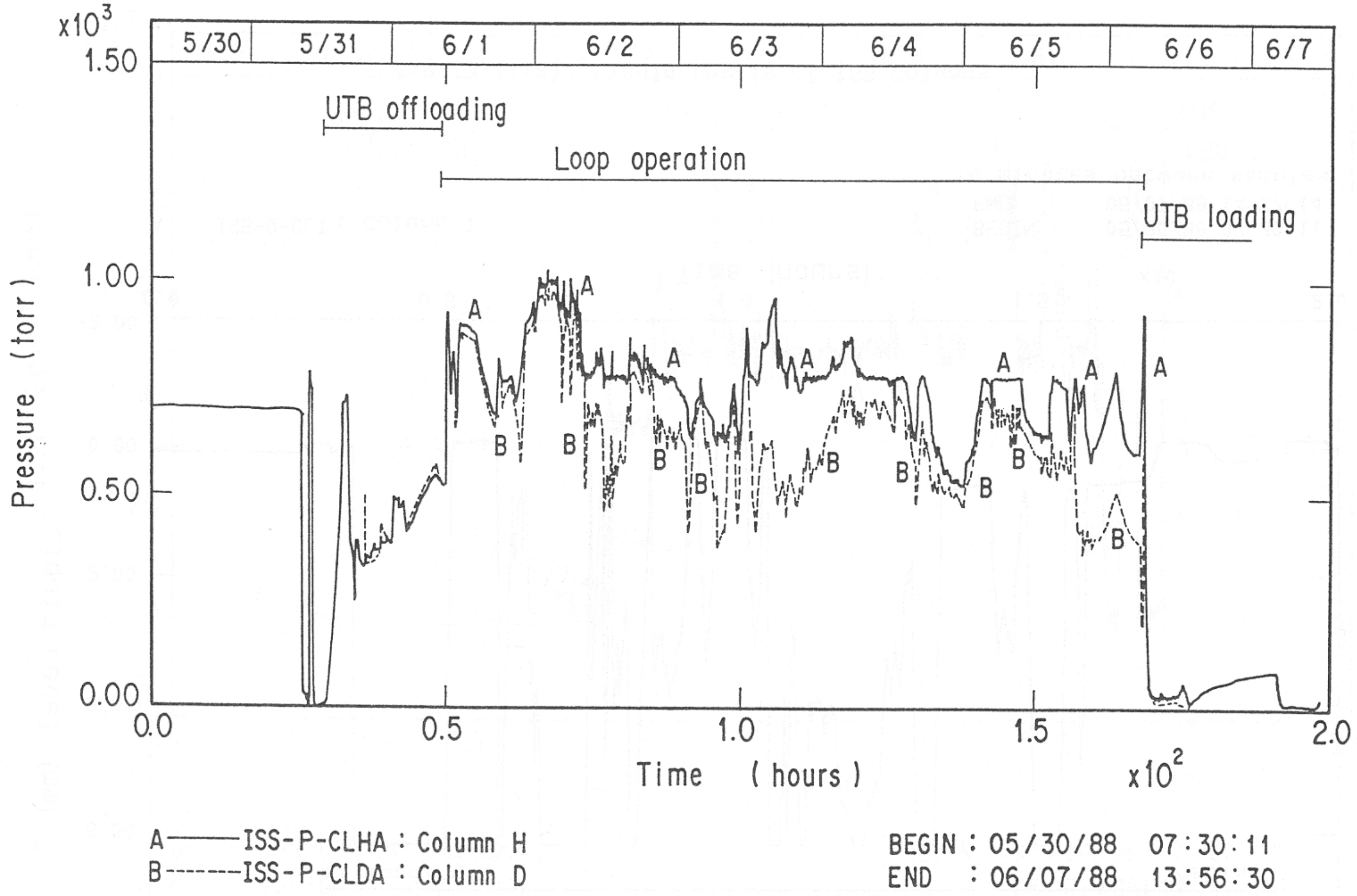


Fig. 3.10(b) Pressures of ISS Columns

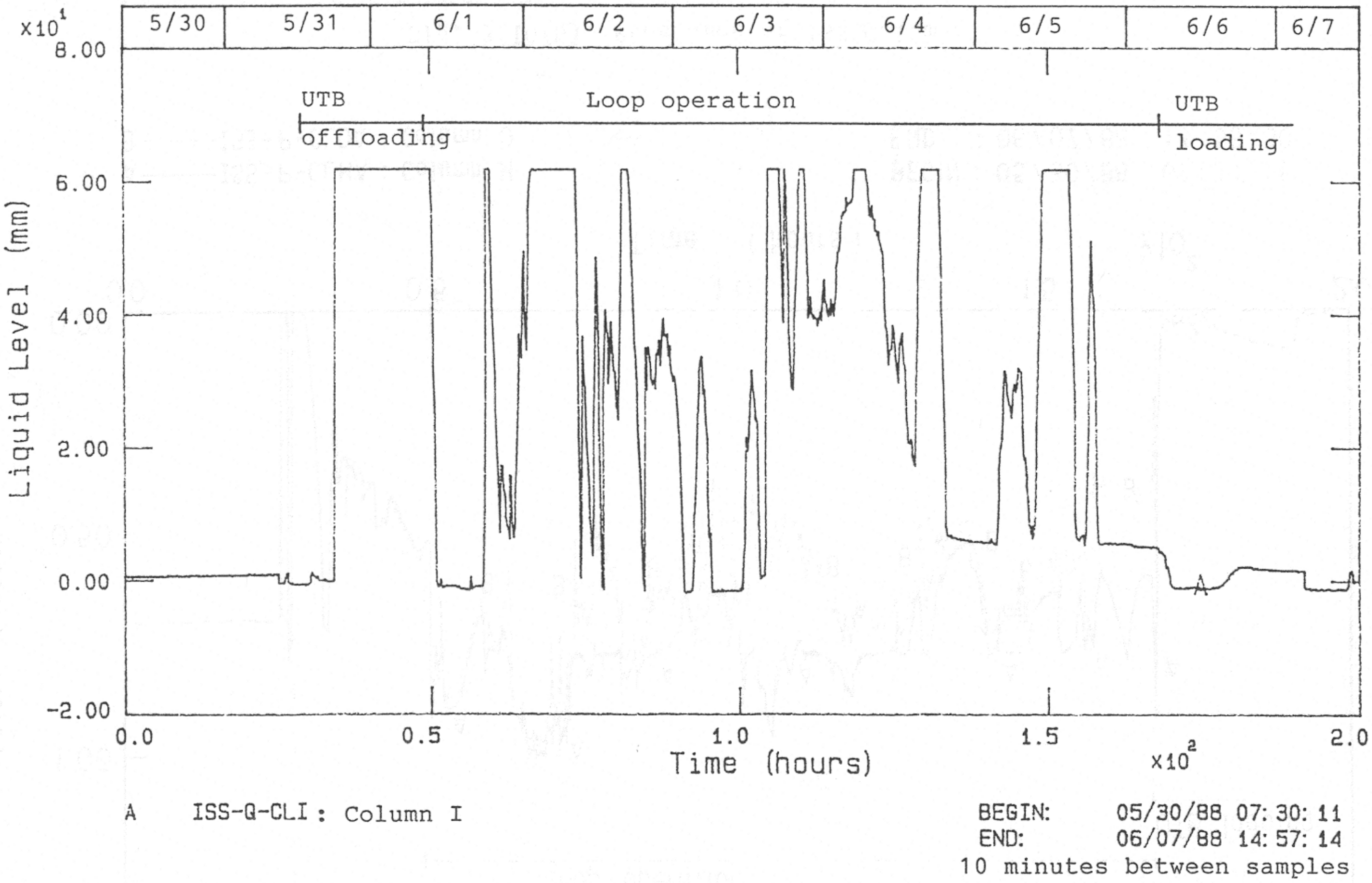


Fig. 3.11(a) Liquid Levels of ISS Columns

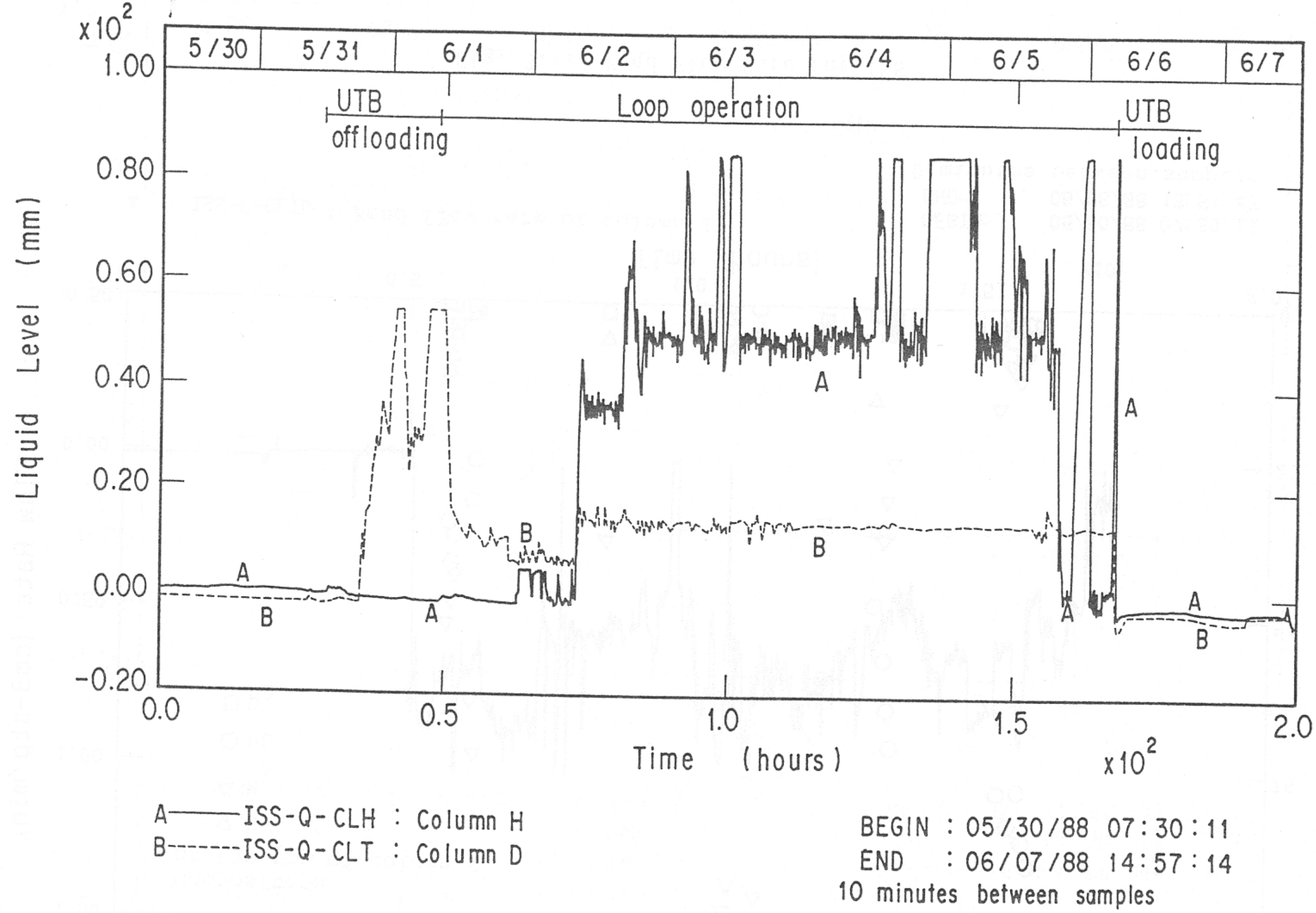


Fig. 3.11(b) Liquid Levels of ISS Columns

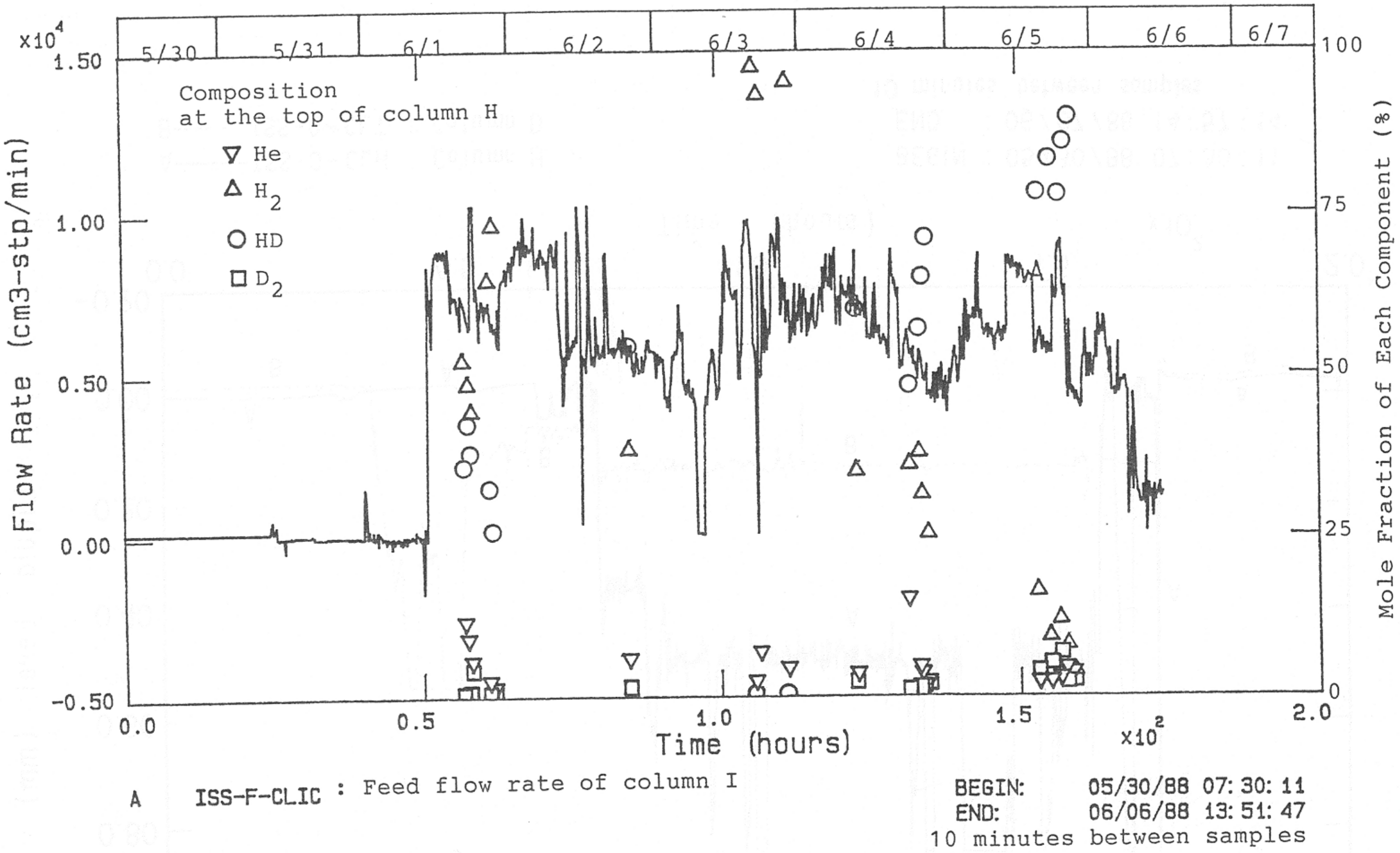


Fig. 3.12 Feed Flow Rate for ISS

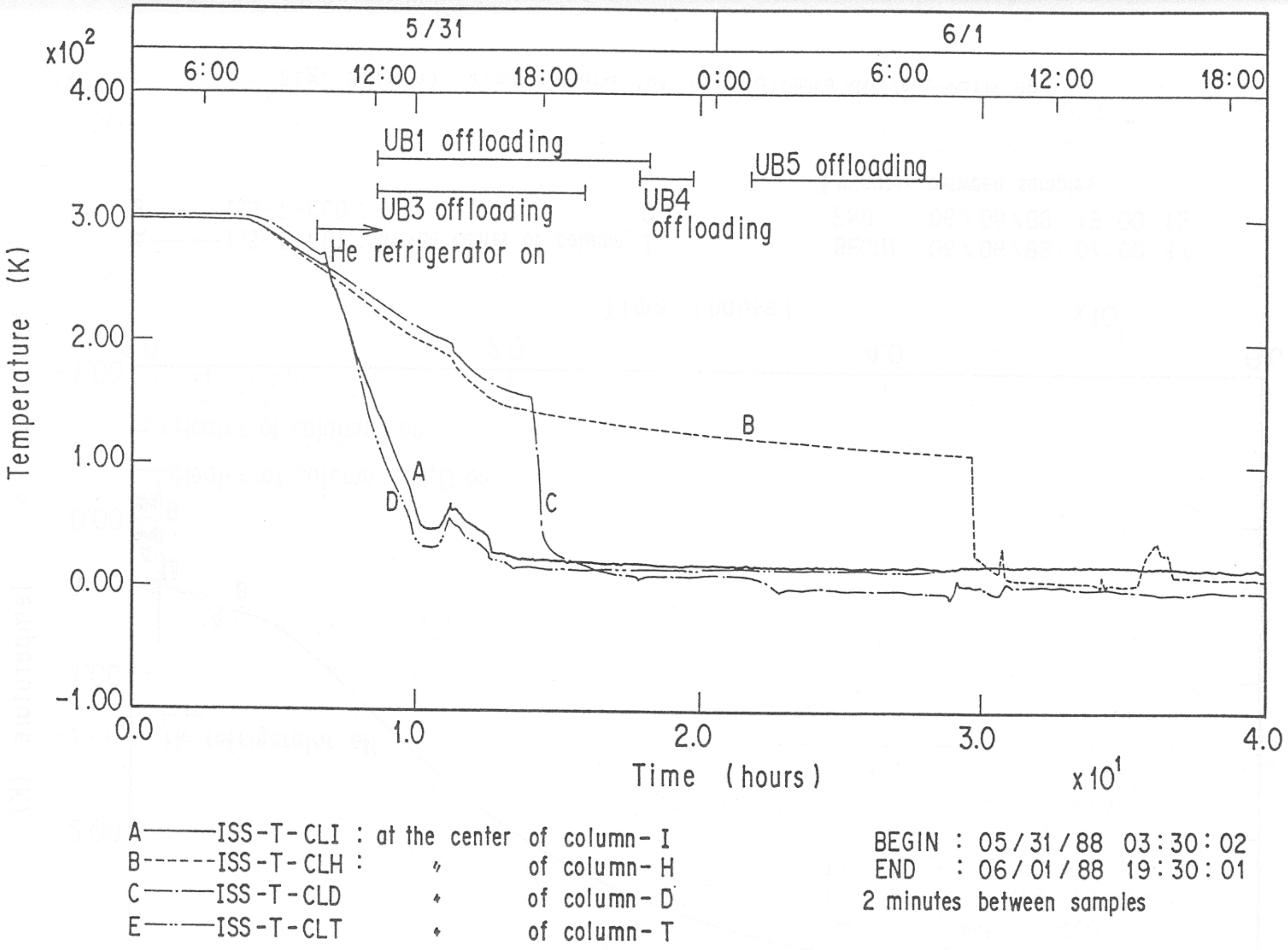


Fig. 3.13 Temperatures of ISS Columns during cool down

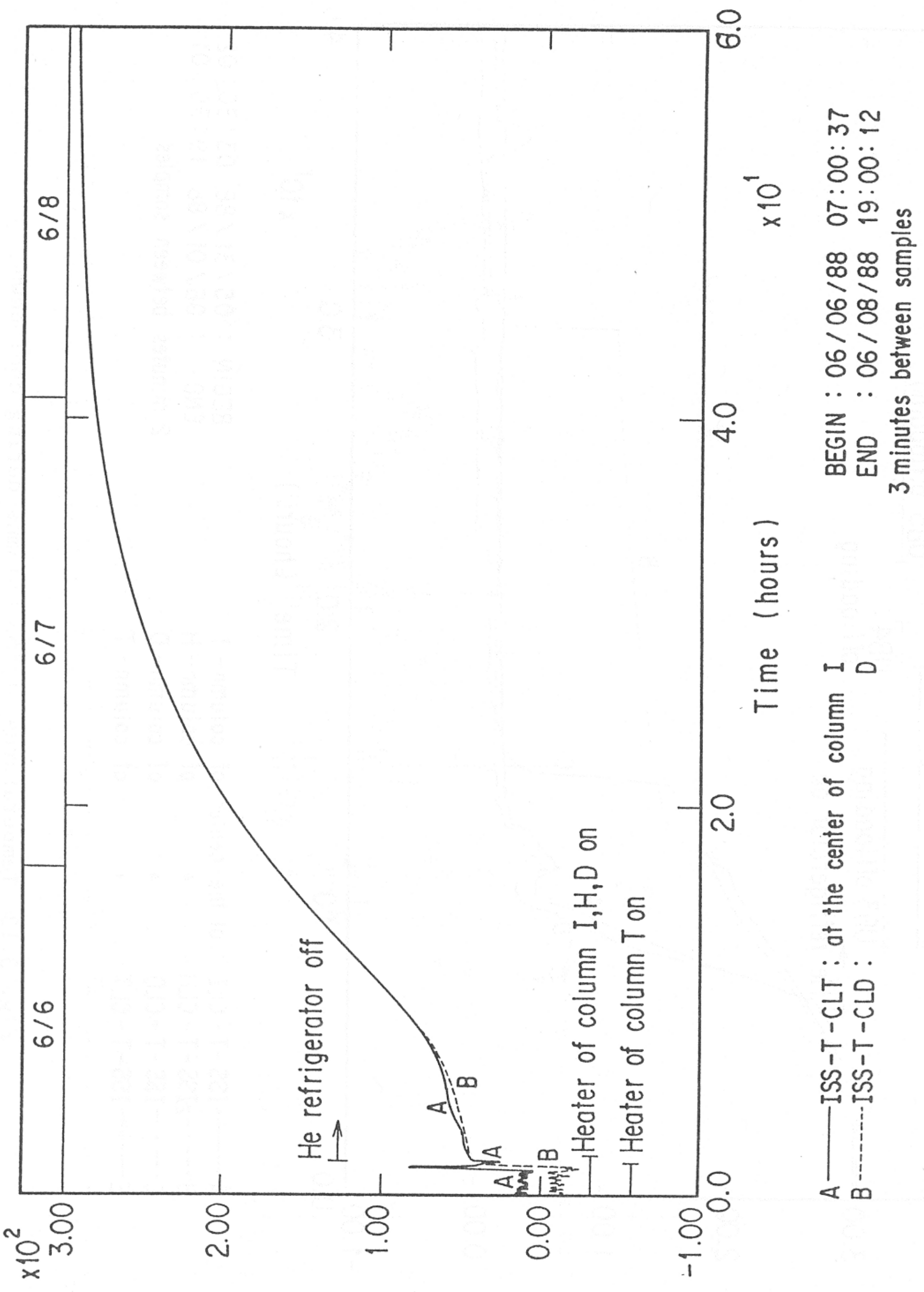


Fig. 3.14(a) Temperatures of ISS Columns during warm up

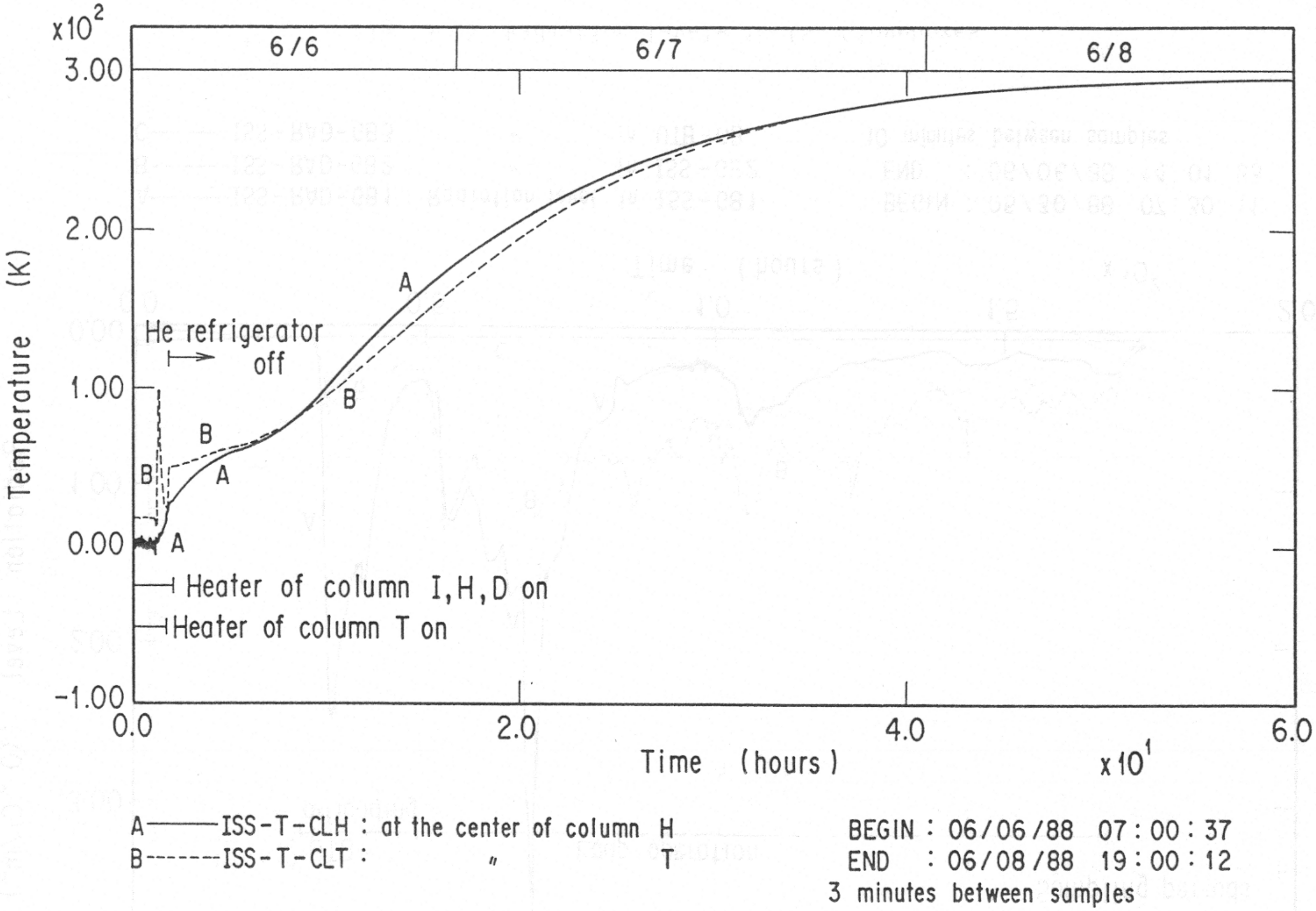


Fig. 3.14(b) Temperatures of ISS Columns during warm up

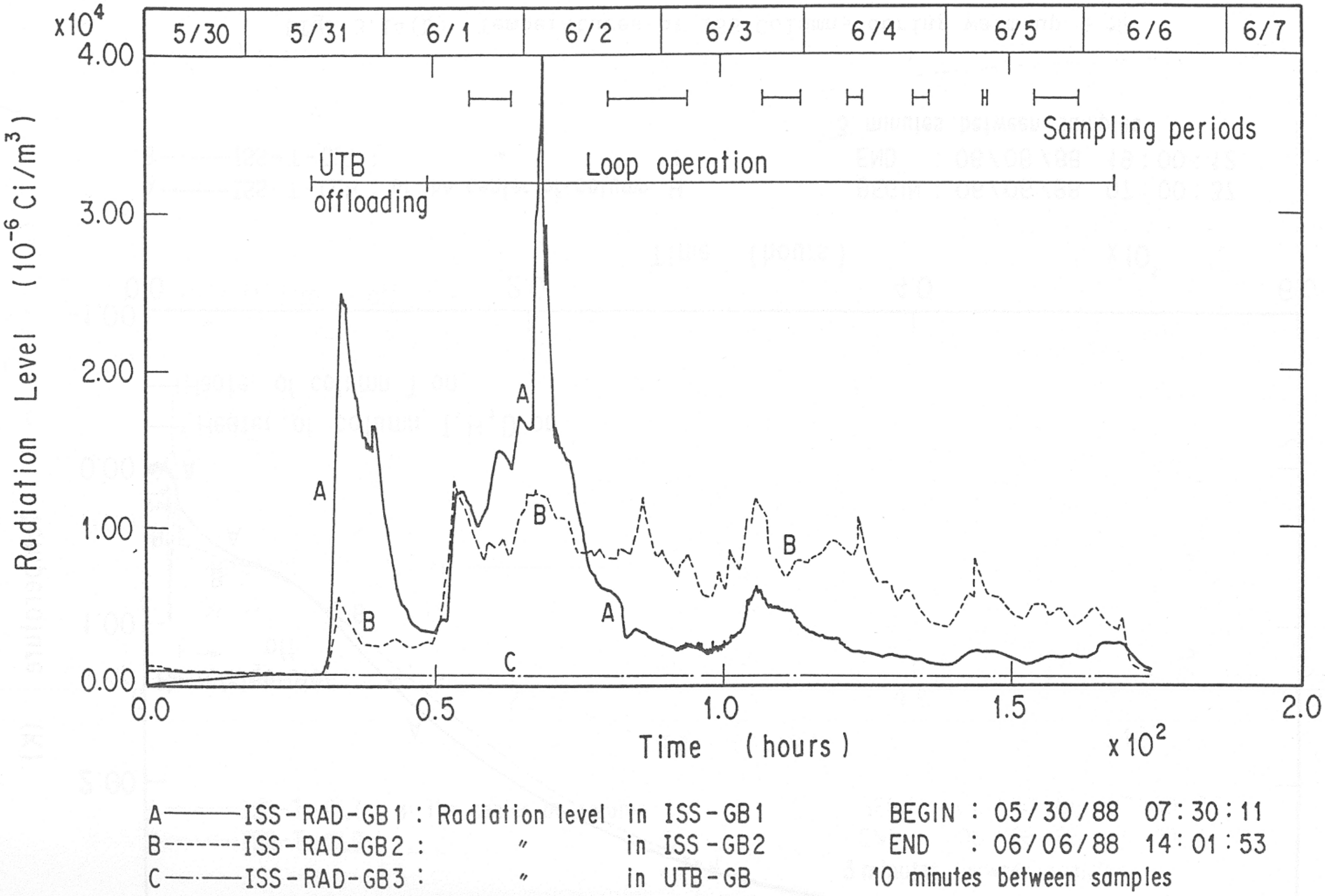


Fig. 3.15 Radiation levels in ISS Gloveboxes

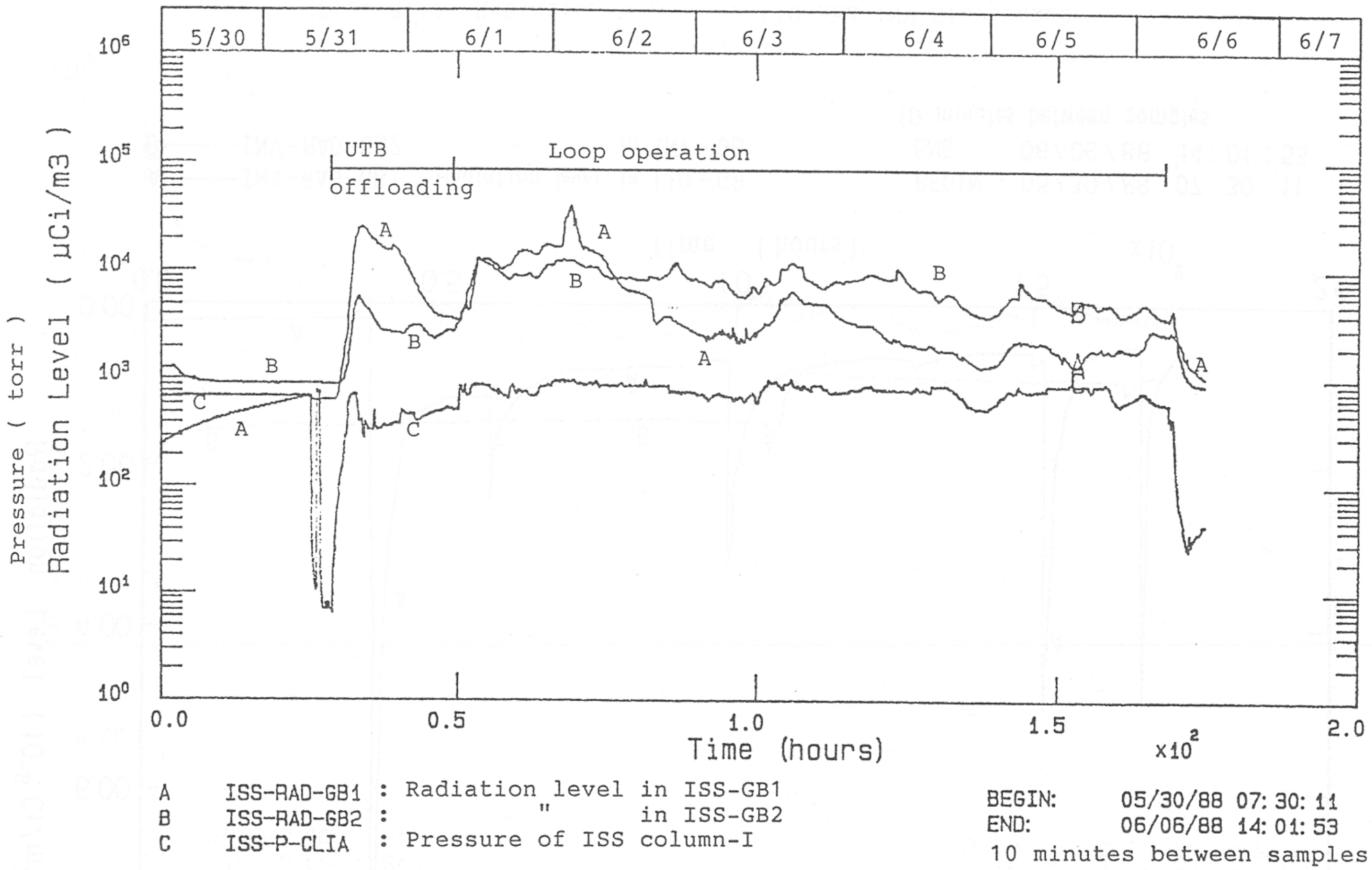


Fig. 3.16 Relationship between Radiation Level and Pressure in ISS

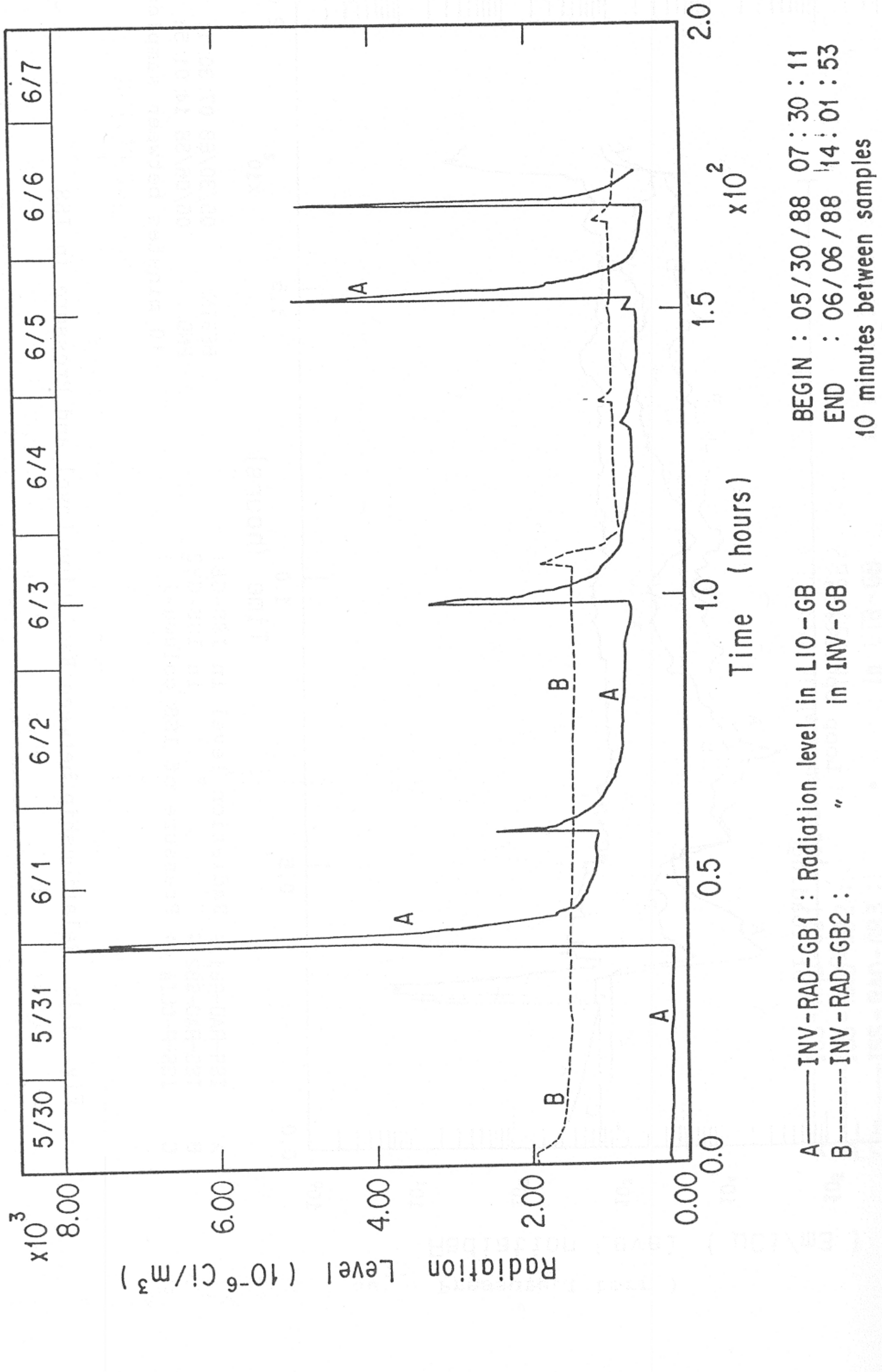


Fig. 3.17 Radiation Levels in LIO and INV Gloveboxes

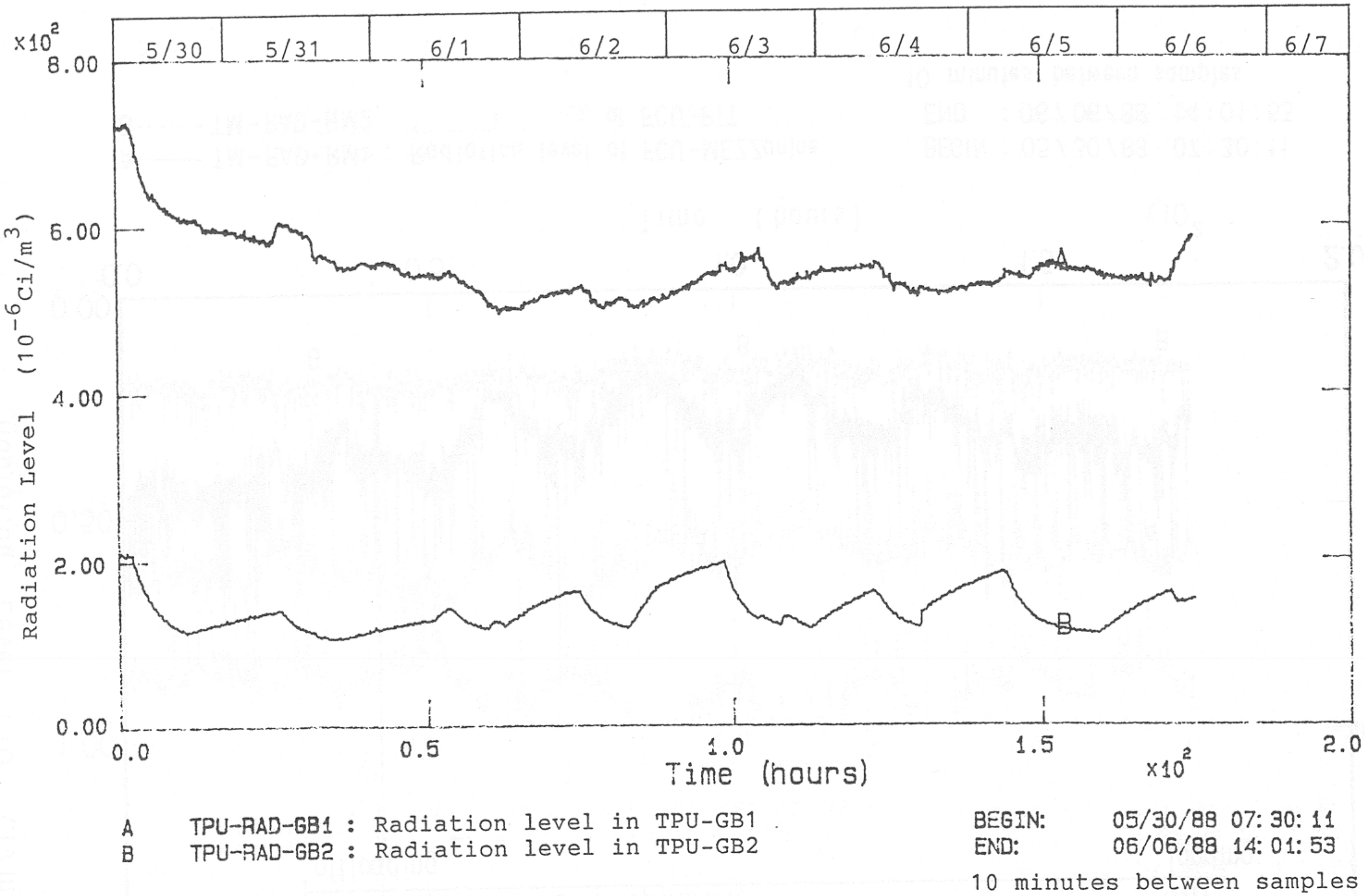


Fig. 3.18 Radiation Levels in TPU Gloveboxes

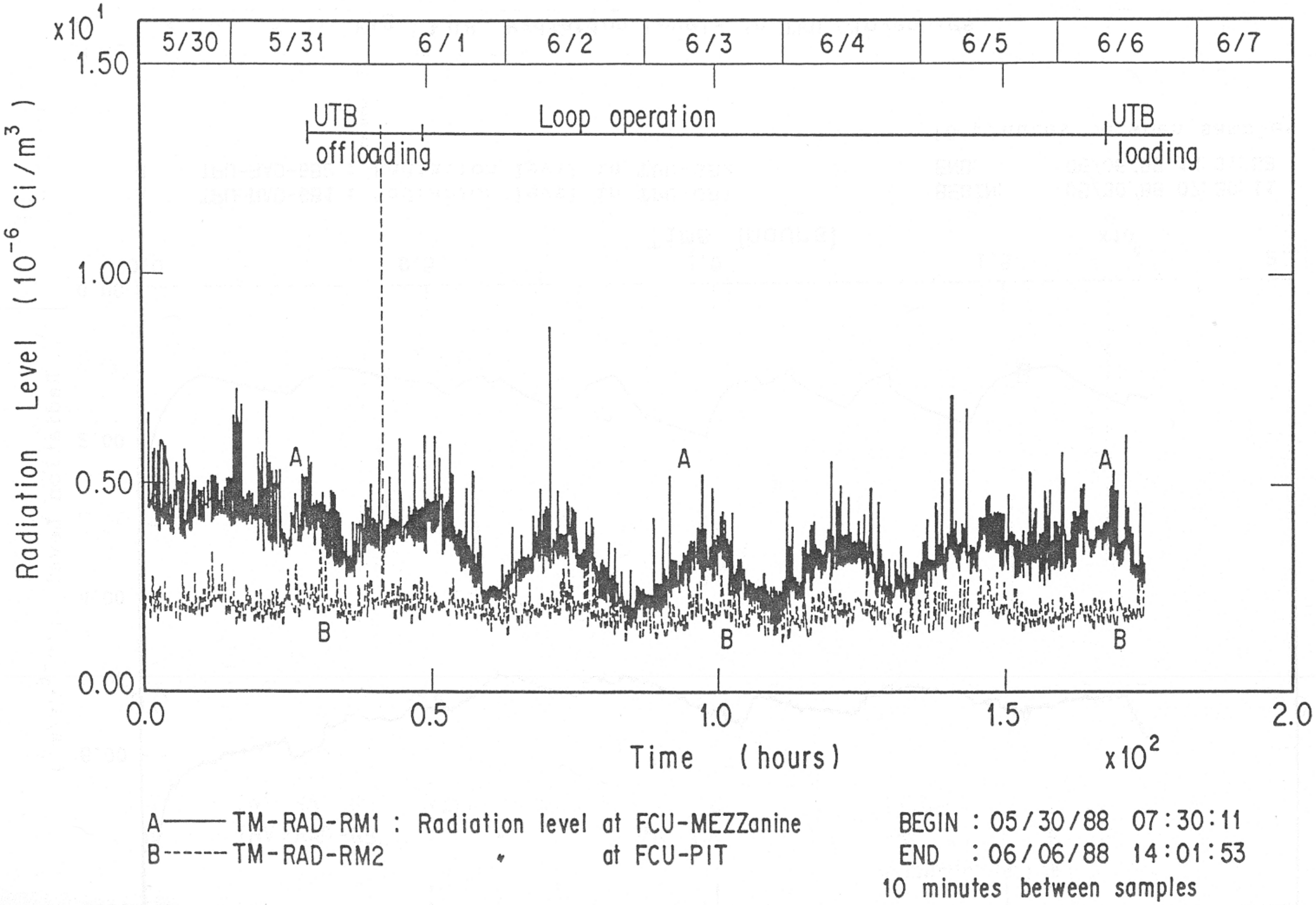


Fig. 3.19 Radiation Levels in Main Cell (1)

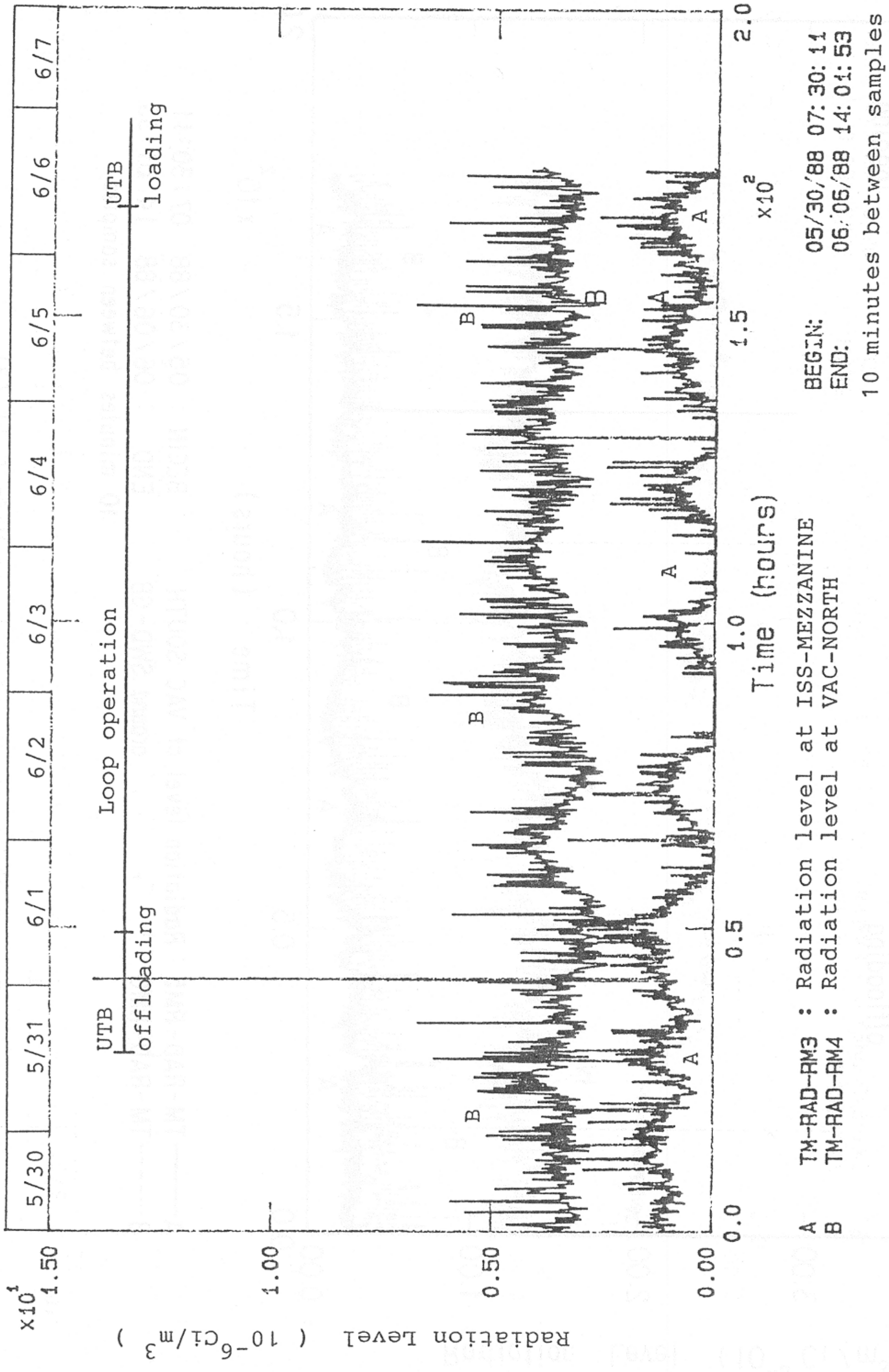


Fig. 3.20 Radiation Levels in Main Cell (2)

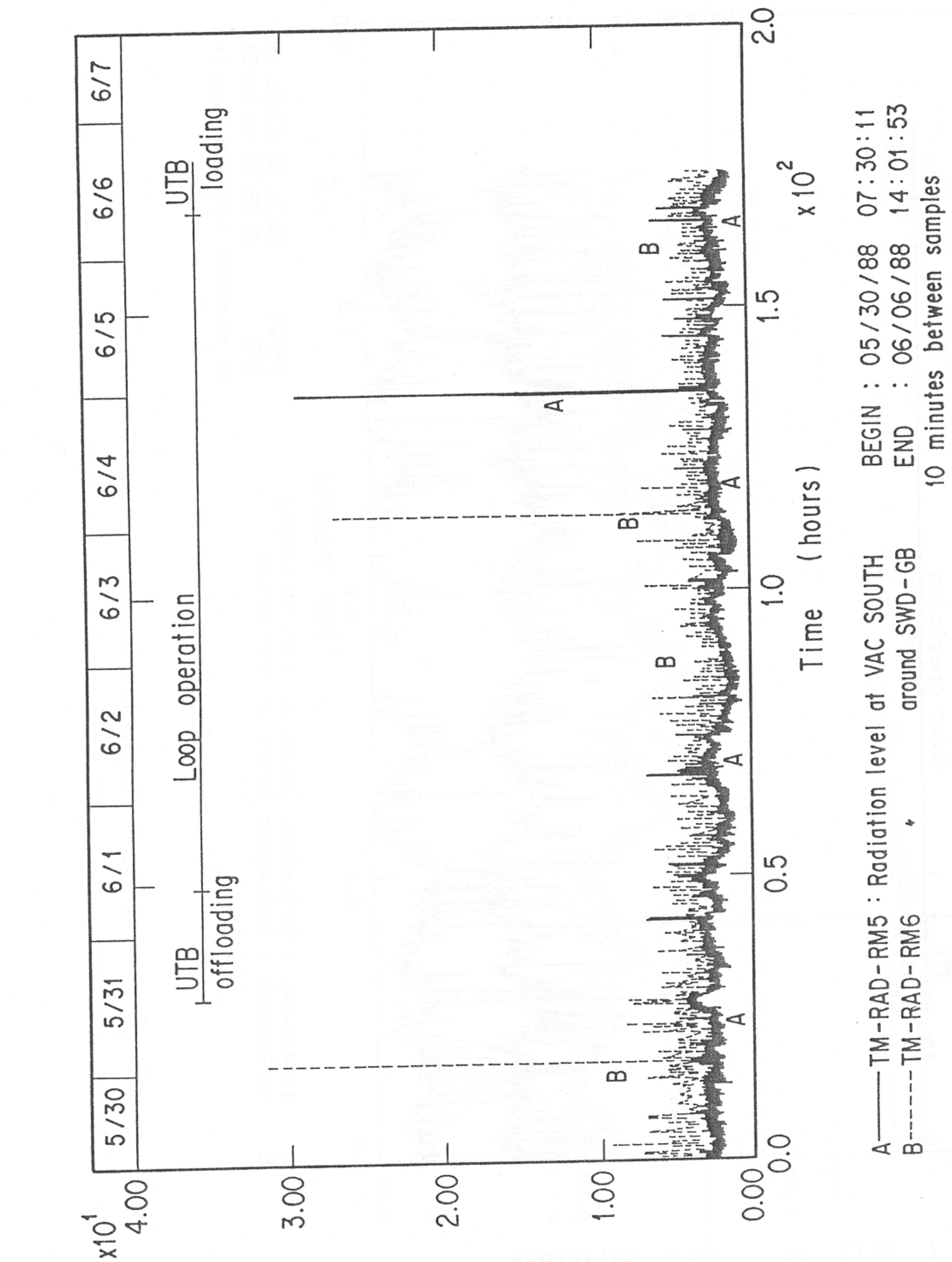


Fig. 3.21 Radiation Levels in Main Cell (3)

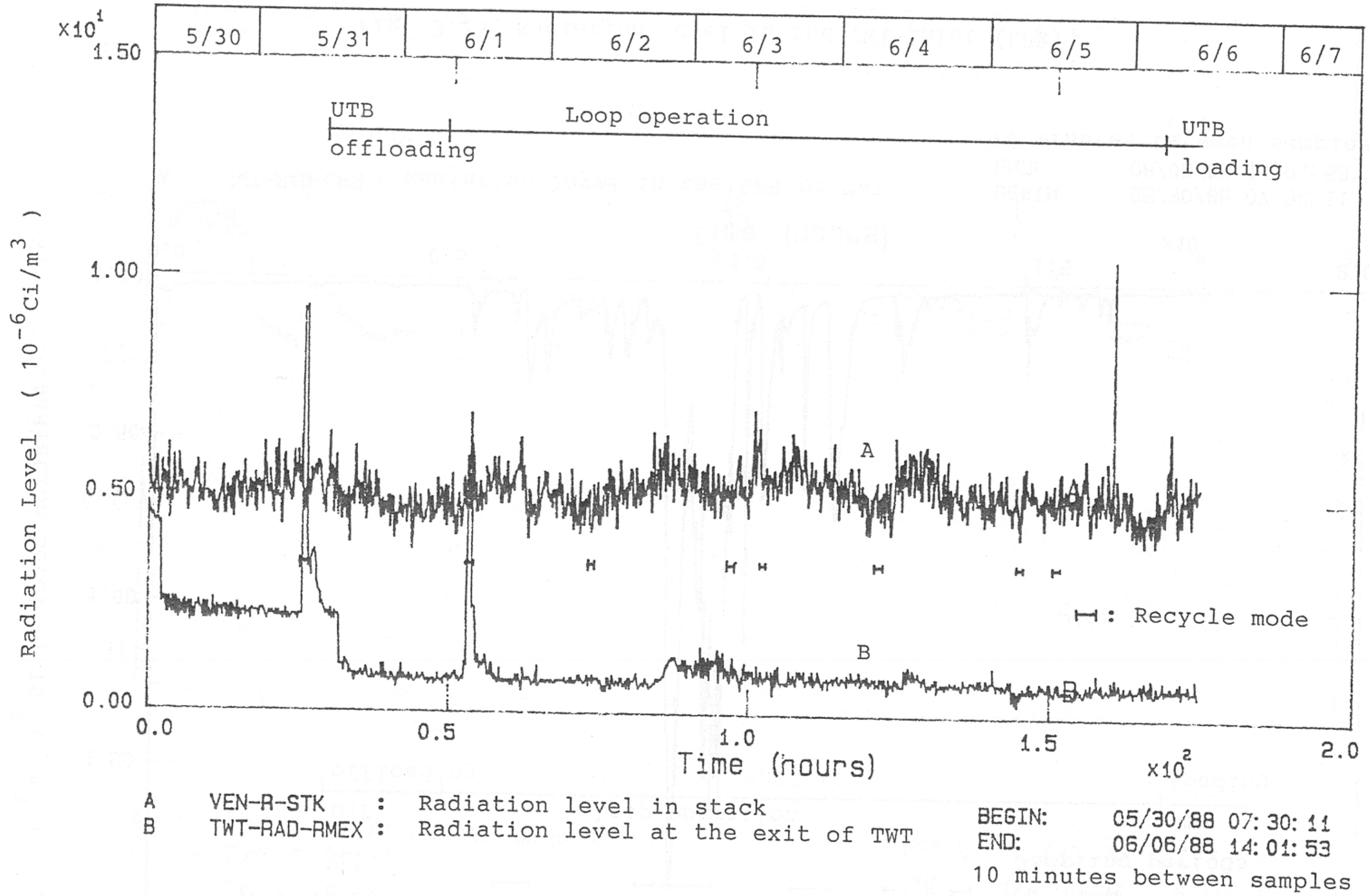


Fig. 3.22 Radiation Levels in the TWT-Outlet

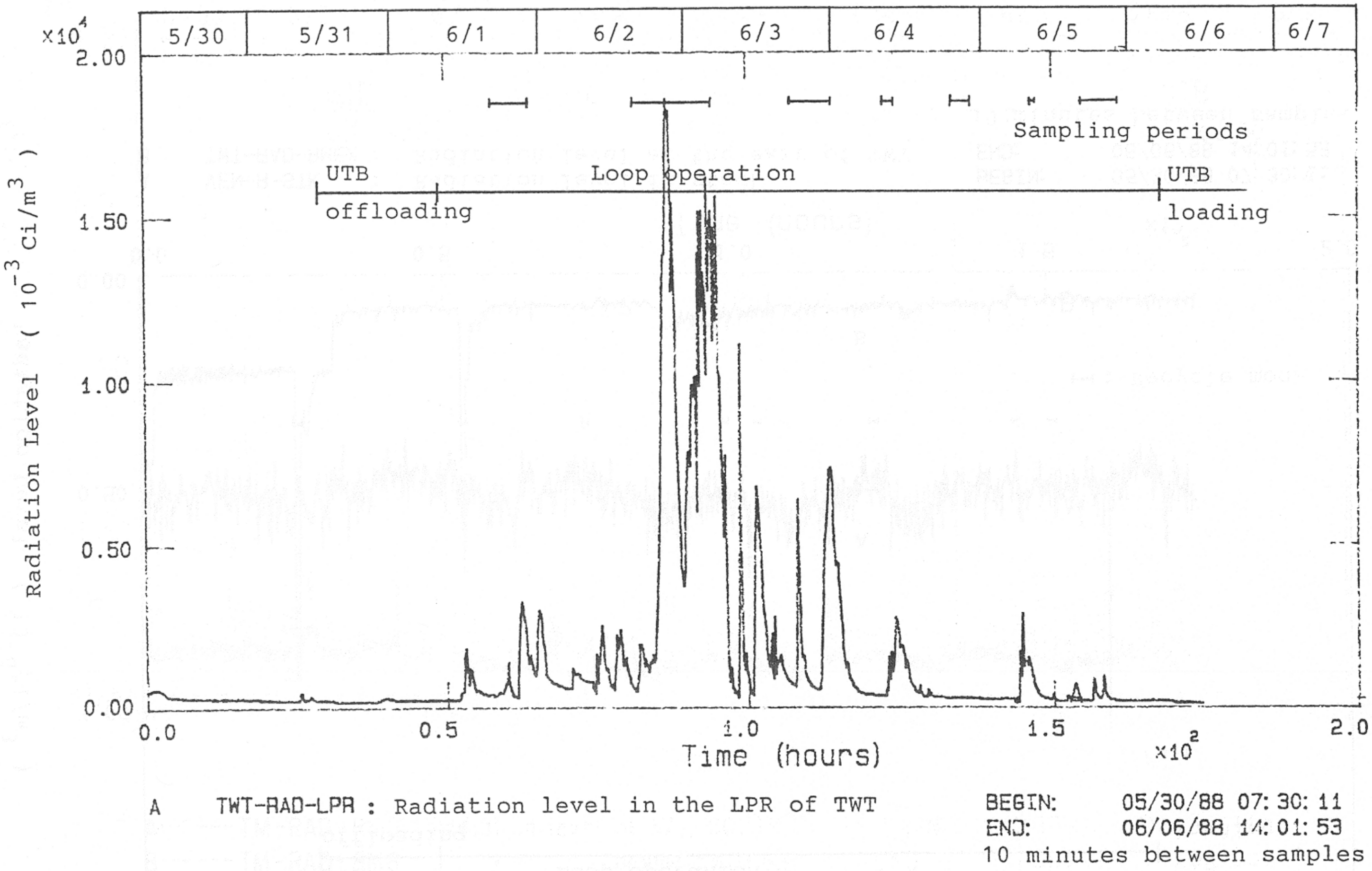


Fig. 3.23 Radiation Level in the TWT-Inlet (LPR)

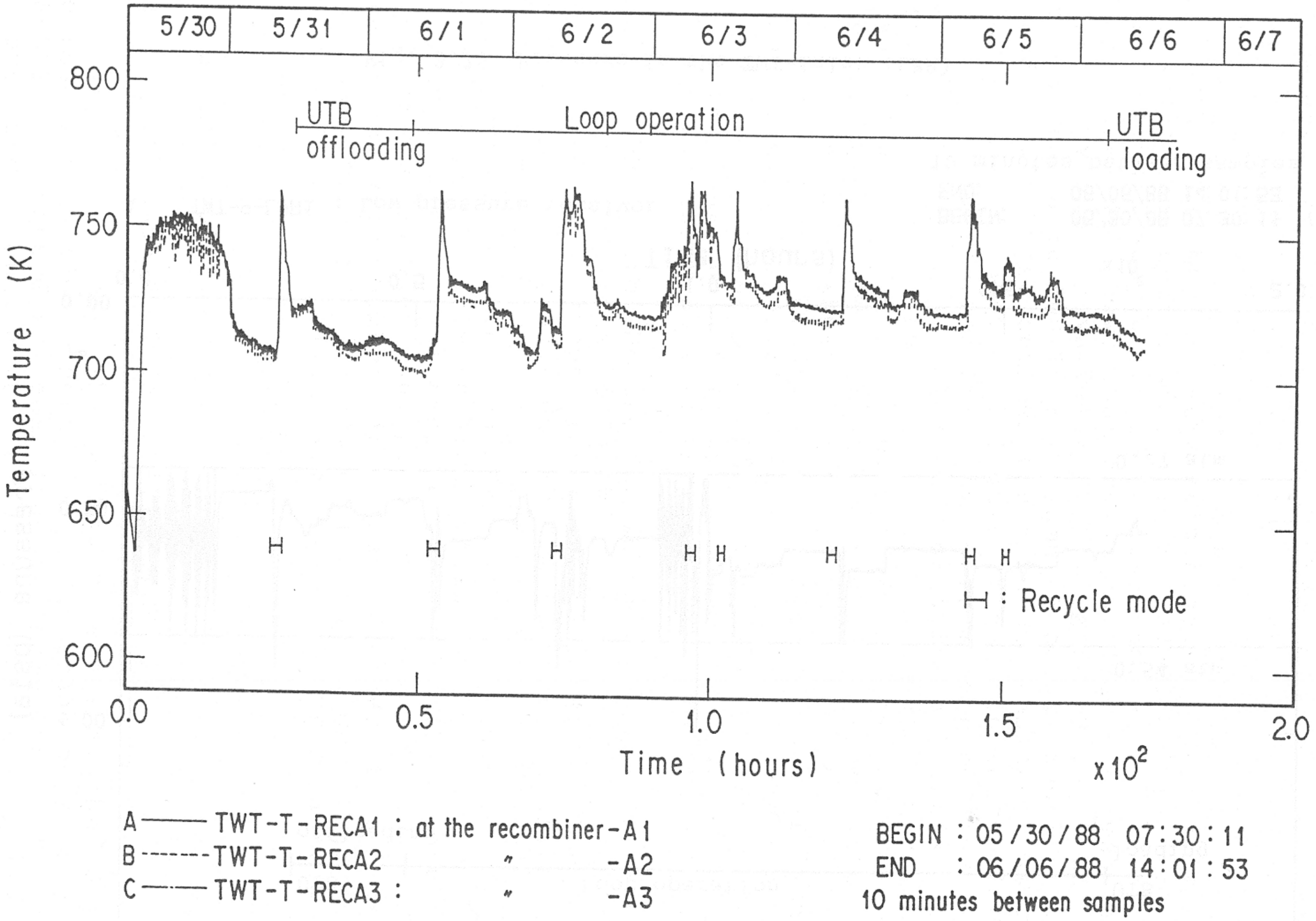


Fig. 3.24 Temperatures at the TWT Recombiner

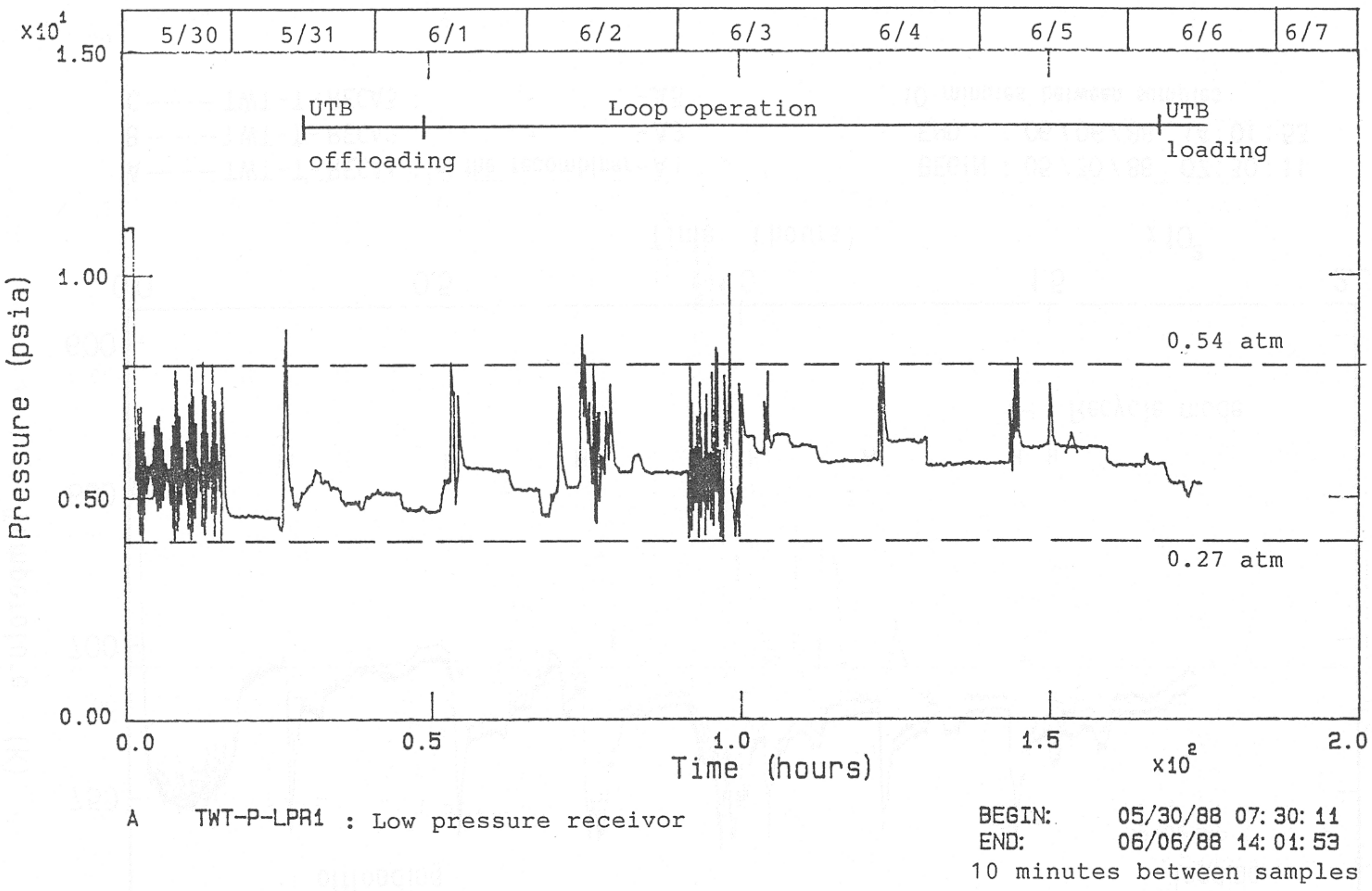


Fig. 3.25 Pressure in the TWT-Inlet (LPR)

4. RESULTS OF SYSTEM SHUTDOWN

4.1 PROCESS SYSTEMS

The following Figures show variations of the major process parameters on the ISS, FCU and UTB during the shutdown operations (Loop operation was stopped: 6/6/88 8:12, H-D-T dumping to UTB: 6/6/88 8:12).

Figure 4.1, outputs of the reboiler heaters in each column, shows that the heaters were maintained for approximately 1 hour because of enhancement of liquid boiled up. They were turned off when no liquid was observed in each reboiler.

Figure 4.2 shows that pressures of all columns immediately dropped by opening valves to UTB (Figures 3.10(a) and 3.10(b)), but increased to 500 Torr (column T) and to 800 Torr (columns I, H and D). These complex pressure changes are assumed to be depending on the amount of liquid in each column. The pressures were again increased after the helium refrigerator was turned off. The pressure of column T took time to increase after the He refrigerator was turned off, because the packed section of column H was cooled by He. Reduction of process loop pressures to a level lower than 400 torr was achieved in about 1 hour.

Figure 4.3 shows pressures in the FCU and NBI. The pressures of the FCU and NBI behaved like that of ISS columns, because gas was circulated in the process loop during shutdown.

During loading to UTB, blanketing effect due to the impurities was not observed in any of the uranium beds. The pressure was under 50 torr (Figure 4.2). The major components of remaining gas were ^{3}He and ^{4}He which were shown in Table 4.1 (N_2 gas was already evacuated to TWT).

Figure 4.4 shows the rapid temperature rise due to the exothermic reaction between H-D-T mixture and uranium beds, that occurred immediately after opening the valves to UTB. The temperature peak levels on UTB2 and UTB4 connected to column H and D respectively were higher than that of the others. This phenomenon might have resulted from the difference in column inventory of hydrogen isotopes. The temperatures of UB1 and UB3 were relatively higher than that of others at a steady state after dumping of H-D-T mixture from the process loop, reflecting the effect of the tritium decay heat from uranium tritide.

4.2 SAFETY SYSTEMS

4.2.1 SECONDARY CONTAINMENT SYSTEM (SEC)

Figure 4.5 shows the radiation levels of the ISS-GB during process loop shutdown operation. The broad peak observed in the ISS-GB2 was caused by leaks from the sampling system of ISS due to pressure increase (up to 900 torr) of column I at shutdown operation (Figure 4.2).

No increase of radiation levels in other GBs was observed.

4.2.2 TRITIUM WASTE TREATMENT SYSTEM (TWT)

Figure 4.6 shows the radiation levels in the LPR and at the exit of TWT. The radiation level in the LPR increased slightly on account of the increase of that in the ISS-GB2. The TWT kept the radiation level low ($< 1\times10^{-3}$ Ci/m^3) at the exit.

Table 4.1 The Result of Residual Gas Analysis of Process Loop after Shutdown of Run

```
6/ 7/88 Residual after Circ     P =   225.00   torr      23.0 C      .050 liters
Mass Spec Analysis 3/ 8/88
70 V Electrons    V
                                Sens     Corr              mol %       Summary    HDT gas
                Obs, %          torr/V  (Calc) |------------------|                  %
H2      2.016                    .688          | H2               |                     H
He-3    3.016    9.1550         1.739    .917  | He-3    49.467   |      .141    74.993 D
HD      3.022                    .716          | HD               |      .047    25.007 T
He-4    4.003    2.6160         1.739    .227  | He-4    12.270   |
HT      4.024                    .795          | HT               |            Q20
D2      4.028     .0480          .729    .002  | D2        .094   |    28.794 CQ4
DT      5.030     .0450          .870    .002  | DT        .094   |      .125 N2
T2      6.032                   1.000          | T2               |--------------------|
CH4    16.031    4.1790          .272    .028  | CH4      1.535   | Moles =       .001 |
NH3    17.027                    .272          | NH3              | as H, D, T gas     |
CH3D   17.038    8.8560          .272    .058  | CH3D     3.155   | H                  |
H20    18.011                    .272          | H20              | D                  |
CH3T   18.040   17.3790          .272    .111  | CH3T     6.016   | T                  |
CH2D2  18.044                    .272          | CH2D2            | Grams H            |
HD0    19.017                    .272          | HD0              | Grams D            |
CHD3   19.050   17.5090          .272    .109  | CHD3     5.898   | Grams T            |
Ne-20  19.992    2.5530         1.080    .062  | Ne-20    3.328   | Curies =           |
HT0    20.019                    .272          | HT0              |--------------------|
D20    20.023                    .272          | D20              | as water           |
CH2T2  20.048                    .272          | CH2T2            | H                  |
CD4    20.056   15.1800          .272    .092  | CD4      4.984   | D                  |
DT0    21.025                    .272          | DT0              | T                  |
CD3T   21.058   11.0990          .272    .066  | CD3T     3.556   | Grams H            |
Ne-22  21.991                   1.073          | Ne-22            | Grams D            |
T20    22.027                    .272          | T20              | Grams T            |
CHT3   22.056                    .272          | CHT3             | Curies =           |
CD2T2  22.060    4.8470          .272    .028  | CD2T2    1.517   |--------------------|
CDT3   23.062    3.4740          .272    .020  | CDT3     1.064   | as methane         |
CT4    24.064    3.5710          .272    .020  | CT4      1.070   | H                  |
C0     27.995                    .230          | C0               | D                  |
N2     28.006     .5330          .230    .002  | N2        .125   | T                  |
02     31.990     .0440          .281          | 02        .012   | Grams H            |
Ar     39.962   32.4760          .210    .108  | Ar       5.816   | Grams D       .001 |
C02    43.990                    .193          | C02              | Grams T            |
                                               |------------------| Curies =       3.5 |
                                                                  |--------------------|
                                        1.853          100.000          .188
```

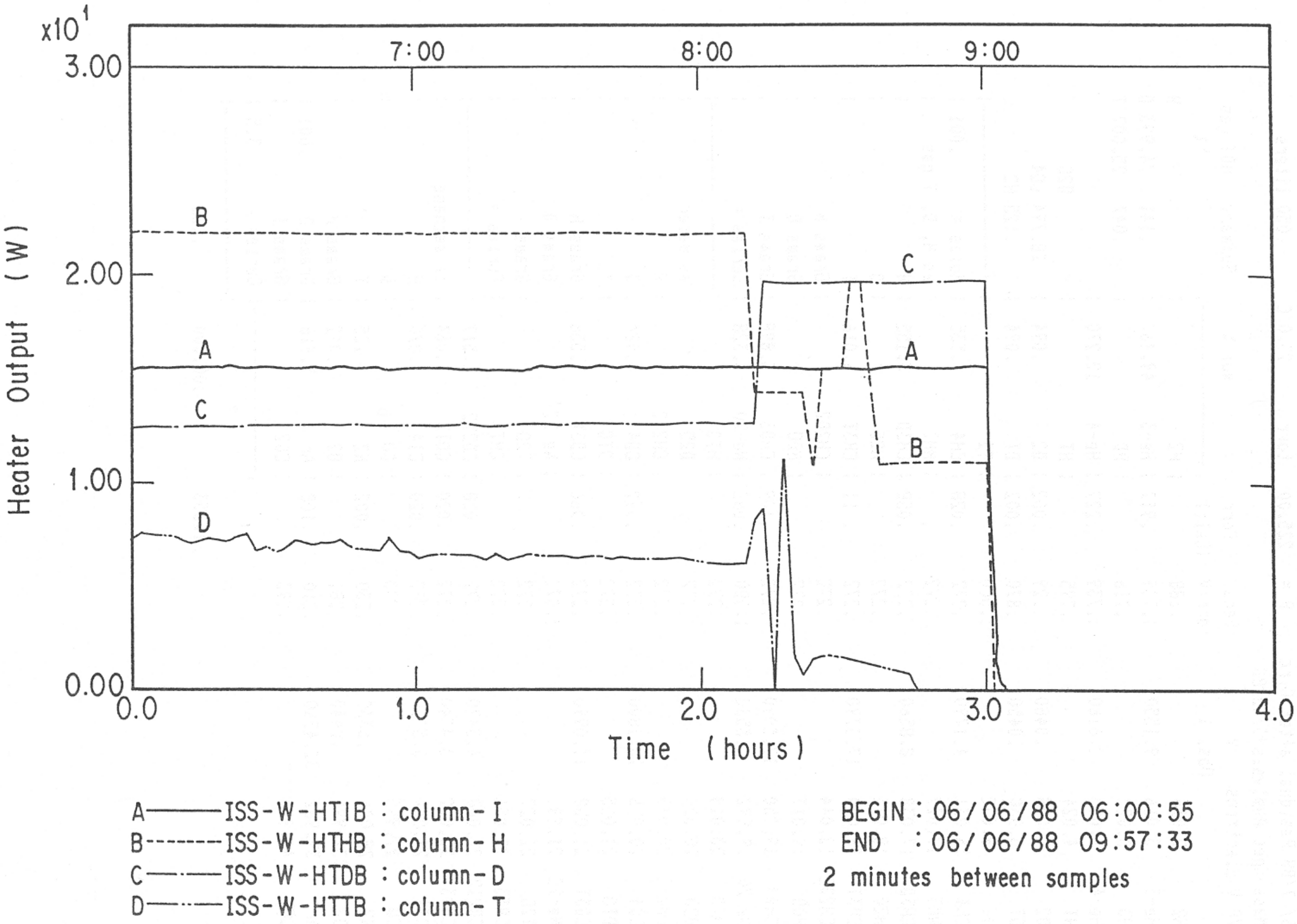


Fig. 4.1 Heater Outputs of ISS

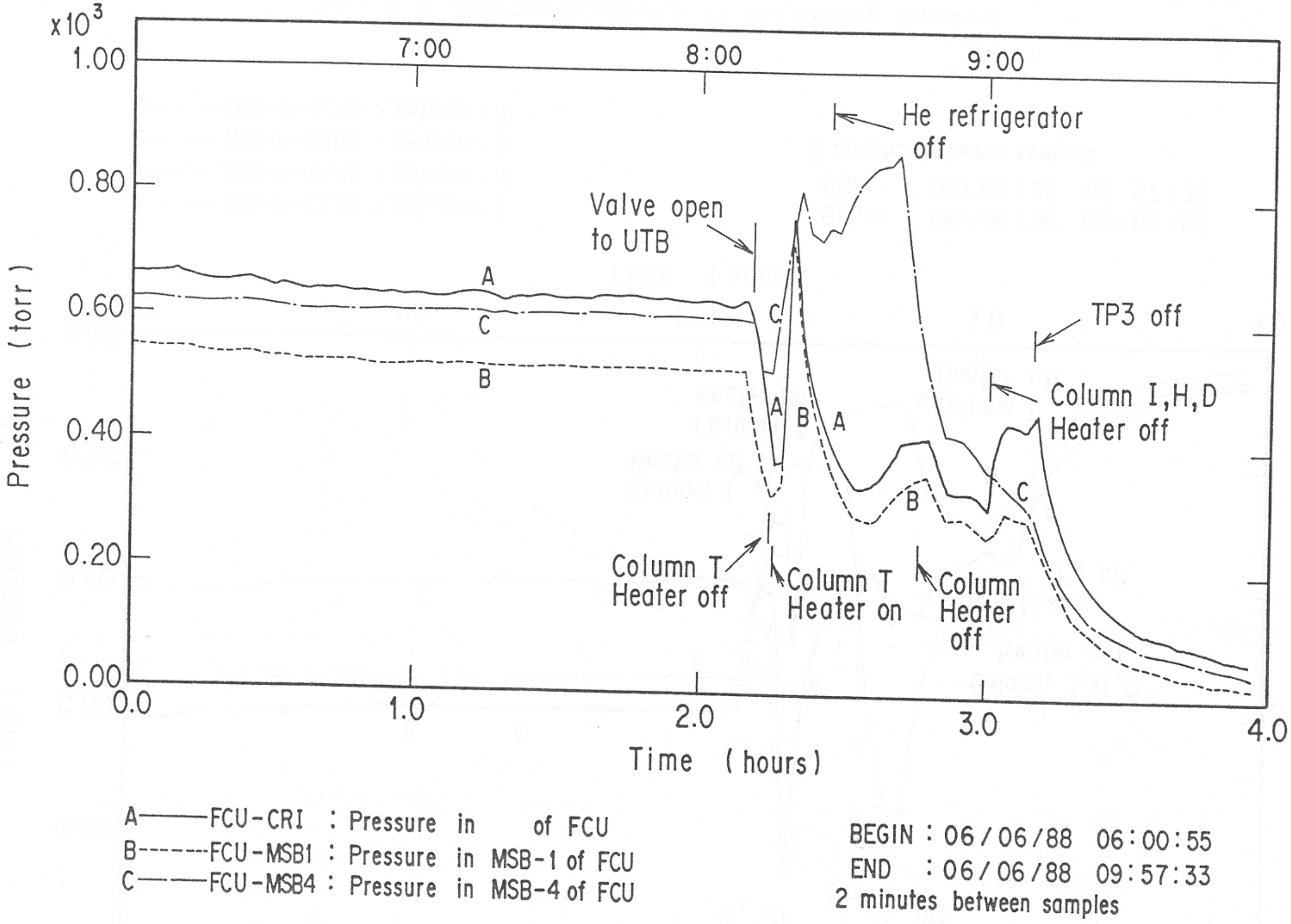


Fig. 4.2 Pressures of ISS Columns during Shutdown

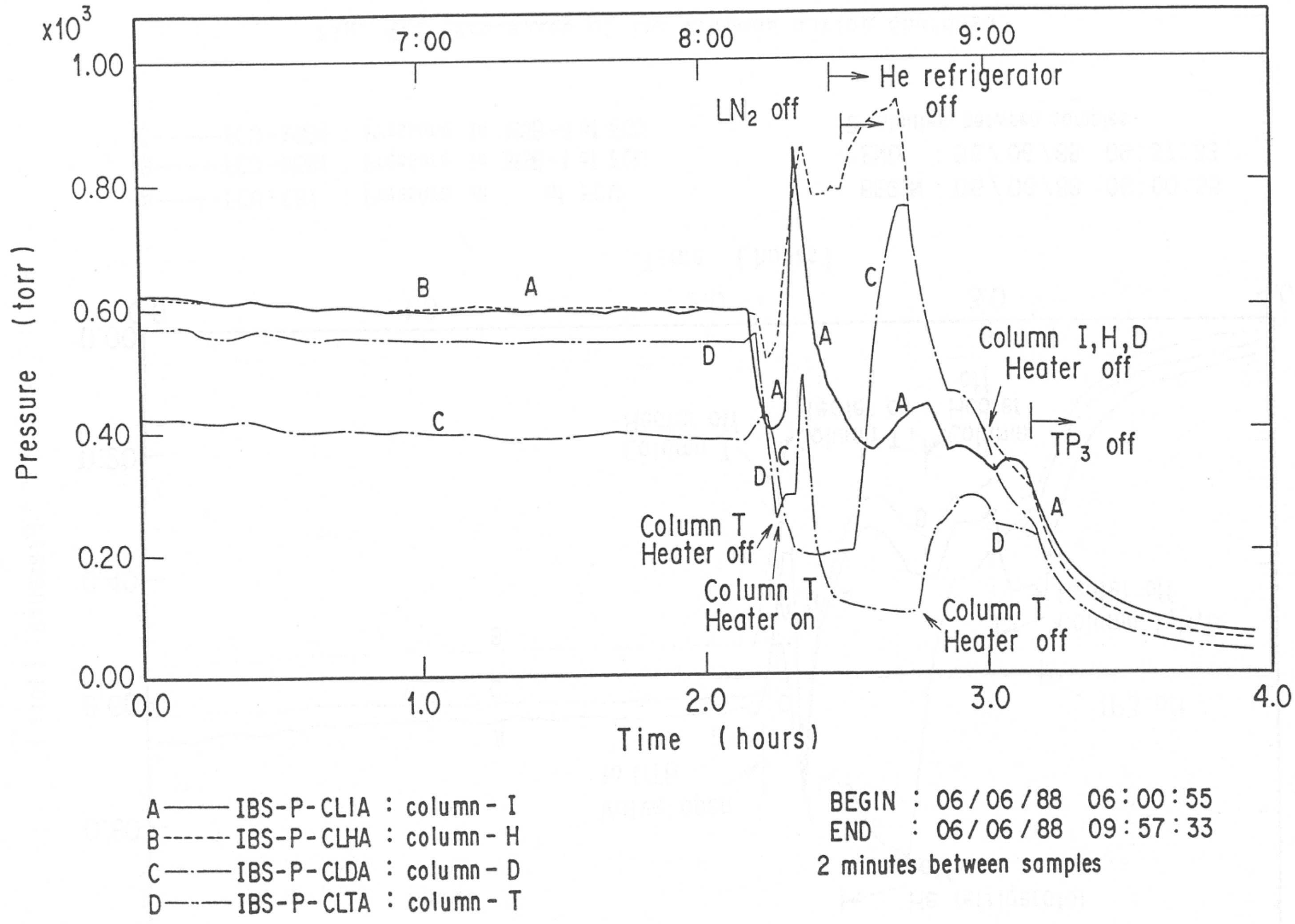


Fig. 4.3 Process Pressures in FCU during Shutdown

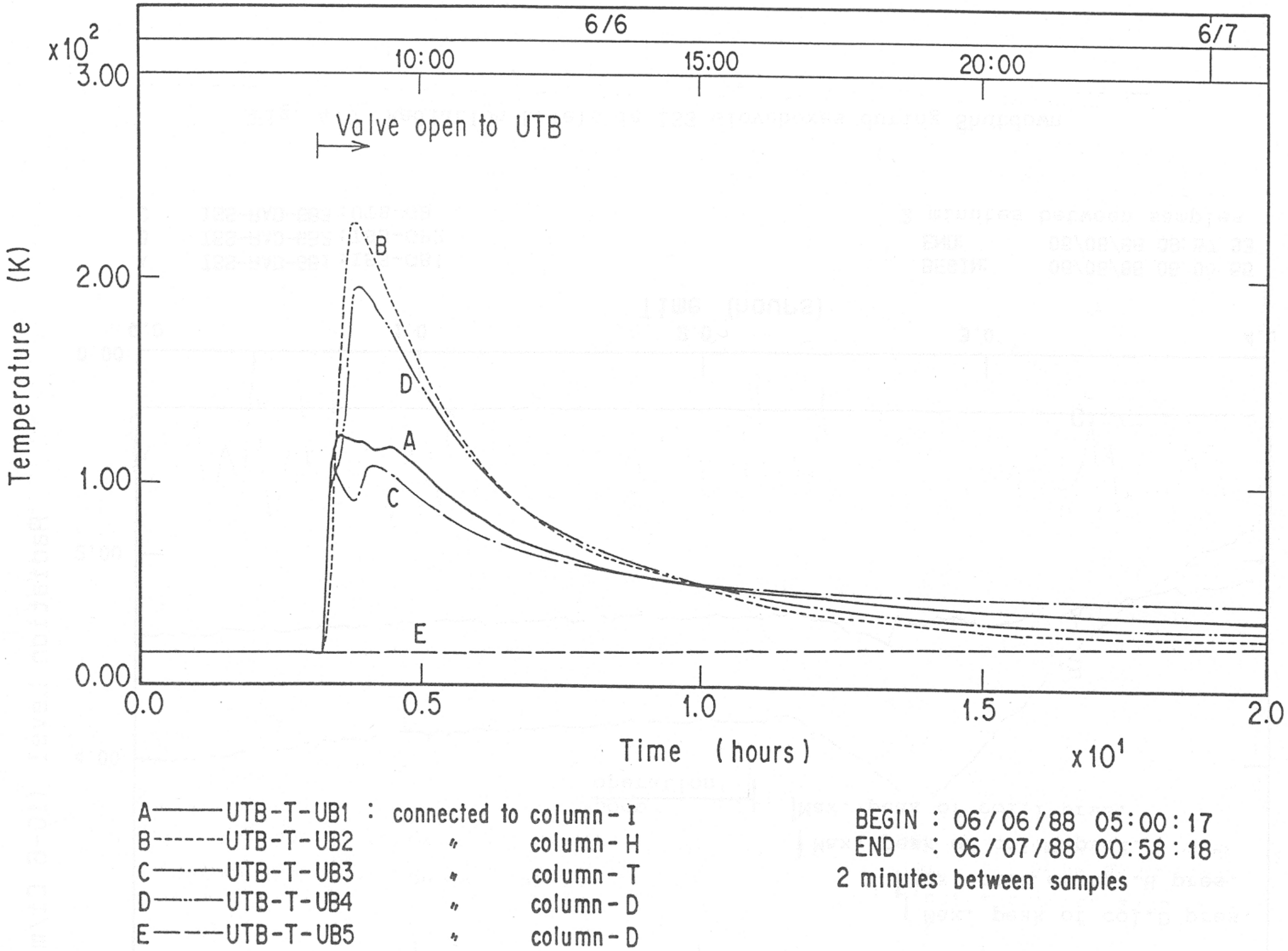


Fig. 4.4 Temperatures of UTB during Shutdown

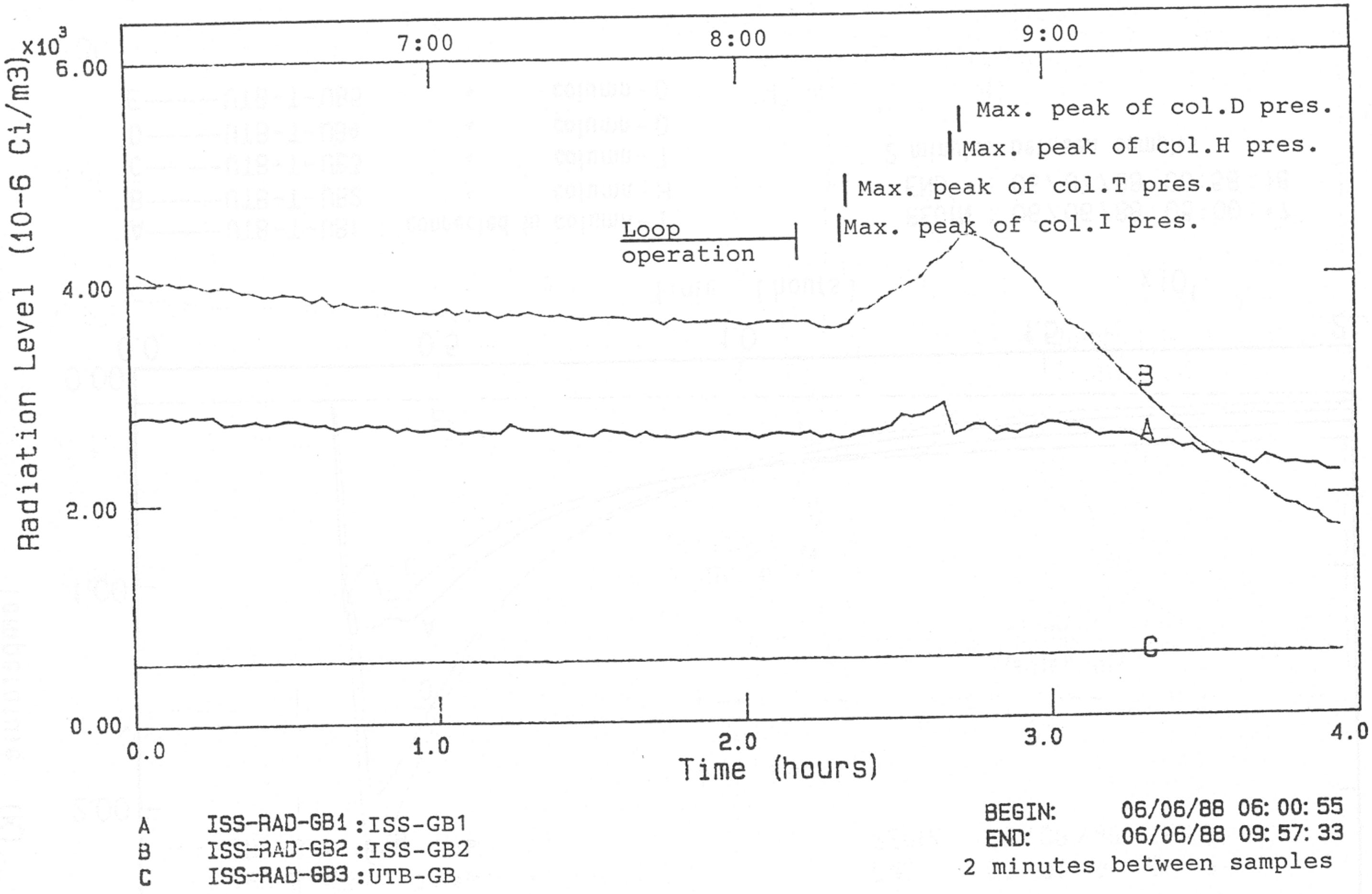
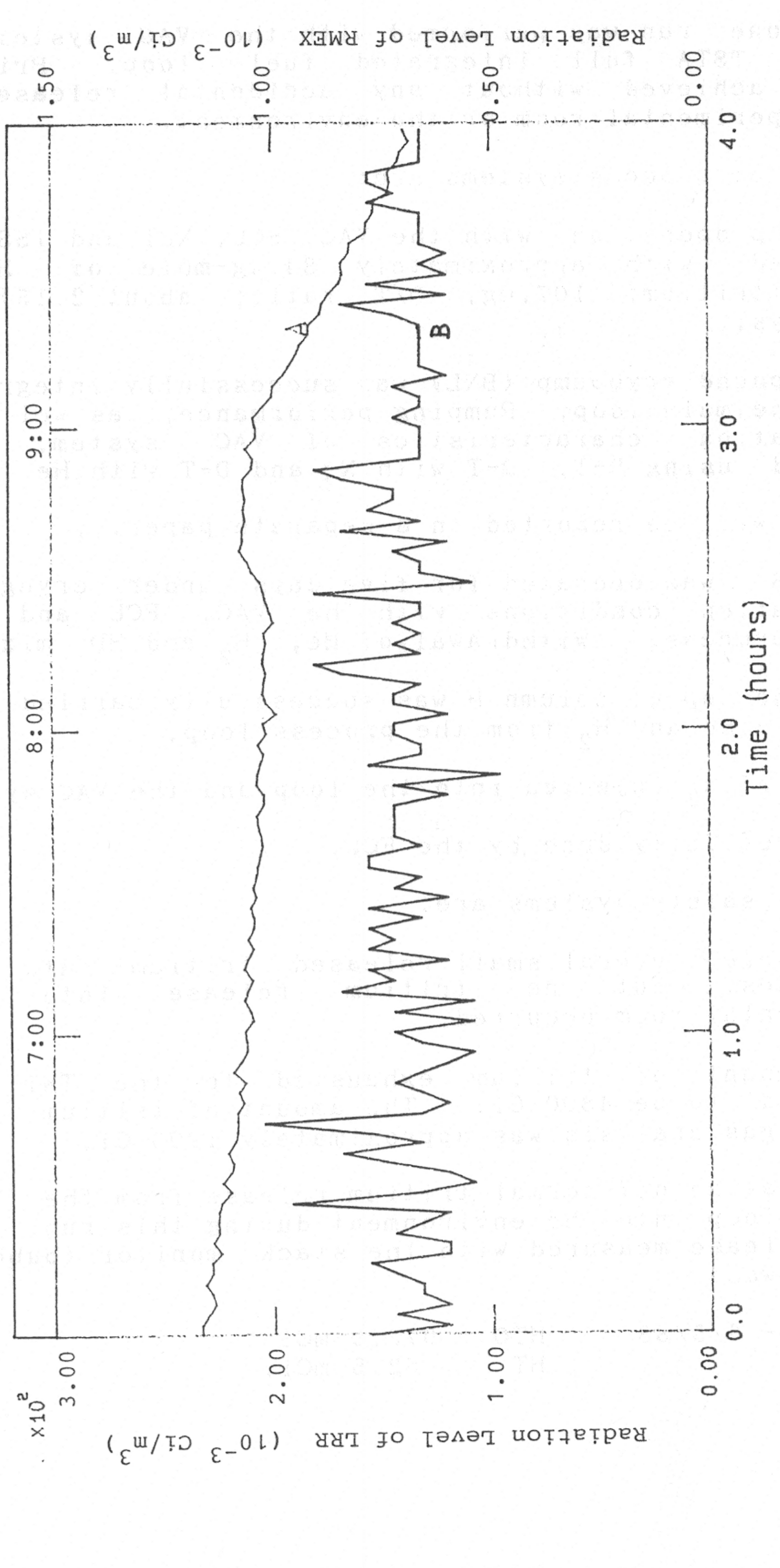


Fig. 4.5 Radiation Levels in ISS Gloveboxes during Shutdown



A TWT-RAD-LPR : in the low pressure receivor of TWT

B TWT-RAD-RMEX : at the exit of TWT

BEGIN: 06/06/88 06:00:55

END: 06/06/88 09:59:37

2 minutes between samples

Fig. 4.6 Radiation Levels in the TWT-Inlet and Outlet during Shutdown

5. CONCLUSION

This milestone run was performed with the VAC system to demonstrate the TSTA full integrated fuel loop. Primary objectives were achieved without any accidental release of tritium to the experimental room or the environment.

Achievements of process systems are:

- full loop operation with the VAC, FCU, NBI and ISS was performed with approximately 84.4g-mole of H-D-T mixture(tritium; 107.0g, D/T ratio; about 2.15) for five days,
- the compound cryopump (BNL) was successfully integrated into the main loop. Pumping performance, as well as regeneration characteristics of VAC system, was measured using D-T, D-T with N_2 and D-T with He (The details will be reported in a separate paper.),
- the ISS was operated for five days under cryogenic distillation conditions with the VAC, FCU and NBI return process. Withdrawal of He, H_2 and HD mixture from the top of column H was successfully carried out to remove He and H_2 from the process loop,
- removal of N_2 injected into the loop and the VAC system was successfully done by the FCU.

Issues of the safety systems are:

- there were several small released tritium into the gloveboxes, but no tritium release into the experimental room occurred,
- the amount of tritium exhausted to the TWT was estimated to be 4800 Ci. The amount of tritium from the ISS gas analysis was approximately 1900 Ci,
- there was no off-normal tritium release from the TSTA process loop into the environment during this run. The total release measured with the stack monitor (bubbler system) was:

5/30/88 - 6/5/88	HTO : 973.0 mCi
	HT : 62.5 mCi.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to Dr. M.Enoeda, who has joined TSTA activity after this milestone run as a member of Annex IV 2nd year program, for all his efforts in the simulation study of ISS.

REFERENCES

1. H. Yoshida, S. Hirata, and T. Naito, T. Yamanishi :JAERI Research Team, and J.L. Anderson, J.R. Bartlit, R.V.Carlson, D.O. Coffin, R.H. Sherman and R.S. Willms : TSTA Research Team, "TSTA Loop Operation with 100 grams-level of Tritium - Milestone Run in June, 1987 -," JAERI-M 88-204 , Japan Atomic Energy Research Institute (1988).

2. H. Yoshida, S. Hirata, and T. Naito, T. Yamanishi :JAERI Research Team, and J.L. Anderson, J.R. Bartlit, R.V.Carlson, D.O. Coffin, R.H. Sherman and R.S. Willms : TSTA Research Team, "TSTA Loop Operation with 100 grams-level of Tritium - Milestone Run in July, 1987 -," JAERI-M 88-205 , Japan Atomic Energy Research Institute (1988).

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ACKNOWLEDGEMENT

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