JAERI - M
88-205

TSTA LOOP OPERATION WITH 100 GRAMS-LEVEL OF TRITIUM

—MILESTONE RUN IN JULY, 1987—

October 1988

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編集兼発行　日本原子力研究所
印　　刷　㈱原子力資料サービス

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(Received September 24, 1988)

The first loop operation tests of Tritium Systems Test Assembly with 100 grams-level of tritium had been completed at Los Alamos National Laboratory in July, 1987. This test was the resumption of the previous milestone run halted on 26 June due to a mechanical failure of the refrigerator for the hydrogen isotope separation system.

The objectives were (i) to operate the TSTA process loop for a week to demonstrate its major process systems such as the fuel cleanup system and the hydrogen isotope separation system, (ii) to demonstrate the safety systems such as the secondary containment system, tritium waste treatment system and tritium monitoring system, and to obtain handling experience with a large amount of tritium.

This report describes characteristics of the safety systems observed during the milestone run.

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

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100グラムレベルのトリチウムを用いたTSTAループ試験
― 1987年7月のマイルストン・ラン ―

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（1988年9月24日受理）

本報告は，日米協力として昭和62年6月に米国ロスアラモス研究所のトリチウムシステム試験施設で開始されたＴＳＴＡ共同試験の計画概要並びに7月に実施された試験の概要を述べたものである。

本試験は前月に実施したマイルストン・ランを補足するものであり，約100グラムのトリチウムを使用して1週間3交代の直勤務体制で行われた。従事した人員は原研側の4名を含めて約25人（施設オペレータ，装置オペレータ，放射線管理等安全担当者，等を含む）。

主要な試験目的は，

(1) D－T ガス供給・回収系，精製系，水素同位体分離系，NBIインターフェイス，D－Tガス循環ポンプ系で構成されたプロセスシステムの連結運転・実証

(2) グローブボックス系，廃ガストリチウム除去系，トリチウムモニタリング系等からなるTSTA安全システムの実証，である。

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Contents

目　　次

ABBREVIATIONS

INV	:	Inventory Control System
INV-P-LOAD	:	Tritium loading pressure at the INV
UTB	:	Uranium Tritide Bed system
UTB-T-UB1 - UB5	:	Temperature of uranium beds in the UTB
ISS	:	Isotope Separation System
ISS-GAN	:	Gas Analysis System
ISS-P-CLIA, A2	:	Pressure of the ISS cloumn I
ISS-P-CLHA, A2	:	Pressure of the ISS column H
ISS-P-CLDA, A2	:	Pressure of the ISS column D
ISS-P-CLTA, A2	:	Pressure of the ISS column T
ISS-T-CLIA	:	Condenser temperature of the column I
ISS-T-CLHA	:	Condenser temperature of the column H
ISS-T-CLDA	:	Condenser temperature of the column D
ISS-T-CLTA	:	Condenser temperature of the column T
ISS-T-CLI	:	Packed section temperature of the column I
ISS-T-CLH	:	Packed section temperature of the column H
ISS-T-CLT	:	Packed section temperature of the column D
ISS-T-CLD	:	Packed section temperature of the column T
ISS-T-CLIB	:	Reboiler temperature of the column I
ISS-T-CLHB	:	Reboiler temperature of the column H
ISS-T-CLDB	:	Reboiler temperature of the column D
ISS-T-CLTB	:	Reboiler temperature of the column T
ISS-Q-CLI	:	Liquid level in the column I
ISS-Q-CLH	:	Liquid level in the column H
ISS-Q-CLD	:	Liquid level in the column D
ISS-Q-CLT	:	Liquid level in the column T
ISS-W-HTI	:	Heater output of the column I reboiler
ISS-W-HTH	:	Heater output of the column H reboiler
ISS-W-HTD	:	Heater output of the column D reboiler
ISS-W-HTT	:	Heater output of the column T reboiler
ISS-T-HESUP	:	ISS inlet temperature of He refrigerant
ISS-T-HEDIS	:	ISS outlet temperature of He refrigerant
TP3-P-D_2	:	Pressure of D_2 stream at the TP3 inlet
TP3-P-DT	:	Pressure of DT stream at the TP3 inlet
TP3-P-T_2	:	Pressure of T_2 stream at the TP3 inlet
TP3-F-D_2	:	Flow rate of D_2 stream at the TP3 inlet
TP3-F-DT	:	Flow rate of DT stream at the TP3 inlet
TP3-F-T_2	:	Flow rate of T_2 stream at the TP3 inlet
TP3-F-DIS	:	Flow rate of TP3 discharge
FCU	:	Fuel Cleanup System
FCU-GAN	:	Gas Analysis System
FCU-P-CR1	:	Pressure of the catalytic reactor
FCU-P-MSB1	:	Pressure of the molecular sieve bed-1
FCU-P-MSB2	:	Pressure of the molecular sieve bed-2
FCU-P-MSB3	:	Pressure of the molecular sieve bed-3

TWT	:	Tritium Waste Treatment System
TWT-P-LPR1	:	Pressure of the low pressure receiver
TWT-T-RECA1	:	Temperature of the TWT recombiner
TWT-T-GGXA	:	Temperature of the heat exchanger
TWT-STATUS	:	Status of TWT operation mode
TWT-RECYCLE-LIMIT	:	Radiation limit to start circulation mode
TWT-RECYCLE-RESET	:	Radiation limit to start stacking mode
INV-RAD-GB1	:	Radiation level in the INV glovebox
TPU-RAD-GB1	:	Radiation level in the TP1, 2 glovebox
TPU-RAD-GB2	:	Radiation level in the TP3 glovebox
ISS-RAD-GB1	:	Radiation level in the ISS glovebox
ISS-RAD-GB2	:	Radiation level in the ISS-GAN glovebox
ISS-RAD-GB3	:	Radiation level in the UTB
ISS-CD-GB	:	Command signal for glovebox purging
FCU-RAD-GB1	:	Radiation level in the FCU glovebox
FCU-CD-GB	:	Command signal for glovebox purging
TWT-RAD-LPR	:	Radiation level in the TWT-LPR
TWT-RAD-RECYCLE	:	Radiation level at the TWT-MSBs outlet
TWT-RAD-RMEX	:	Radiation level at the TWT outlet
TWT-DF	:	Decontamination factor of the TWT
TM-R-RM1	:	Room radiation level at the FCU-MEZ
TM-R-RM2	:	Room radiation level at the FCU-PIT
TM-R-RM3	:	Room radiation level at the ISS-MEZ
TM-R-RM4	:	Room radiation level at the VAC-North
TM-R-RM5	:	Room radiation level at the VAC-South
TM-R-RM6	:	Room radiation level at the SWD glovebox
FCU-MEZ	:	Mezzanine located over the FCU glovebox
FCU-PIT	:	Pit area for the FCU glovebox
ISS-MEZ	:	Mezzanine for the ISS and ISS-GB1 and 2
SWD glovebox	:	Glovebox used for solid waste disposal
VEN-R-STK	:	Radiation level of the stack exhaust gas
VEN-R-STKI	:	Integrated radiation level of stack exhaust gas

1. INTRODUCTION

1.1 LAYOUT OF JAERI/TSTA-LANL COLLABORATION

A new collaboration program(Annex IV) for fusion tritium technology(Fusion Fuel Program) has been established between JAERI and DOE/LANL(Department of Energy/ Los Alamos National Laboratory) in June, 1987.

This program, which will be conducted for a five-years period, consists of the following phases;

Phase-I : the existing TSTA process loop is operated in the first three years,
Phase-II : TSTA will be upgraded and operated in the next two years.

The objectives of this program are to perform the joint work of planning, experiments and analysis by using TSTA (Tritium Systems Test Assembly) having a tritium inventory and circulation flow rate of about 100 g-T and 1800 g-DT/day, respectively. The goals of this collaboration are to establish a fusion fuel processing technology of practical engineering scale and to demonstrate the safety technology for handling a large amount of tritium.

Table 1.1 shows the schedule of TSTA loop operation in the first year of the Annex IV program. Major features of these operations are (i) to demonstrate TSTA process loop functions with 100 grams-level of tritium for a time period of a week, (ii) to upgrade the FCU function by incorporating additional processes such as the impurity regeneration train composed of a catalytic reactor(CR2), DTO freezer(DTOF) and DTO converter(HMB4 and 5), and high temperature uranium beds(HMB1 and 2), (iii) to incorporate compound cryopumps in the TSTA process loop, and (iv) to perform basic cryogenic distillation experiments by using a single column and multi-columns of the TSTA-ISS.

This report briefly describes the milestone run performed from July 19(Sun) through July 25(Fri),which was done as the resumption of the milestone run of June[Ref. 1], and describes characteristics of the TSTA safety systems observed during this run.

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

1.2.1 PROCESS SYSTEMS

The latest TSTA process loop(Figure 1.1) is composed of the following sub-systems:

(1) UTB
Tritium and other hydrogen isotopes storage /supply system with five large uranium beds(UB-1, 2, 3, 4 and 5).

(2) ISS
Hydrogen isotope separation system with four inter-linked cryogenic distillation columns(I, H, D and T) and a surge tank.

(3) TP3
Transfer pump system with the metal bellows pumps(MBPA and MBPB), the gas mixer(MX) and the hydrogen isotope equilibrator(EQ).

(4) TP1
Transfer pump system with a scroll pump(S) and the metal bellows pumps(MBPA and MBPB).

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

(6) LIO
Load-in/Load-out system for tritium using T_2 gas shipping cylinders.

(7) INV
Tritium inventoring system to transfer tritium from LIO to the TSTA process loop.

1.2.2 SAFETY SYSTEMS

The major environmental and safety sub-systems of the TSTA facility are as follows;

(1) SEC
The primary process equipment and process lines are doubly contained with secondary containers such as gloveboxes and plastic tubes with nitrogen gas purge and control of their atmospheric pressures. Figure 1.2 shows the concept of the instrumentation of a typical glovebox. Purge gas(N_2) will be supplied to the glovebox at a preset tritium level.

(2) TWT

The tritium waste treatment system can process all tritium-bearing gaseous effluents generated in various subsystems in TSTA. This system is operated either in once-through or circulation modes as necessary, and routes the effluents to the TSTA stack after tritium removal by monitoring the tritium release level.

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

(3) TM

A number of tritium monitors(Stack, Duct, Room, Glovebox and Process) have been installed in the TSTA facility. They 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(to secondary containments 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 3000m^3 of building atmosphere which would be contaminated with tritium in the event of an accidental release from a secondary tritium containment. This system, the emergency tritium cleanup system, has the primary function to reduce the probability and amount of a tritium release to the environment from the TSTA cell after such an accident.

The free air capacity of the primary compressor is 2.5×10^3 m^3/hr at 585Torr(0.77atm) and 293K.

(5) VEN

The ventilation system is divided into two 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(0.23Torr) with respect to atmospheric pressure. The Zone II system(shown in Figure 1.3) for the main cell and other tritium handling rooms is maintained at a slight negative pressure(0.23Torr) with respect to atmospheric pressure to minimize possible diffusion of tritium to the environment.

The ventilation capacity of the Zone II system is 1.5×10^4 m^3/hr.

(6) MDAC

The TSTA is designed to be a computer controlled system and will not process tritium unless the master data acquisition and control(MDAC) is operational. This system contains two computer systems (shown in Figure 1.4); the process system consisting of two mini-computers and an interface, the safety system consisting of two micro-computers and an independent interface. Both systems include a backup computer, respectively.

The detailed description of above systems is given in a previous report "TSTA Loop Operation with 100 grams-level of

Tritium - Milestone Run in June, 1987 - "[Ref.1].

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 determined to reduce radiation exposure with tritium to As Low As Reasonably Achievable(ALARA).

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

1.2.4 ACCIDENT CONSIDERATIONS

(1) Failure Modes and Effects Analysis

TSTA subsystems have been analyzed with a 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.2].

(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 level 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(10^6Ci) of tritium into the facility only 10 Ci would be released from ETC to the environment.

(3) Emergency Evacuation Procedures

Evacuation procedures for a TSTA emergency have been established in accordance with the TSTA Quality Assurance Program. Any tritium release to the room atmosphere is quickly picked up by the room monitor, and 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 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).

Table 1.1 Schedule of TSTA Operation

(June, 1987 - July, 1988)

Mid. June, 1987	:	Integrated loop test with ISS and FCU*1 (100 grams-level T_2)
Mid. July	:	Integrated loop test with ISS and FCU*2 (100 grams-level T_2)
Early October	:	ISS single column test in total reflux and recycle(no FCU, H-D separation)
Early November	:	ISS single column test in total reflux and recycle(no FCU, D-T separation, 60g-T_2)
Early Feburary, 1988	:	Integrated loop test with ISS and FCU*3 (100 grams-level of T_2)
Early March	:	ISS two columns test(no FCU, H-D-T separation, 100 gram-level T_2)
Early June	:	Integrated loop test with ISS, FCU*4and VAC*5(100 grams-level T_2)
Mid July	:	Loop operation for TSTA Technical Safety Assessment(100 grams-level of T_2)*6

*1 Impurity removal front end : CR1(catalytic reactor to remove O_2) + MSB1 and 2(cryogenic molecular sieve beds to remove N_2 and CH_4).

*2 The same front end as that of Mid. June run.

*3 Back end of FCU is incorporated: Regeneration train with CR2(oxidizes CH_4 from regenerated MSBs) + DTOF(freeze out moisture from CR2) + HMB4 and 5(uranium bed to convert moisture from regenerated DTOF to hydrogen isotope gas).

*4 Front end with a high temperature uranium bed will be incorporated: Impurities such as CT_4 and NT_3 are directely reduced to T_2 througu the following reactions; $U + CT_4 \rightarrow UC + 2T_2$, $U + NT_3 \rightarrow UN + 3/2T_2$

*5 Compound cryopump(BNL or LLNL type with charcoal panel is incorporated.

*6 Demonstration for the Technical Safety Assessment of the TSTA

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.

[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 Ci	Form	Mitigation Method[1]	Release to Stack Ci	Boundary[2] Site Whole Body Dose (mrem)	Whole Body Worker Dose Rate[3] (mrem/min)	Freq
1. a) Rupture or large leak from torus plus loss of SEC	100	DT	A	100	1×10^{-6}	1×10^{-3}	E
			B	1×10^{-3}	7×10^{-7}	1×10^{-3}	E
b) Same as 1a, accompanied by a fire	100	DTO/HTO/T_2O	A	100	7×10^{-2}	67	E
			B	1×10^{-3}	7×10^{-7}	67	E
2. a) Rupture of cryopump plus loss of SEC	5.8×10^{4}	DT	A	5.8×10^{4}	7×10^{-4}	0.8	E
			B	5.8×10^{-1}	4×10^{-4}	0.8	E
b) Same as 2a, accompanied by a fire	5.8×10^{4}	HTO/T_2O	A	5.8×10^{4}	38	3.9×10^{4}	E
			B	5.8×10^{-1}	4×10^{-4}	3.9×10^{4}	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	9.7×10^{5}	1×10^{-2}	13	E
			B	9.7	6×10^{-3}	13	E
c) Same as 3b, accompanied by a fire, release at 50 m	9.7×10^{5}	D_2O,DTO,T_2O	A	9.7×10^{5}	6×10^{2}	6.5×10^{5}	E
			B	9.7	6×10^{-3}	6.5×10^{5}	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	3000	4×10^{-5}	4.0×10^{-2}	E
			B	3×10^{-2}	2×10^{-5}	4.0×10^{-2}	E
c) Same as 4b, accompanied by a fire	3000	DTO,D_2O,T_2O	A	3000	2	2.0×10^{3}	E
			B	3×10^{-2}	2×10^{-5}	2.0×10^{-3}	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	NA	NA	0.23	NA	E
		HTO	NA	NA	11×10^{3}	NA	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	10 g	T_2,DT,DTO
	DTOF	to 30 g	$C(D,T)_4$,$N(D,T)_3$
ISS	a. Total	100 g	T_2,DT
INV	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.

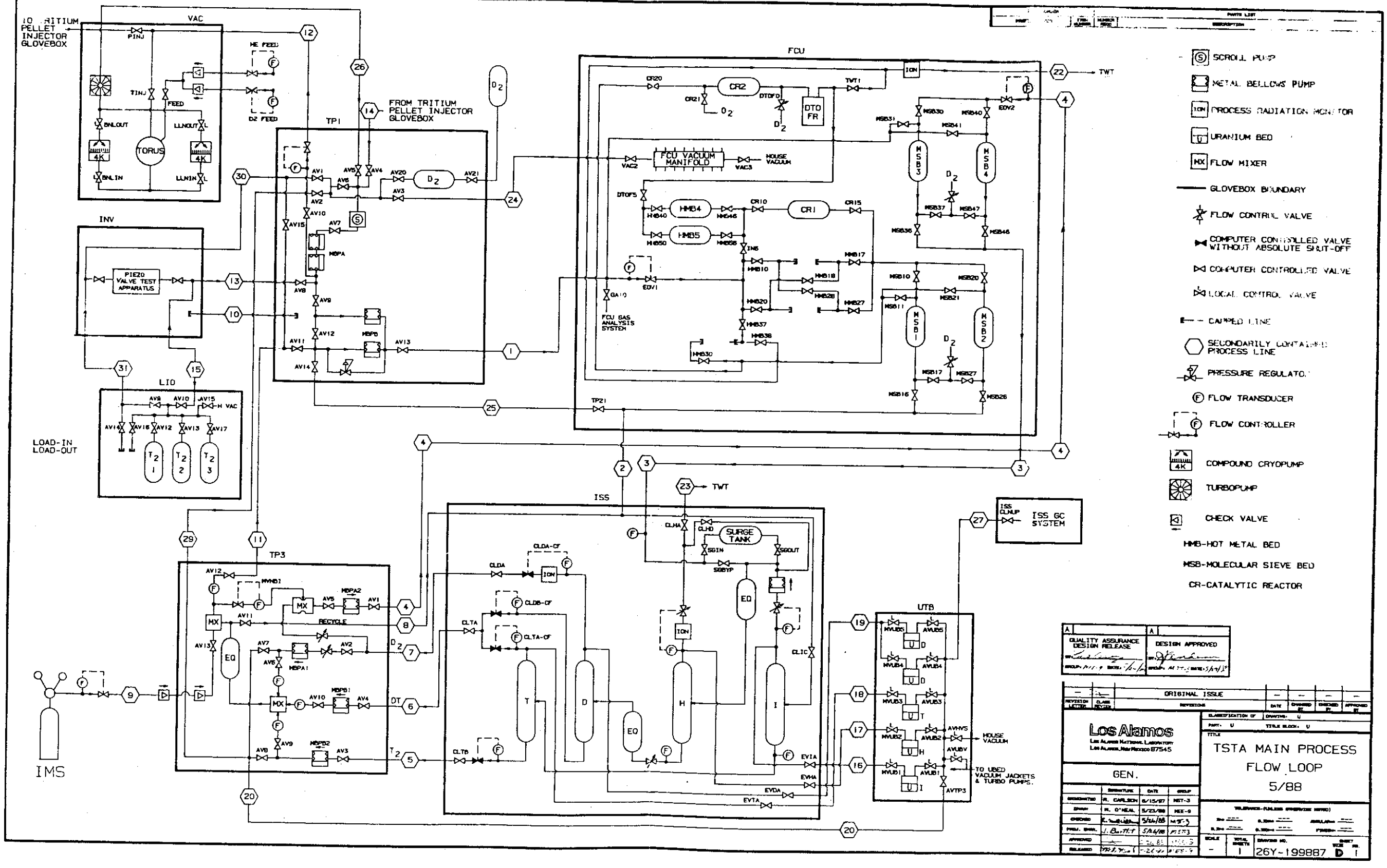


Fig. 1.1 Configuration of the TSTA Process Loop

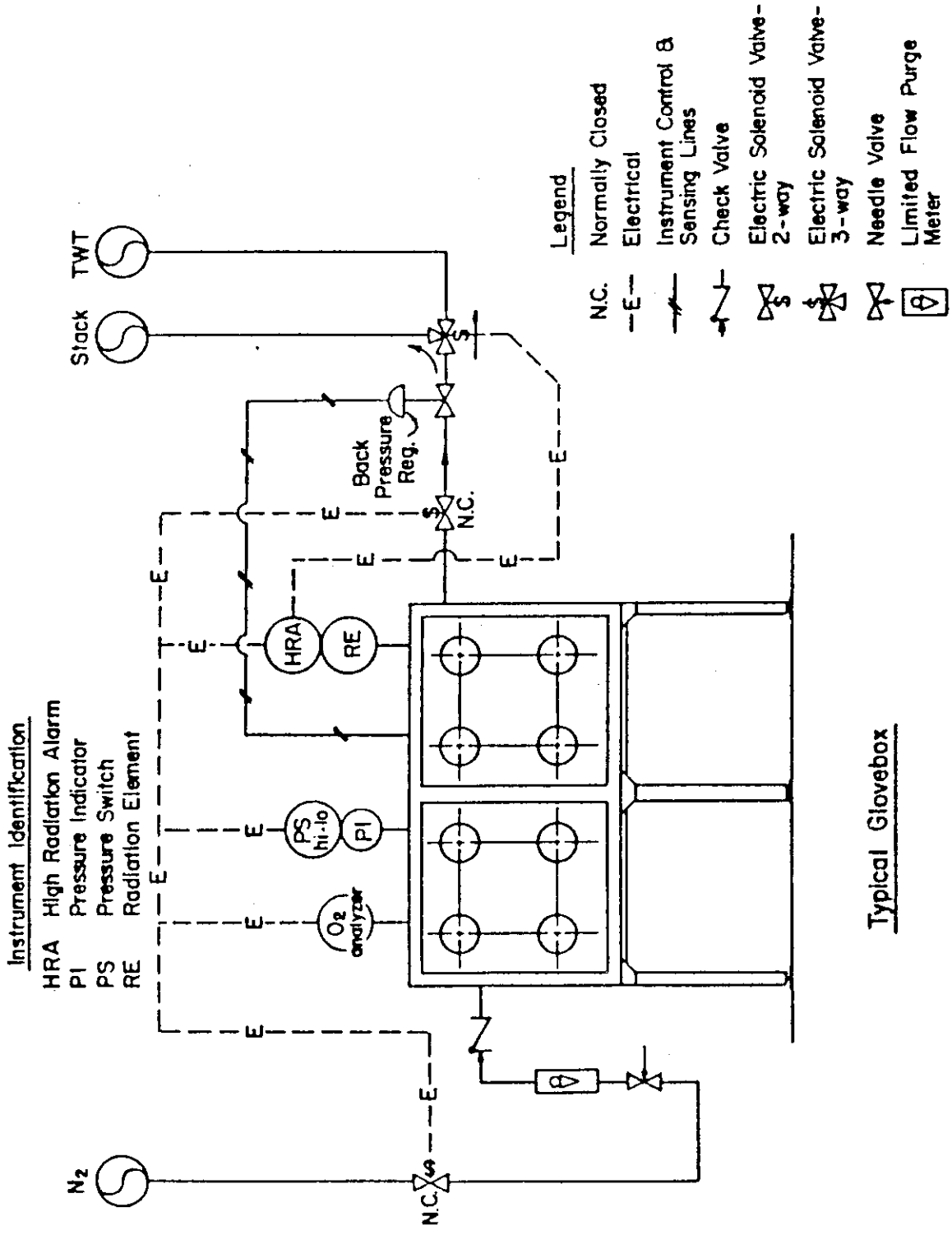


Fig. 1.2 Concept of the TSTA Secondary Containment

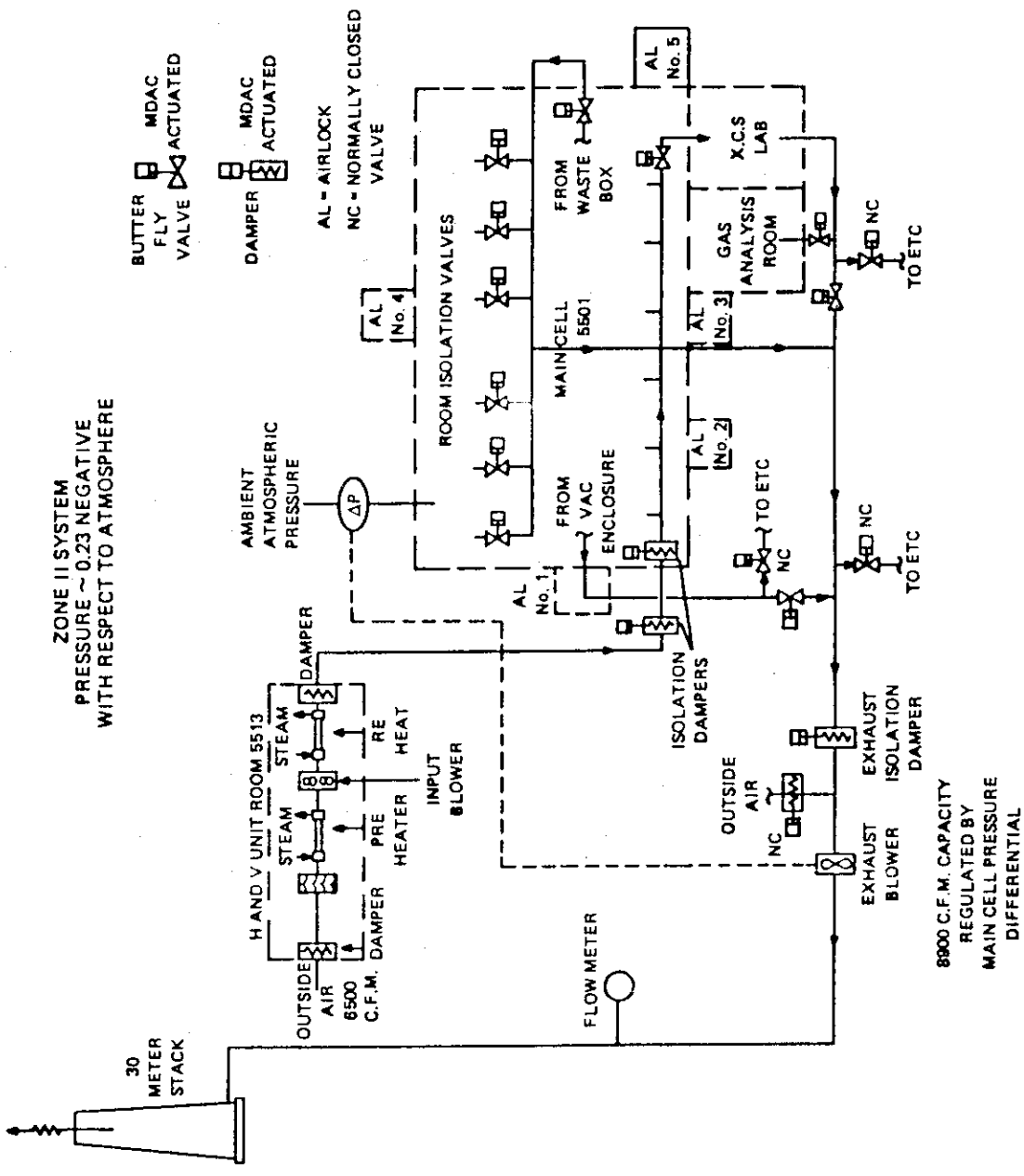


Fig. 1.3 TSTA Ventilation System

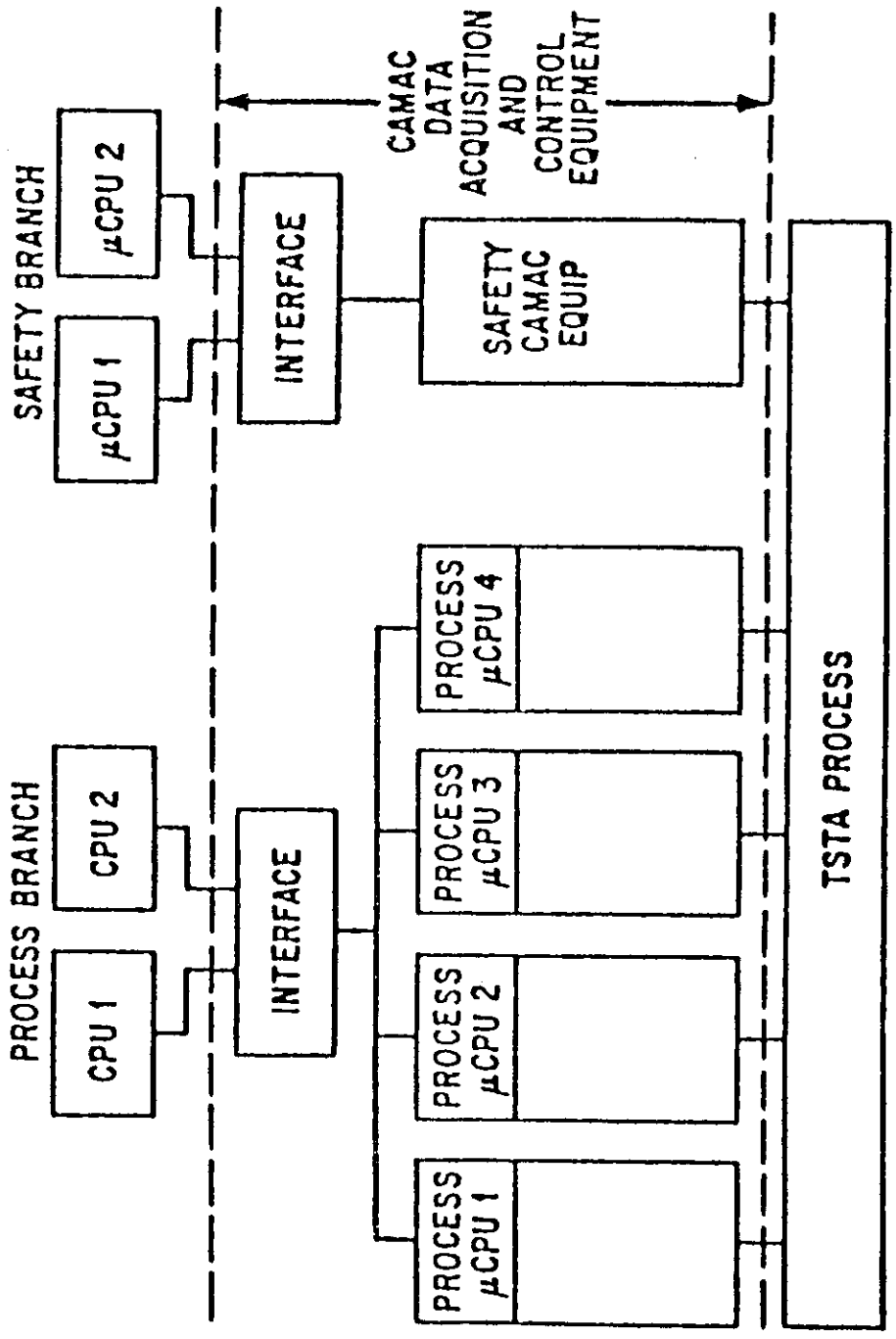


Fig. 1.4 Constitution of the TSTA Master Data Acquisition and Control System

2. TEST PLAN

2.1 OBJECTIVES

The objectives of this milestone run were:
- Operate TSTA process loop with 100 grams-level of tritium,
- Demonstrate major process functions such as impurity removal on the fuel cleanup system, H-D-T and H^3 separation on the hydrogen isotope separation system, and the neutral beam return flow process,
- Demonstrate functions of safety systems such as secondary containment system, tritium waste treatment system,and the process and room monitoring system.

2.2 CONFIGURATION

The TSTA process loop is configured as shown in Figure 1.1. 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 computer manual mode during this run.

Process systems used were: LIO, INV, UTB, IMS, FCU, ISS, TP1 and TP3 and GAN.
Required safety systems were: SEC, TM, TWT, VEN,ETC, MDAC, and the emergency generator and uninterruptable power supply. Utilities were the vacuum system(House Vac), low and high pressure nitrogen gas, cooling water, breathing air, etc.

2.3 PROCEDURES

(1) Start up operation
Major steps for the start up of the process systems are:
- evacuation of the ISS vacuum jacket, pre-cooling of the ISS columns with liquid nitrogen and cooling down with the cryogenic He refrigerator,
- evacuation of the vacuum jackets of FCU process components, and cooling down of cryogenic molecular sieve beds and heating the catalytic reactor,
- supply H_2 gas to the FCU to pre-saturate the cryogenic molecular sieves(MSB1 and 2),
- evacuation of the vacuum jackets and cooling down of NBI return process components(cryogenic molecular sieve beds),
- evacuation of the UTB vacuum jackets and pre-heating UTB.

(2) Tritium loading and ^{3}He stripping

The loading of tritium into the process loop is performed from the UTB and if necessary from the tritium gas shipping cylinders attached to the LIO. Approximately 70 g-mole of H-D-T mixture(91g-T) was supplied from the UTB and 11g-T was from two tritium gas cylinders in this run. Approximately 2.7g-mole of H_2 was supplied to pre-saturate the FCU cryogenic molecular sieve beds(MSB1 and 2). The stripping of ^{3}He and excessive H_2 and D_2 was performed by using the ISS columns H and D during the full loop operation. The mixture of 3He-H_2 was withdrawn several times from the top of ISS column H to the TWT(maximum flow rate: 500STP-cm^3/min, total time period of withdrawal: approximately 8hrs, tritium level: level less than 1Ci/m^3). Withdrawal of D_2 (approximately 30 STP-liters) to a tritium gas cylinder was performed from the top of ISS column D.

(3) Loop operation

Full loop operation through the flow paths FCU-ISS-TP3-TP1-FCU and ISS-TP3-NBI-ISS was started after the completion of the tritium loading(approximately 91g-T) from the UTB(UB2,4 and 5). Loading of additional tritium(approximately 11g-T) from a tritium gas cylinder was carried out after getting a steady state operating condition on the full loop. The major tasks performed during loop operation were:

- withdrawal of ^{3}He, H_2-HD, D_2 and pure T_2 from the ISS under continuous distillation conditions,
- impurity removal with the FCU cryogenic molecular sieves(MSB1 and 2) by injecting an impurity stream(90%N_2-10%CH_4, 60 STP-cm^3/min) into the FCU(time periods: 24hrs for each bed),
- ISS stabilization to obtain H-D-T separation characteristics under steady state distillation,

(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-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 NBI return process by stopping liquid nitrogen supply,
- if, blanketing effect occurred over the uranium beds in the UTB, circulate process gas through the flow path FCU-ISS-UTB-TP3-TP1,
- Isolate the FCU from the ISS, and warm up cryogenic molecular sieve beds by stopping liquid nitrogen supply and by turning on their electrical heaters, and transferring process gas(including impurities) to empty tritium gas cylinders by using the TP1,
- turn off all electrical heaters of process components and heaters in the ISS.

The residual gas(approximately 200 STP-liters) adsorbed on the two molecular sieve beds at liquid nitrogen temperature was transfered to the ISS surge tank (volume: 0.35 m^3) after completion of this run. The gas composition in the tank was as follows: N_2: 89%, $C(H,D,T)_4$: 4.8%, T_2: 2%, DT: 4%, HT: 0.2%.

3. RESULTS OF LOOP OPERATION

3.1 PROCESS SYSTEMS

3.1.1 TRITIUM STORAGE AND SUPPLY SYSTEM(UTB)

Approximately 70g-mole of H-D-T mixture(91g-T) was loaded to the process system from five uranium beds in the UTB and from tritium gas cylinders(11g-T). Hydrogen isotopes from UTB were loaded directly to ISS during cooling down with the cryogenic He refrigerator, and tritium gas from gas cylinders was supplied through the FCU to remove impurities included in the cylinders.

Figures 3.1 and 3.2 show temperatures of the uranium beds(each contains 6kg-U) and process pressures in the ISS during offloading of the UBs. The required time periods to heat the UBs from 473K to 700K were approximately 2hrs, and a day to cool to ambient temperature.

3.1.2 FUEL CLEANUP SYSTEM(FCU)

An impurity injection experiment(60 STP-cm^3/min of 90%N_2 - 10%CH_4) was performed under full loop operation for 53.1hrs; 26.6 hrs to one molecular sieve bed(MSB1 at liquid nitrogen temperature) and 26.5hrs to a second bed(MSB2). Gas analysis(13 samples) was performed with off-line Laser Raman spectroscopy(Table 3.1). A typical inlet composition (measured on July 24, 9:00) was: N_2: 0.37%; CH_4: 0.078%; H: 0.37%; D: 47.46%; and T: 52.17%. It is indicated that the isotopic composition of the ISS feed stream is very close to the ISS design operating conditions. No cryogenic plugging of the ISS and FCU was observed during full loop operation but the outlet concentration of these species appeared to be 0.04-0.14%N_2 and 0.002-0.004%$C(H,D,T)_4$, respectively.

The major chemical form of CH_4 in the outlet stream of molecular sieves was tritiated methane. Blank analysis after this run showed background levels of N_2 and CH_4 of the gas analysis system(FCU-GAN) comparable to that measured on the process gas existing the cryogenic molecular sieve beds.

3.1.3 ISOTOPE SEPARATION SYSTEM(ISS)

This system was operated with the FCU and NBI for 115hrs. Most of this time was spent achieving steady state distillation conditions. Withdrawals of ^3He, 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. Approximately 120 samples of gas analysis were performed with the on-line gas chromatograph system to measure the separating performance of each column.

The demonstration of enriching tritium to purities higher than 99.9% and withdrawal of above the species was fully achieved

as primary objectives of this milestone run.

It appeared that some improvements of existing instruments of the ISS are required to establish good control conditions for steady state distillation. Detail results and discussion of this system are described in separate reports.

3.2 SAFETY STSTEMS

3.2.1 SECONDARY CONTAINMENT SYSTEM(SEC)

Notable increments in the radiation levels of glovebox were observed in ISS(GB1 and 2), FCU(GB1), TPU(GB1) and INV(GB1). The following are the characteristics of these tritium releases in each glovebox.

(1) Radiation levels of ISS gloveboxes

Figure 3.3 shows radiation levels of these gloveboxes and operating modes of the TWT during the entire period of this run. The three major increments on the ISS-GB1 were related to the offloading of UB1 and 2(on July 19), adjustments of ISS distillation conditions(on July 21) and a large disturbance in the ISS column I(
July 25). Most peaks on the ISS-GB2 were caused by the start of ISS gas analysis(approximately 120 samples were withdrawn from columns to ISS.GAN during this run).

Figure 3.4 shows a relationship among radiation levels of ISS gloveboxes, loading pressures of ISS and the status of TWT operating modes.

The GB1 radiation level started to increase(from 0.7×10^{-3} Ci/m^3 to 8×10^{-3} Ci/m^3) with the increase of ISS column I pressure during loading tritium from two uranium beds(UB1 and 2). This offnormal radiation level has been identified as due to a leak through a rupture disc on the top of column I. The radiation levels decreased gradually with the decrease of tritium concentration in the top of this column with the progress of isotope separation, as well as the start of glovebox gas purge. The purge was automatically performed at a level higher than 1×10^{-3} Ci/m^3.

The increase of radiation level of July 21 was caused by the pressure increase of the column I during adjustment of ISS distillation conditions. The increase of June 25 was caused by a large disturbance of flow balance and liquid level in column I (the pressure was stable at around 850 Torr).

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), which employed many swagelock type tube connectors. This glovebox was purged with nitrogen, since the tightness of isolating valve sheats between the sampling manifold and the ISS columns have been deteriorated. The rapid decrease of the radiation level from 5×10^{-3} Ci/m^3 was due to the pumping out of residual gas(approximately 600 Torr) in the manifold.

(2) Radiation levels of FCU glovebox

As shown in Figure 3.5 radiation levels of FCU-GB1 gradually increased due to small leaks in the FCU process components(a flange of a FCU rupture disc and connections of the oxygen monitor), following initiation of loading tritium into the process system on July 20. This radiation level was related to the process pressure in the FCU(Figure 3.6). On the contrary, peaks(maximum; 27×10^{-3} Ci/m^3) observed during July 21 through 25 occurred during gas sampling with the Laser Raman sampling cell. The peaks of S1 to S6 and S8 were related to the replacement of the sampling cell in the FCU-GAN system. The sharp peaks of S6, S7 and S9 resulted from leaks on the sampling cell itself.

(3) Radiation levels of INV glovebox

As shown in Figures 3.5 and 3.7, only a small peak(maximum; 5×10^{-3} Ci/m^3) was observed on July 22. This offnormal release occurred when an empty tritium gas cylinder, which was previously used for tritium supply to the process loop, was attached to the LIO manifold for recovery of ^{3}He from ISS. The source of tritium was residual gas in a short connecting tube on the gas cylinder. Successive leak was not occurred during loading(amount of ^{3}He; 25 STP-liters, pressure; 370Torr) of ^{3}He withdrawn from the top of column H.

(4) Radiation levels of TPU glovebox

There appeared two radiation peaks(maximum; 12×10^{-3}Ci/m^3) in TPU-GB1(Figure 3.5), which contains the TP1 system composed of two sets of double-headed metal bellows pumps and a scroll pump. These tritium leaks were caused by a break of a metal bellows pump(MBPA). Because this pump is indispensable for gas sampling on the FCU-GAN and for pumping of pure T_2 gas withdrawn from ISS to a tritium gas cylinder(attached to the LIO)., the pump was replaced after necessary flushing with D_2 gas to decontaminate the surface of the pump.

The glovebox window was removed for the replacement work when the radiation level dropped to approximately 2×10^{-3}Ci/m^3. The flexible ventilation duct was used for this operation.

Figure 3.8 shows a typical detritiation curve observed on this glovebox(this offnormal release occurred from the above mentioned pump). It is apparent that the tritium reduction rate can be expressed by the theoretical equation, $C = C \exp(-0.52t)$; unit of time t is hour, which was derived from the perfect mixing model, except during the very early stage of release, at which time tritium monitor detected local tritium concentrations. The value in the parenthesis(0.52) is the volumetric change ratio of glovebox atmospheric gas(ratio of the volumetric flow rate of glovebox purge gas to the glovebox volume) in this glovebox.

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 milestone run.

3.2.3 STACK RADIATION LEVELS

Only one, but marked, offnormal radiation peak was detected for approximately four hours in the evening of July 24(Figures 3.9 and 3.10). It was caused by tritium leakage from a gas sampler(Laser Raman cell) placed in a hood(part of the Solid Waste Disposal system), whose ventilation air is routed to the TSTA stack without detritiation. The sampler was that used for the FCU gas analysis and identified to have large leakage (Figure 3.5). It was moved to the SWD glovebox after the detection of the offnormal stack radiation level. The amount of tritium released to the environment was evaluated to be approximately 1Ci based on the stacking flow rate and the radiation level.

The total environmental release measured with the stack monitor (bubbler system) was evaluated as follows:

July 16 - 22

HTO	;	240×10^{-3} Ci
HT	;	63×10^{-3} Ci

July 23 - 29

HTO	;	647×10^{-3} Ci
HT	;	624×10^{-3} Ci

3.2.4 CHARACTERISTICS OF TRITIUM WASTE TREATMENT SYSTEM(TWT)

The tritium waste treatment system operated the entire period of this run without any problems.

Figures 3.11 shows the TWT outlet radiation level in the first day of this run. The source of the peak radiation level(maximum; 30×10^{-3} Ci/m^3) was pumping gas from ISS-GAN manifold through the House Vac system(Figure 3.12). This pumping was performed to remove residual gas leaked from the ISS during loading of tritium to the ISS from UB1 and 3, since the radiation levels of the ISS-GAN glovebox(ISS-GB2) increased to 5×10^{-3} Ci/m^3 due to a leak from the ISS-GAN manifold(Figure 3.4). Because the TWT catalyst temperature had not reached its normal temperature(750K) yet, the radiation levels in the TWT outlet streams increased to 9×10^{-3} Ci/m^3 on RAD-RMEX(TWT exhaust monitor on line to stack, pressure of the stream ; 36kPa) and to 27×10^{-3} Ci/m^3 on RAD-RECYCLE(TWT dryer outlet monitor, pressure; 2100 Torr(2.8 atm)). These levels began to drop when the recombiner temperature reached about 750K.

Figure 3.13 shows the TWT inlet and outlet radiation levels during full loop operation of the TSTA process. Variations on the inlet radiation levels reflect tritium concentration and

pressure in the TWT low pressure receiver(LPR), and the TWT recombiner temperature during TWT operation in the recycle mode. The major tritium sources during full loop operation were glovebox purge gas, exhaust gas from ISS-GAN(approximately 120 times of ISS gas analysis), pumping gas from the FCU pass-box on FCU-GB1(13 times of Laser Raman sampling), purge gas of TP1 and pumping gas of the UTB during replacement work on the broken pump(MBPA), and withdrawal of gas from the top of ISS column H. The pressure variations(Figure 3.14) on July 19 represented the status of the TWT compressor, whose operation is regulated to keep pressure of the TWT-LPR within the level of 30-60kPa. The high temperature peaks observed on July 19 and 21(Figure 3.15) were caused by operating the larger compressor of TWT to process stagnant gas including tritiated hydrocarbons in the House Vac system. The stagnant gas is likely to be delivered during pumping large gas volumes such as evacuation gas from the FCU pass-box and purge gas from TP1 in preparation for replacement of its broken pump. The peaks of the outlet radiation levels observed on July 23 may be considered due to these tritiated hydrocarbons.

Figure 3.16 shows typical response of the TWT inlet radiation levels to the exhaust gas from the ISS gas analysis system(ISS-GAN) and from the FCU pass-box. Exhaust gas(tritium concentration 30-100%) from ISS-GAN was the source of marked radiation peaks, but the effects of exhaust gas from the FCU pass-box seems very little. Small peaks due to the withdrawal stream from the top of ISS column H indicated that the tritium concentration in this stream was also very low.

Figure 3.17 shows the TWT decontamination factor obtained by normalizing pressures in the inlet and outlet streams. The maximum value reached 5×10^{4}. The lower values of about 10^{3} reflected the lower inlet tritium concentrations.

Figure 3.18 compares typical radiation levels when TWT processed elemental tritium from ISS and tritiated methane from impurity injection experiments on the FCU cryogenic molecular sieve beds(not tritiated hydrocarbon formed in the House Vac system). The peak levels(maximum; 15Ci/m^3 in the TWT inlet) corresponded to receiving exhaust gas of ISS gas analysis. The source of the peaks(maximum; 40Ci/m^3 on July 28 and 29) was a small part of the regeneration gas including tritiated methane(0.9%) from the FCU molecular sieve beds which were used for impurity(0.9%N_2-0.1%CH_4) injection experiments. Because the TWT recombiner temperature was almost constant(730K) from July 24 through 30, outlet radiation peaks(maximum; 0.1Ci/m^3) on July 28 and 29 reveal that the conversion rate of tritiated methane was comparatively lower than that of elemental tritium from ISS.

Figure 3.19 shows a typical detritiation curve observed in the low pressure receiver. The major species of this peak radiation is considered to be elemental tritium, since the source was exhaust gases from ISS-GAN and the top of ISS column H. It is apparent that the reduction rate can be expressed by the theoretical equation, $C = C \exp(-3.5t)$, derived from the perfect mixing model. The value in the parenthesis represents the volumetric change ratio of the gas in the receiver. Deviation from the linear curve may have resulted from subsequent receiving

of exhaust gas from ISS-GAN and its imperfect mixing.

3.2.5 AMOUNT OF TRITIUM PROCESSED IN TWT

It is possible to estimate total amount of tritium exhausted from process systems as well as secondary containment systems. As mentioned above, the major source of tritium routed to the TWT under normal operating conditions was exhaust gas of the ISS gas analysis system(ISS-GAN). The following are estimates of total tritium determined by three methods:

Table 3.2 summarizes the amount of tritium based on a calculation using data such as increments of radiation levels, pressures and volume of the TWT low pressure receiver. Because this calculation did not include small peaks, the estimated value(3000Ci) would be less than actual one.

Next is the breakdown of tritium exhausted from the ISS-GAN based on data such as gas composition, pressures and number of samples analyzed with the ISS gas analysis system and holdup of its sampling manifold($40cm^3$):

Column I (27 samples,	54 times of flushing);	1067 Ci
Column H (23 samples,	46 times of flushing);	negligible
Column D (11 samples,	22 times of flushing);	117 Ci
Column T (50 samples,	100 times of flushing);	6282 Ci
	total ;	7455 Ci

Figure 3.20 shows the integrated amount of tritium. Calculation was done with the stacking flow rate($0.425M^3$/min) and the reading of the LPR radiation monitor every minute. The total value($1.3x10^4$Ci) would include the background contribution($4x10^2$ - $4x10^3$Ci) of the LPR tritium monitor (background radiation level ; $1x10^{-7}$ - $1x10^{-6}$Ci/m^3).

Table 3.1 Results of Raman Analysis for FCU

Date	Time	Analysis point	Concentrations of components (%)					Note
			H	D	T	N_2	CH_4	
7/21/87	10:00	ISS1(down-stream of MSB1)	0.435	47.685	51.880	0.061	0.0040	Total time of impurity injection was 0.5 hr.
7/21/87	17:55	ISS1(down-stream of MSB1)	0.026	71.335	28.638	0.0487	0.0023	Total time of impurity injection was 9 hr.
7/22/87	9:27	ISS1(down-stream of MSB1)	0.051	71.082	28.867	0.0449	0.0024	Before impurity injection
7/22/87	11:50	ISS1(down-stream of MSB1)	0.048	71.245	28.707	0.0572	0.0027	Total time of impurity injection was 15.8 hr.
7/22/87	16:15	ISS1(down-stream of MSB1)	0.075	83.956	15.968	0.0724	0.0033	Total time of impurity injection was 20.2 hr.

Table 3.1 (Continued)

Date	Time	Analysis point	Concentrations of components (%) H	D	T	N_2	CH_4	Note
7/23/87	10:18	ISS1(down-stream of MSB1)	0.261	58.679	41.060	0.1484	0.0017	Before imputiry injection
7/23/87	10:50	IN1(upper-stream of MSB1)	0.220	63.232	36.549	0.0528	0.0025	Before impurity injection
7/23/87	14:30	IN1(upper-stream of MSB2)	0.271	55.884	43.846	0.0976	0.0017	Before impurity injection
7/23/87	15:30	ISS1(down-stream of MSB2)	0.350	66.064	33.586	0.0679	0.0021	Before impurity injection
7/23/87	19:10	ISS1(down-stream of MSB2)	1.768	62.550	35.682	0.0763	0.0020	Total time of impurity injection was 0.5 hr. for MSB2.
7/24/87	8:20	ISS1(down-stream of MSB2)	1.502	65.911	32.587	0.1372	0.0020	Total time of impurity injection was 13.7 hr. for MSB2.
7/24/87	9:00	IN1(upper-stream of MSB2)	0.368	47.463	52.169	1.3373	0.0777	Total time of impurity injection was 14.3 hr. for MSB2.
7/24/87	14:50	ISS1(down-stream of MSB2)	0.123	70.396	29.480	0.1167	0.0028	Total time of impurity injection was 20.3 hr. for MSB2.

Table 3.2 Amount of Tritium Transfered to TWT

Date	Major peaks		Sub total(Ci)
	Time	Amount of tritium (Ci)	
7/20	23:00	13	31
7/21	0:50	26	
	8:45	39	
	22:50	31	110
7/22	5:50	24	
	8:30	70	
	9:40	85	
	14:40	32	
	15:30	35	
	22:25	42	350
7/23	4:25	29	
	7:30	52	
	9:25	290	
	12:20	130	
	14:05	170	
	16:40	130	
	18:50	93	
	22:30	130	1100
7/24	8:00	150	
	8:40	170	
	10:00	79	
	13:00	42	
	15:00	61	
	17:30	61	
	21:30	100	870
7/25	8:05	190	
	9:05	150	
	11:40	74	540
		Total	3001

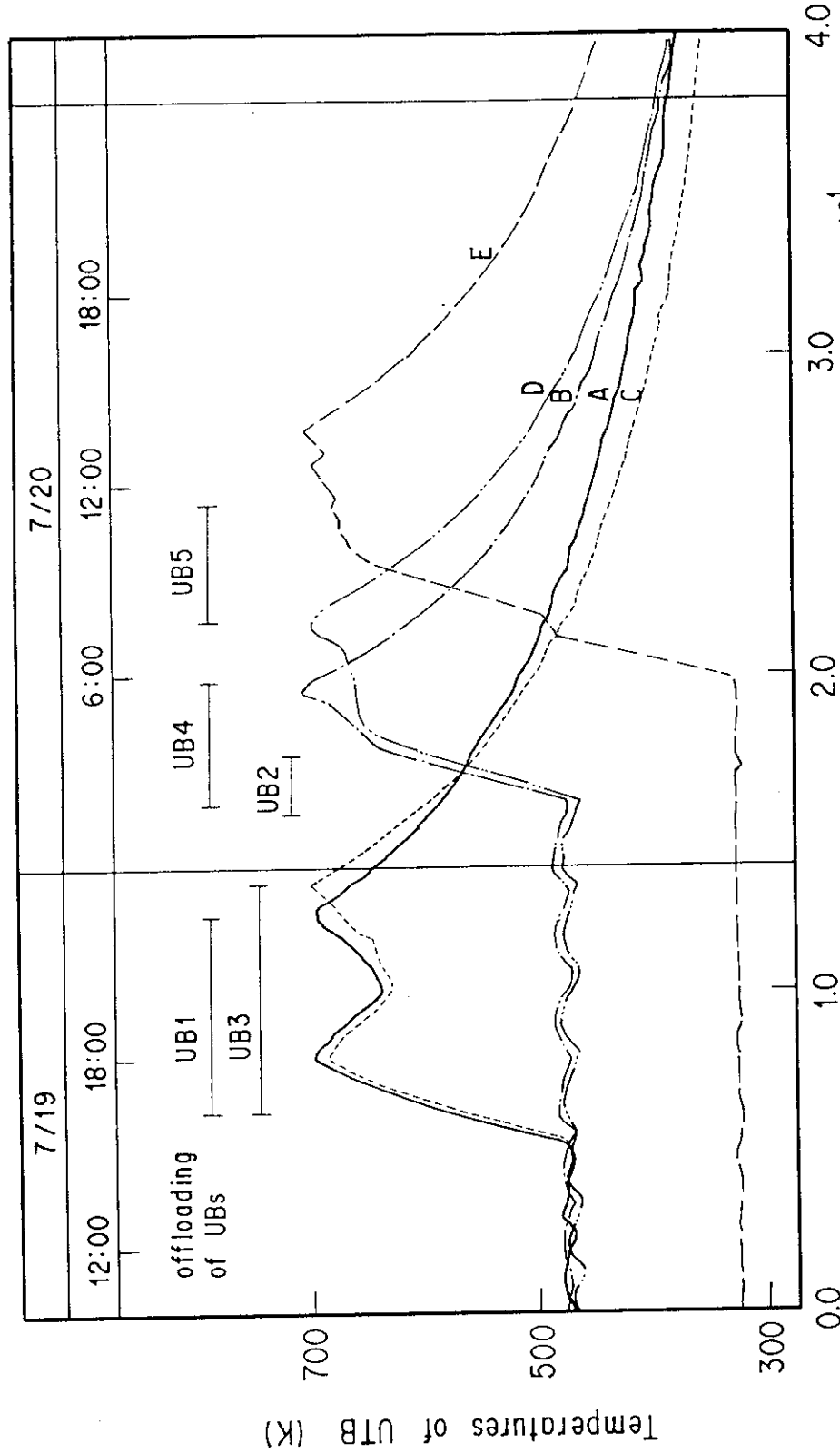


Fig. 3.1 Temperature scheme of the UTB

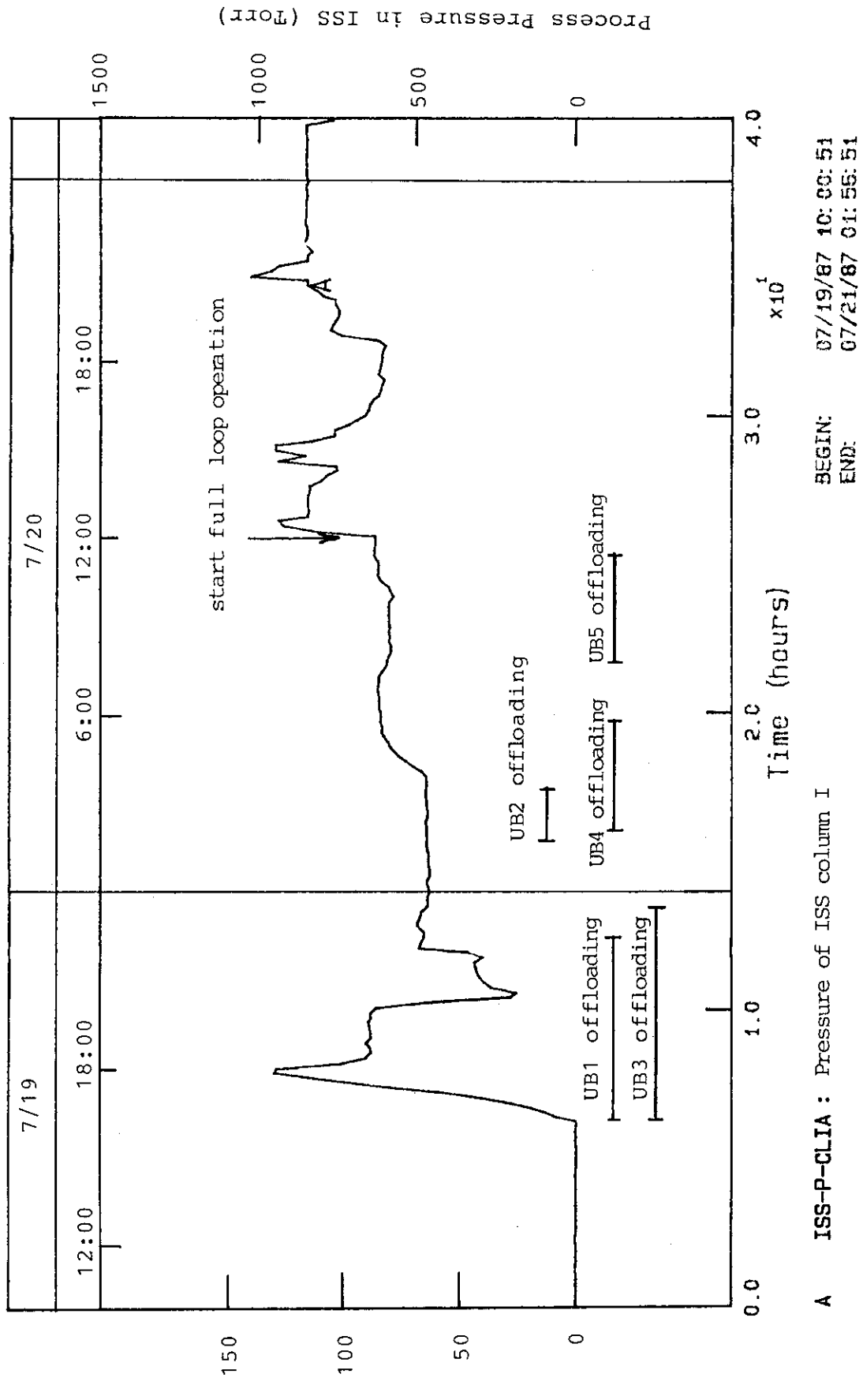


Fig. 3.2 Process pressure at the ISS column I

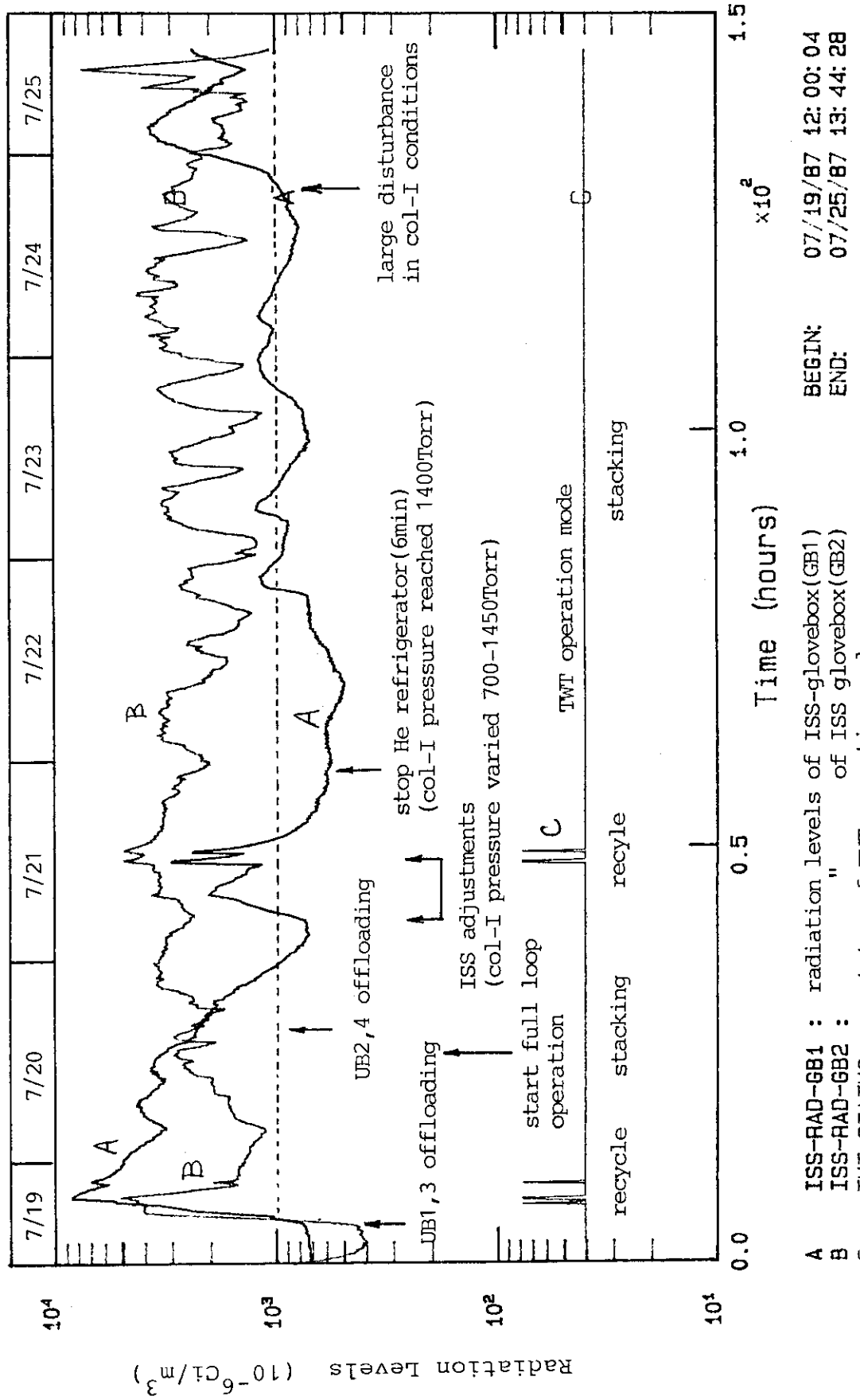


Fig. 3.3 Radiation levels in the ISS gloveboxes and the status of TWT

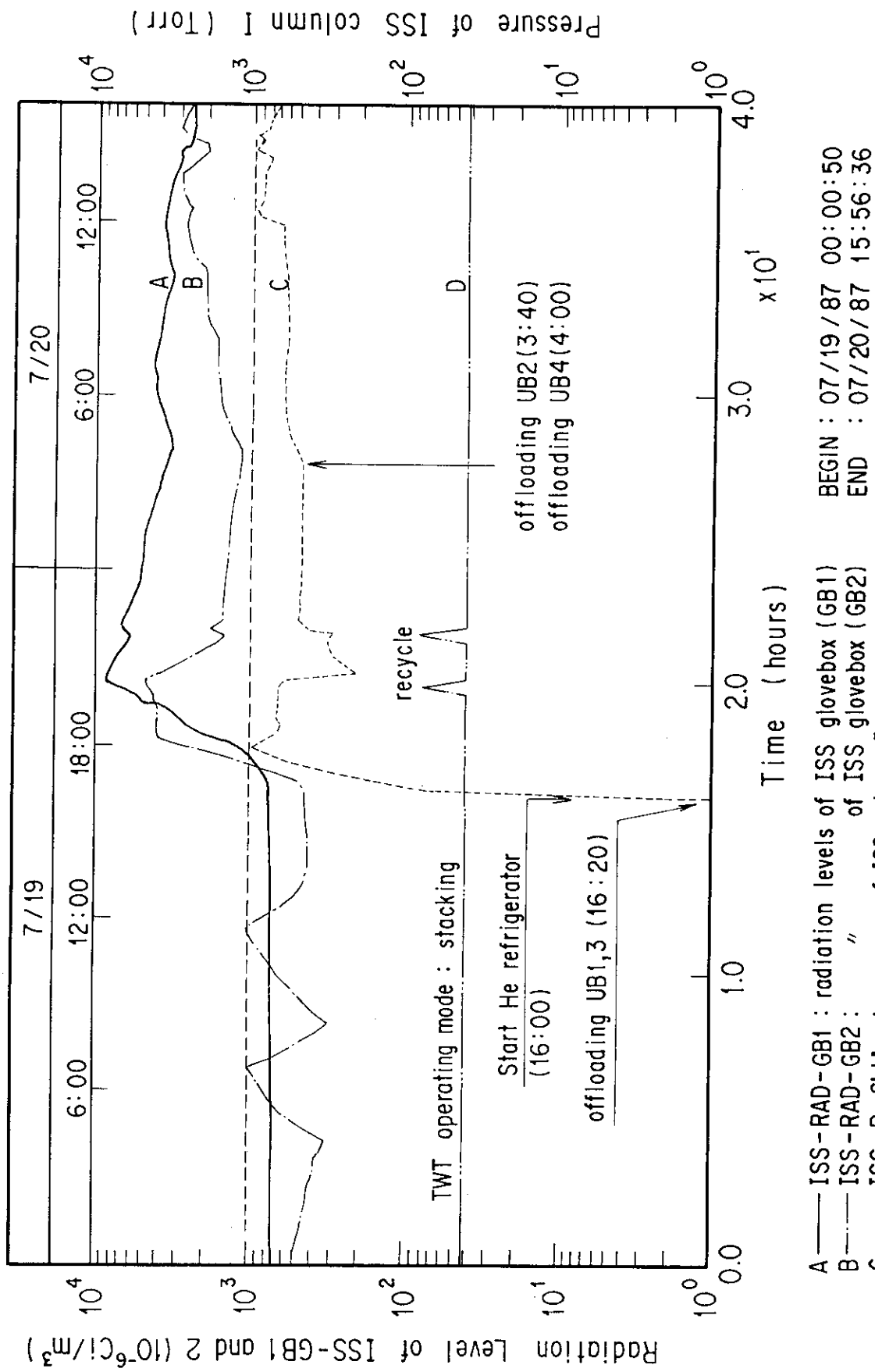


Fig. 3.4 Relationship between the ISS glovebox radiation levels and the pressure in the ISS column I

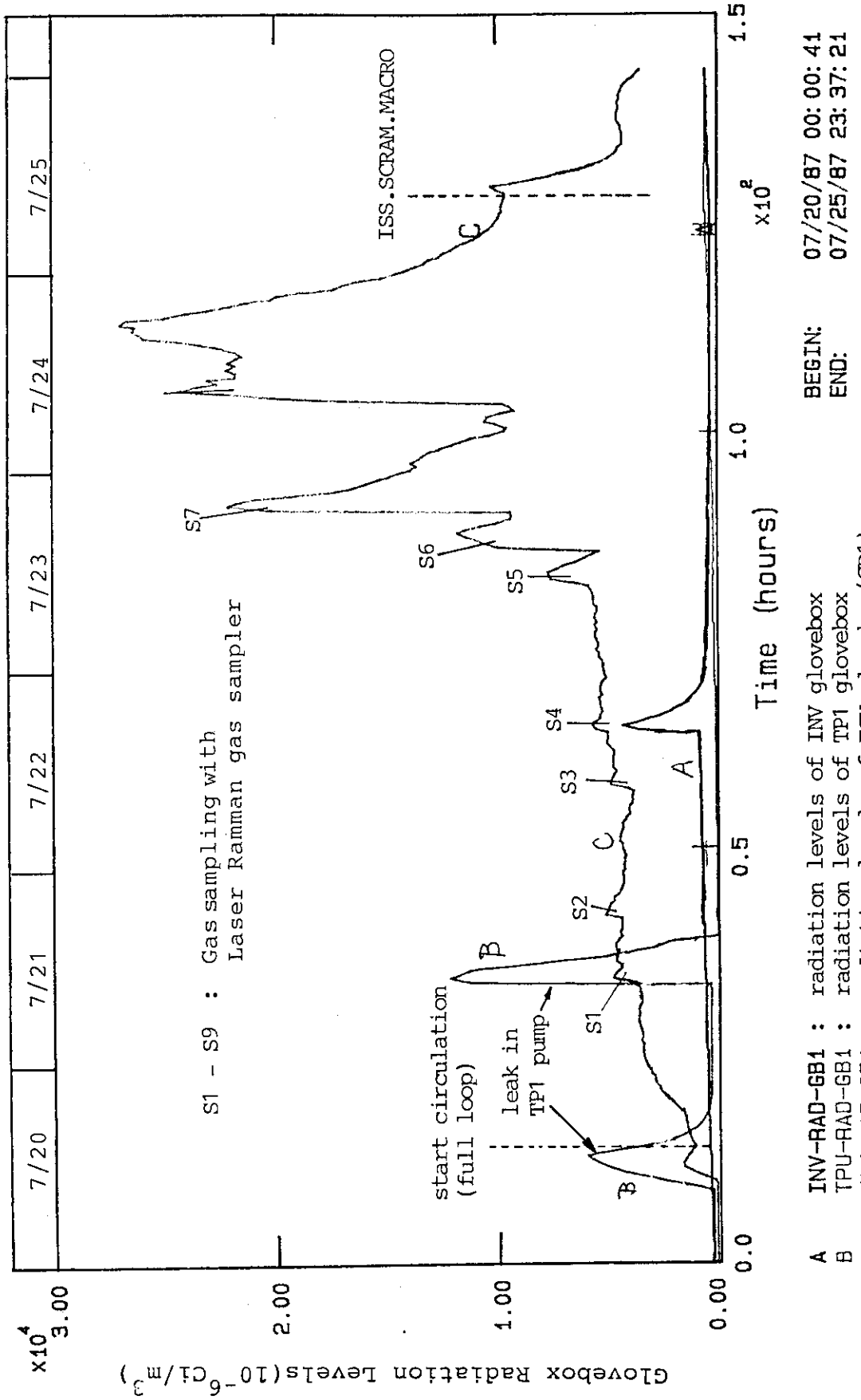


Fig. 3.5 Glovebox radiation levels of the INV, TPU and FCU

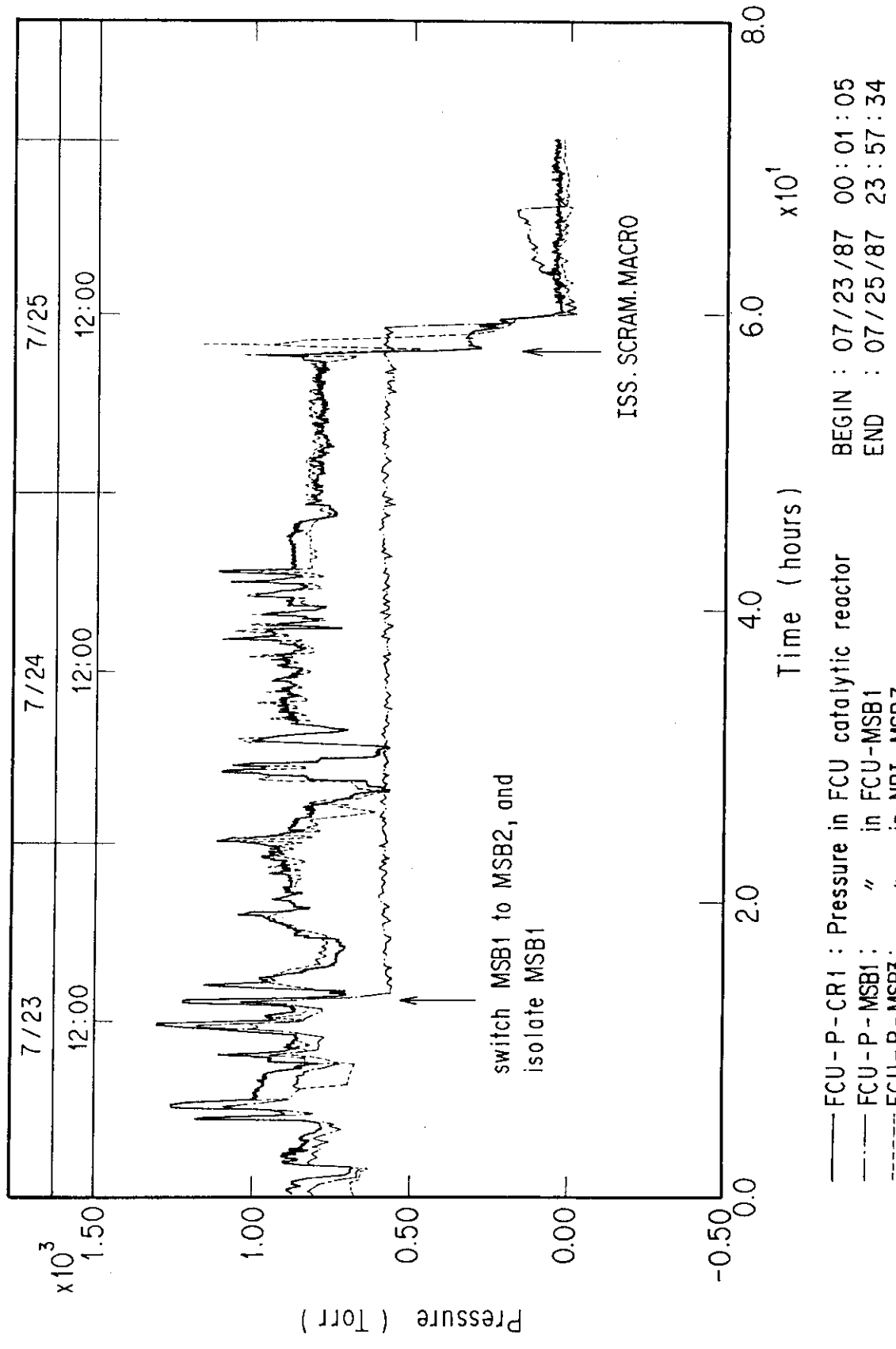
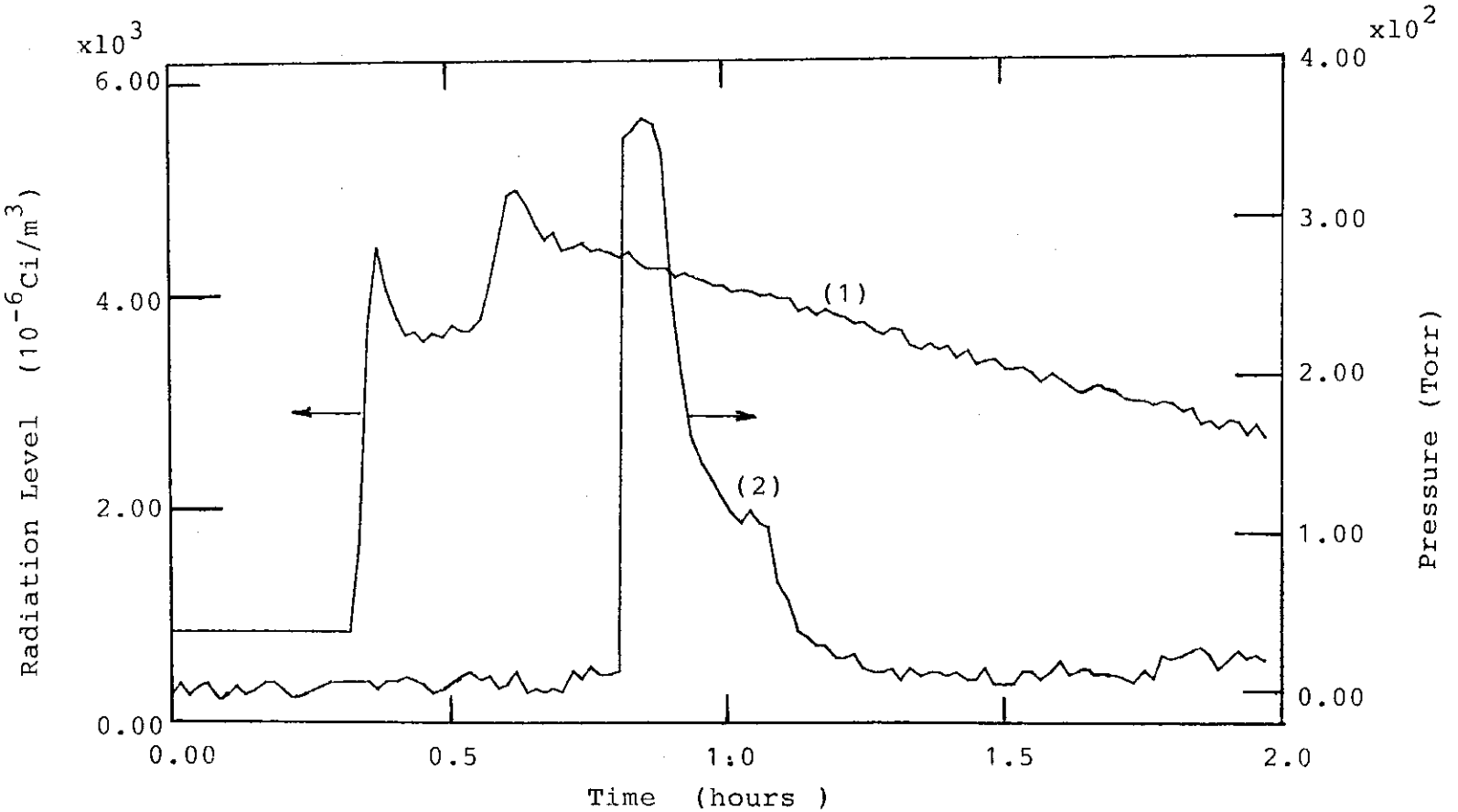


Fig. 3.6 Process pressures in the FCU



(1) INV-RAD-GB1 : Radiation level in INV-GB1

(2) INV-P-LOAD : Pressure of recovered gas in INV-LOAD

BEGIN: 07/22/87 16:00:46
END 07/22/87 17:59:05

Fig. 3.7 Relationship between the INV radiation levels and the INV process pressures

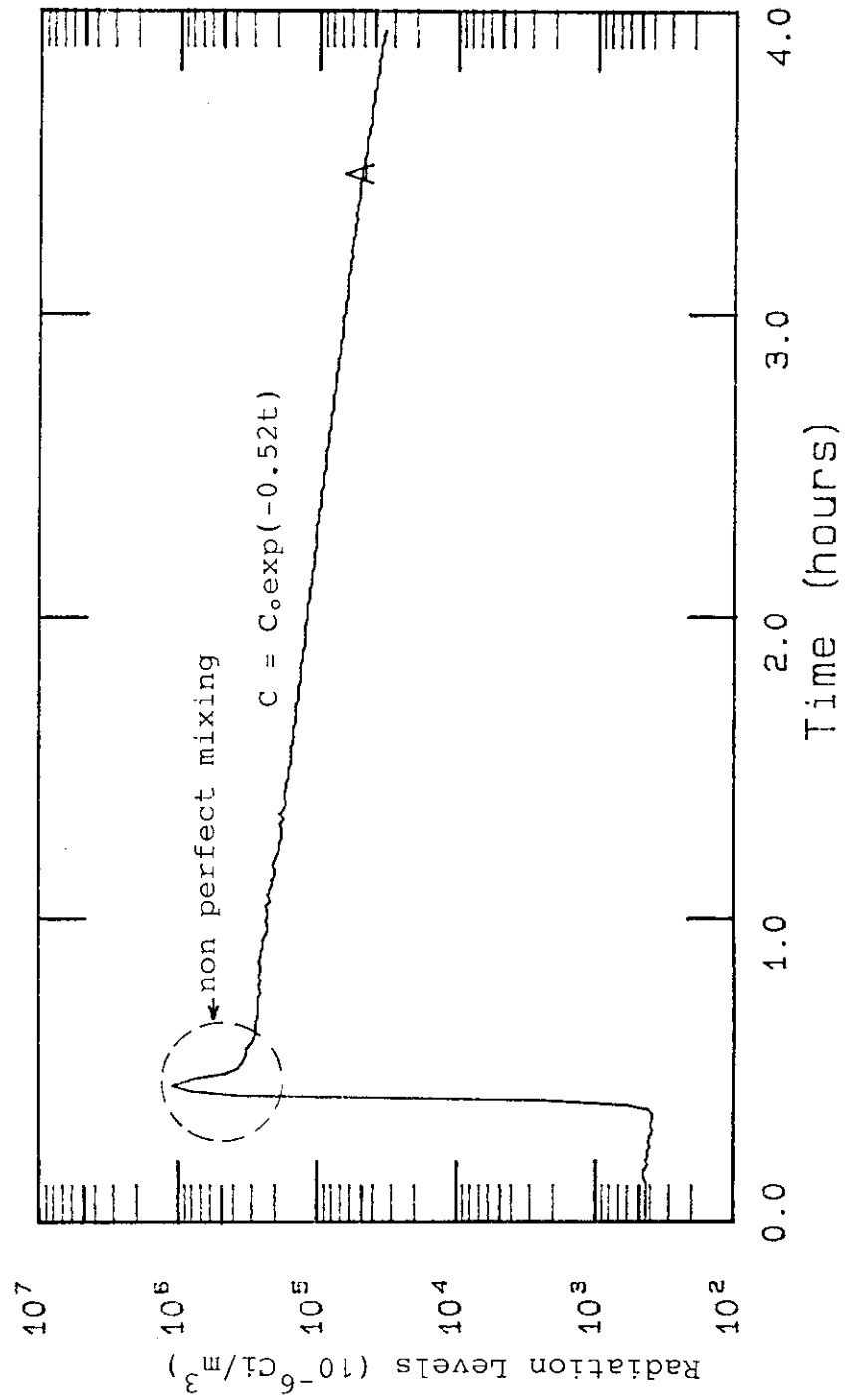


Fig. 3.8 Radiation levels in the TP1

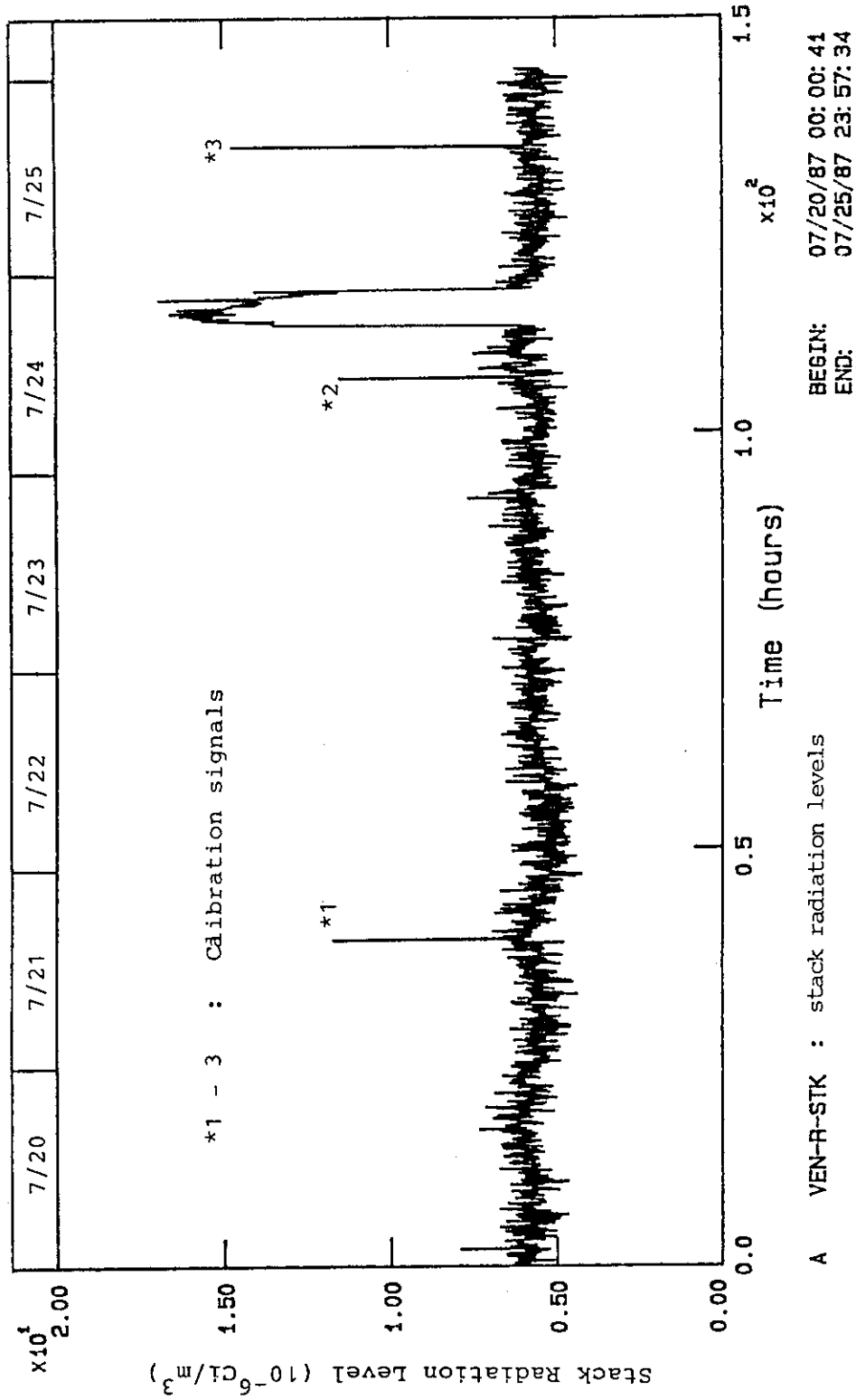


Fig. 3.9 Stack radiation levels during the run

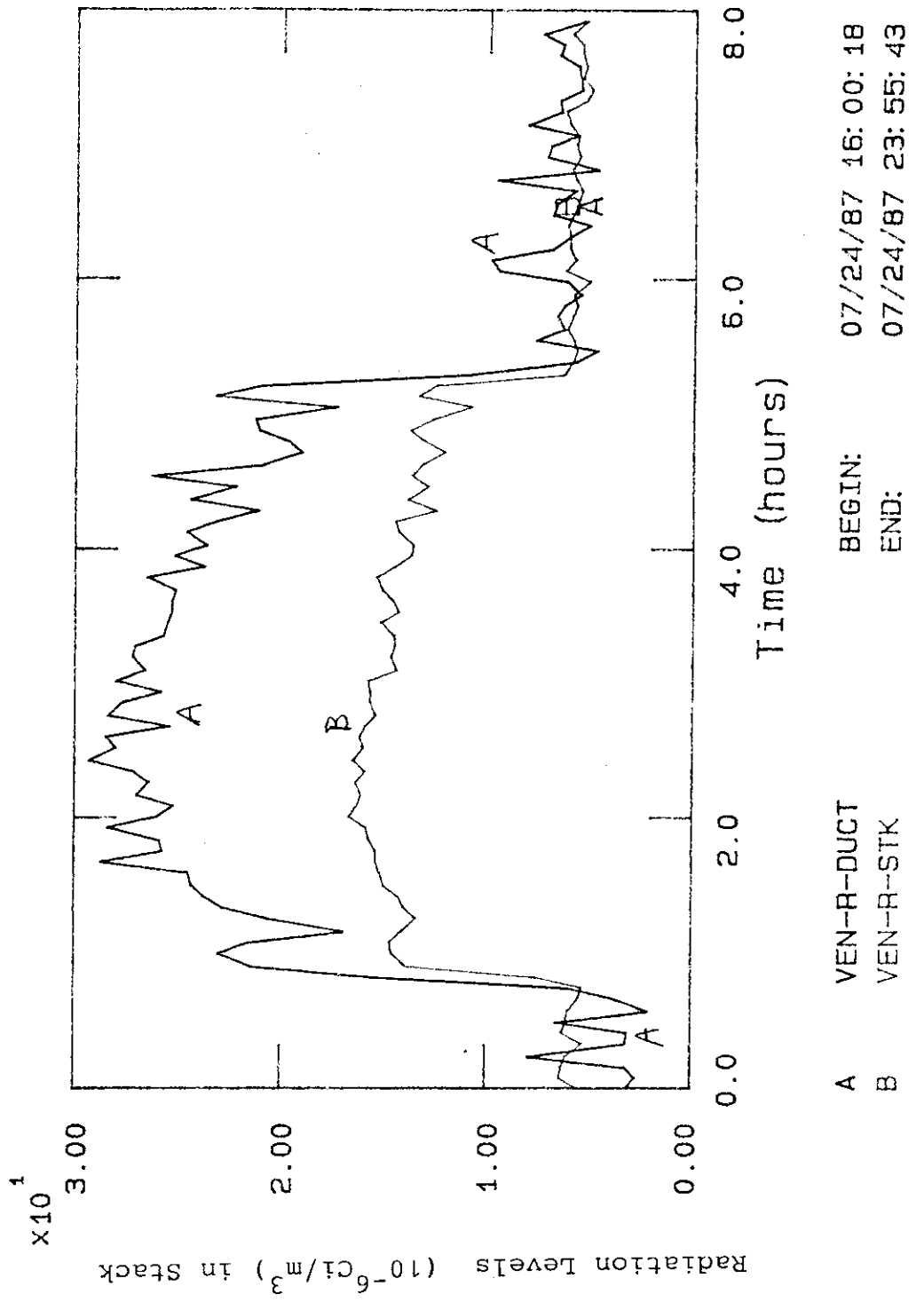
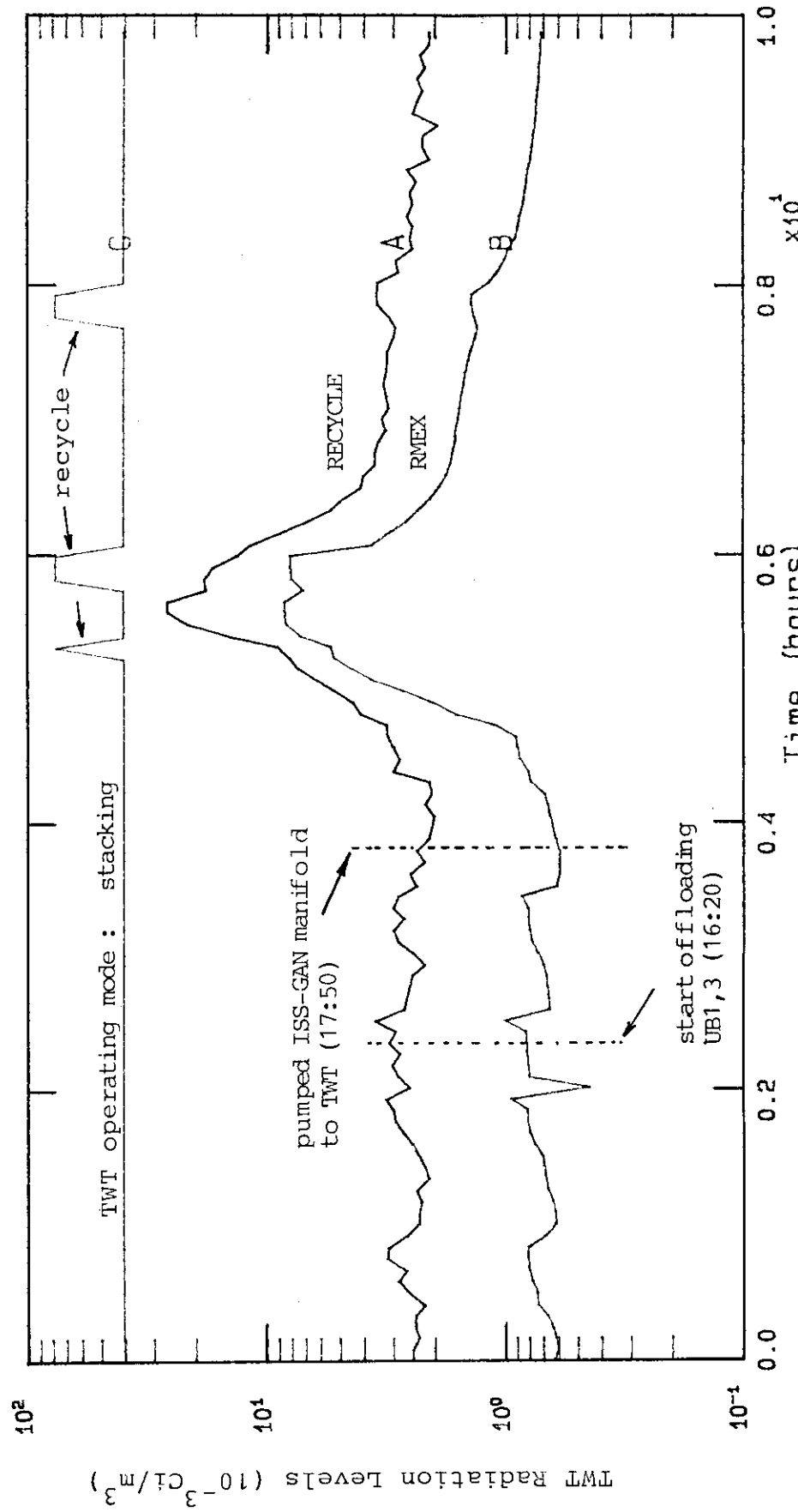


Fig. 3.10 Off-normal release from the TSTA stuck



A TWT-RAD-RECYCLE : TWT dryer outlet radiation level
B TWT-RAD-RMEX : TWT outlet radiation levels
C TWT-STATUS : status of TWT operation modes

BEGIN: 07/19/87 14:00:18
END: 07/19/87 23:52:36

Fig. 3.11 Relationship between TWT radiation levels and its operating status

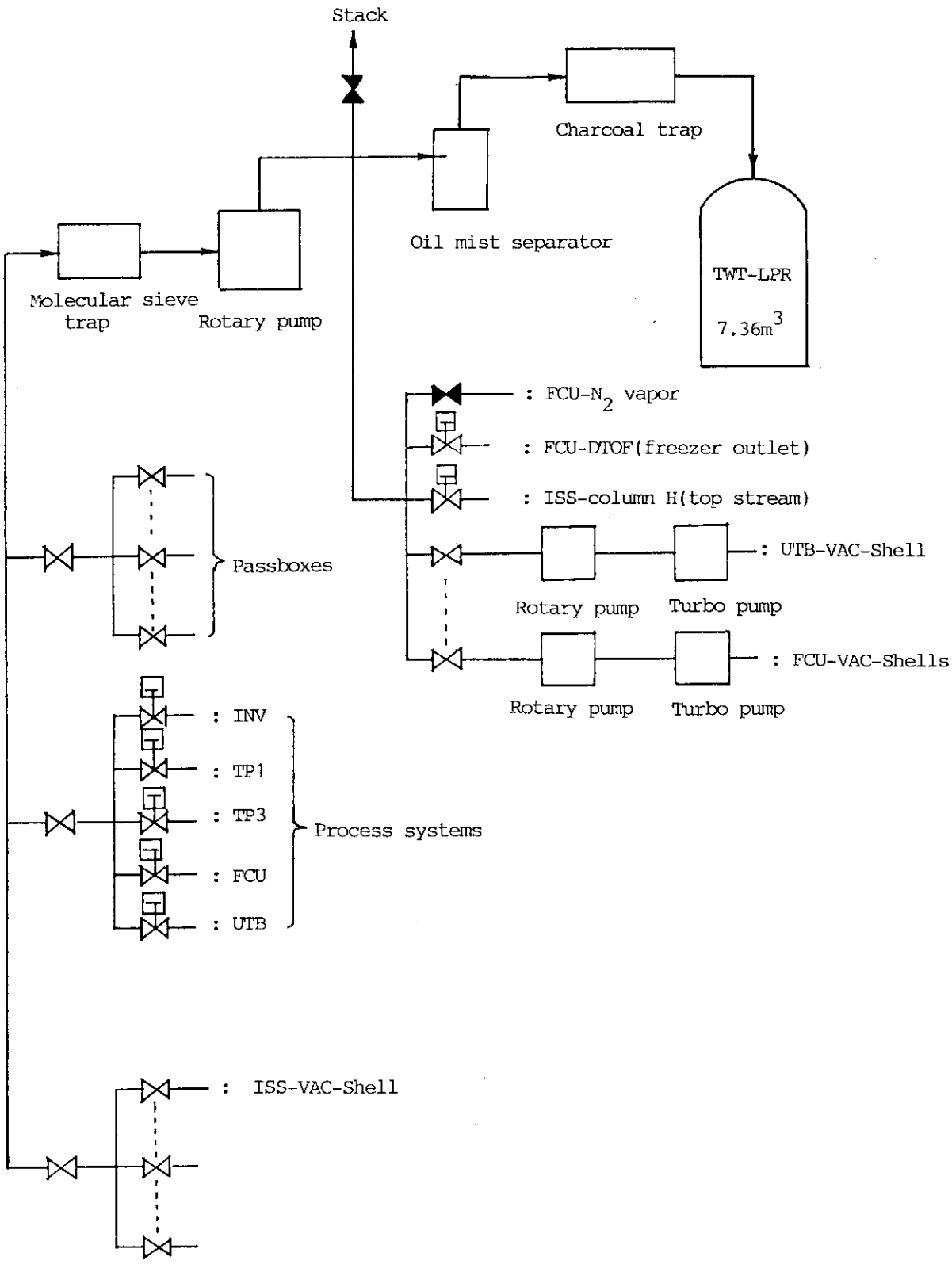


Fig. 3.12 Sources of exhaust gas transferred to the TWT low pressure receiver

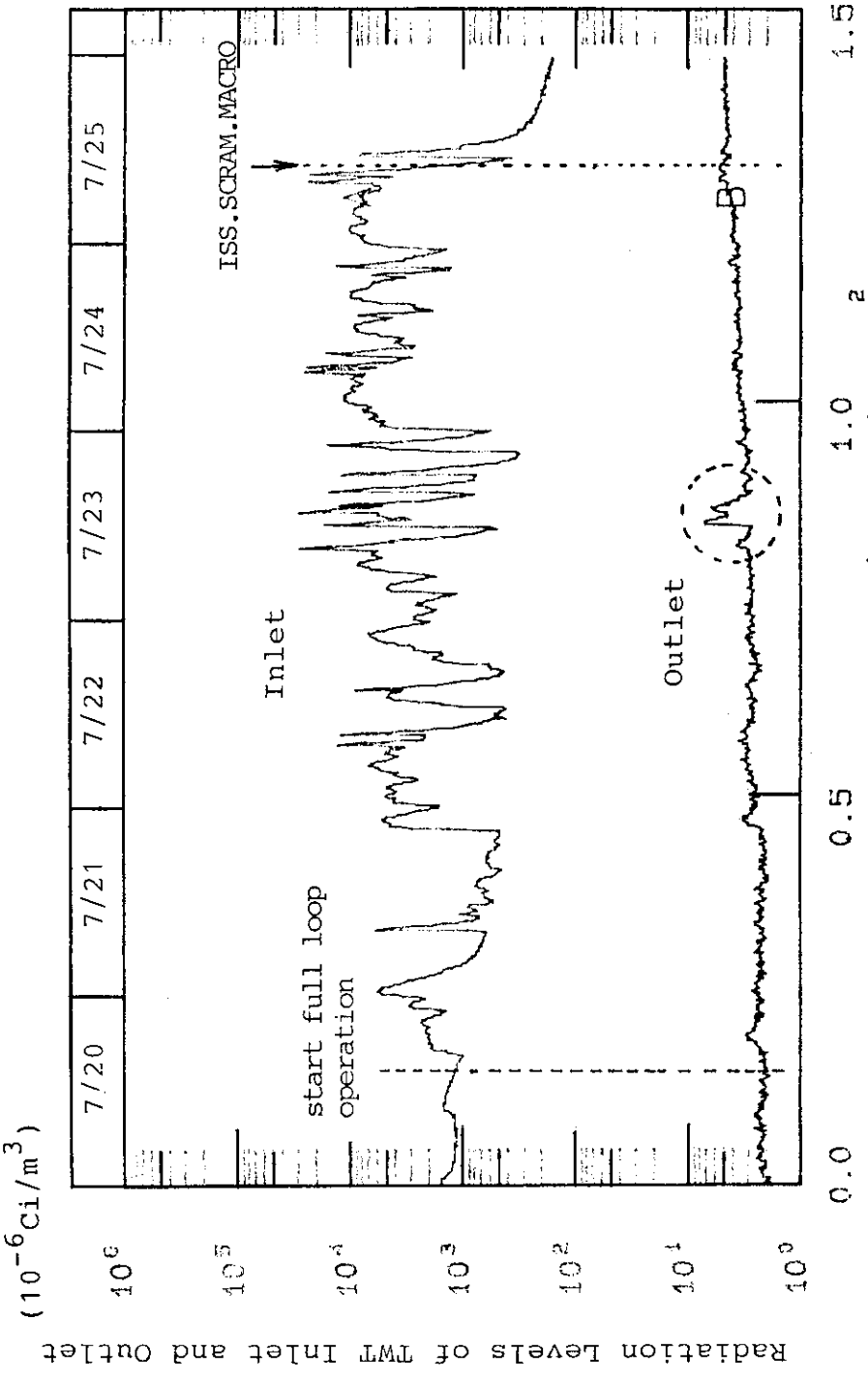


Fig. 3.13 Radiation levels in the inlet and outlet of the TWT

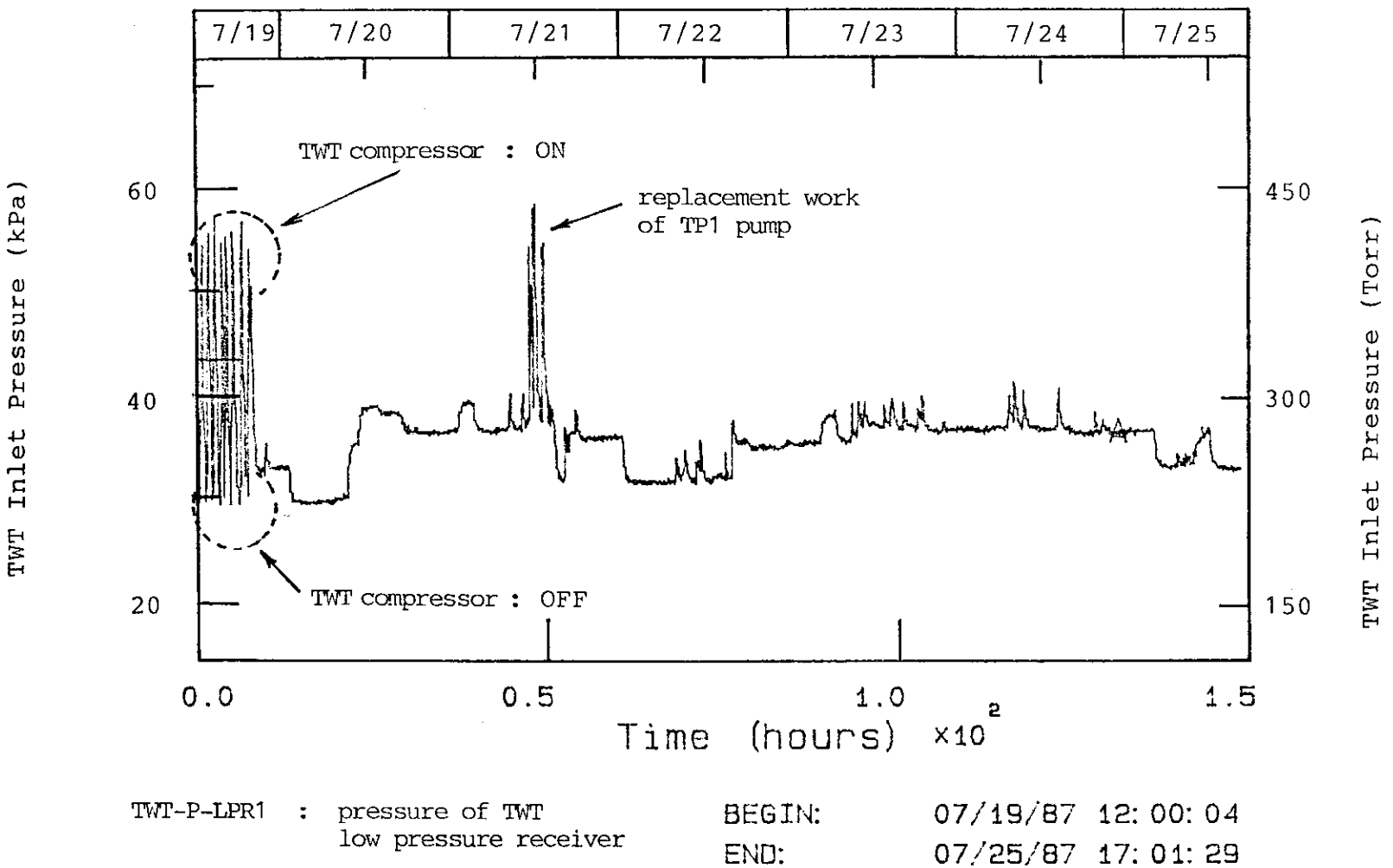


Fig. 3.14 Pressure variation at the TWT low pressure receiver

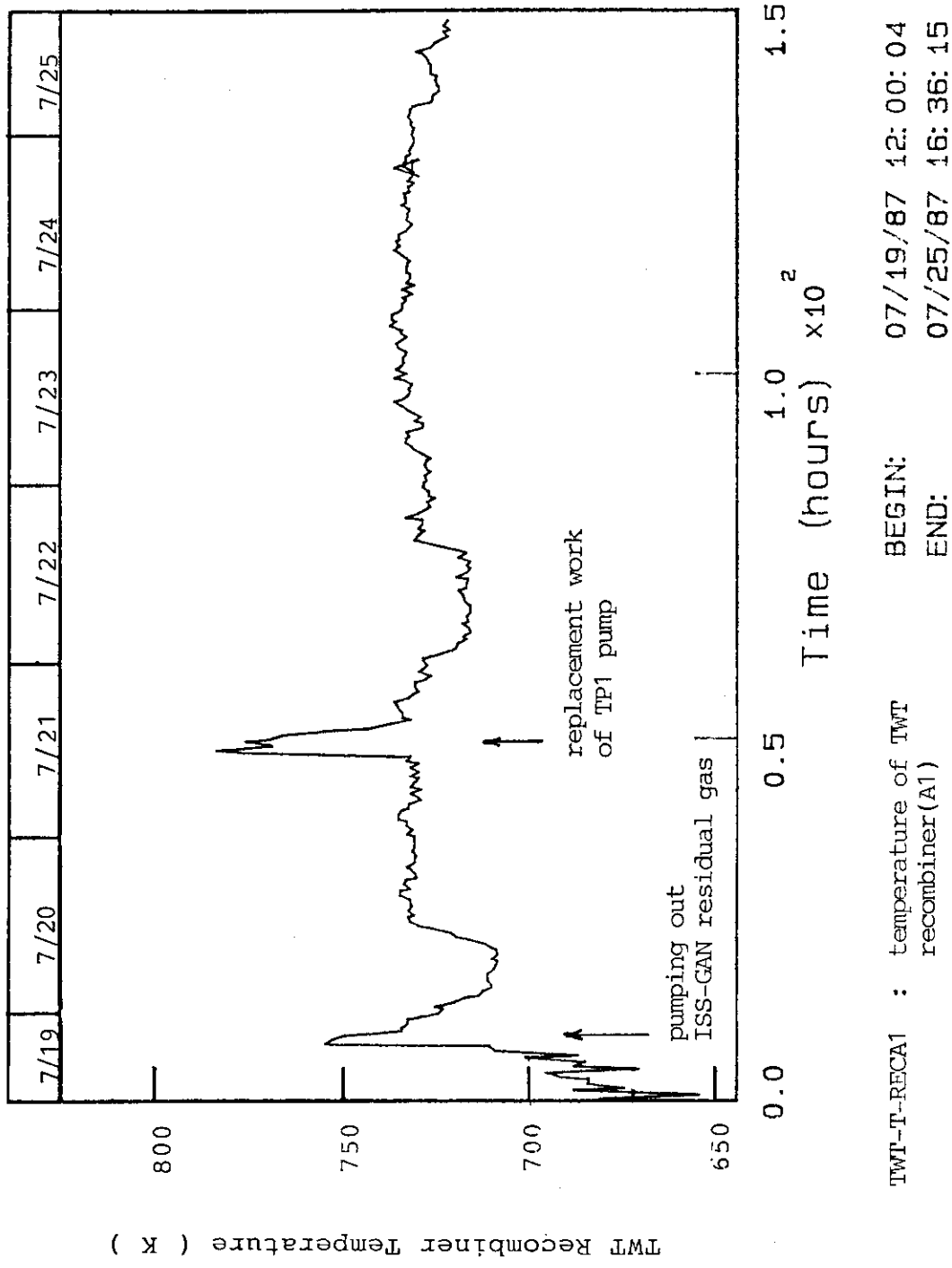


Fig. 3.15 Temperature profile of the TWT recombiner

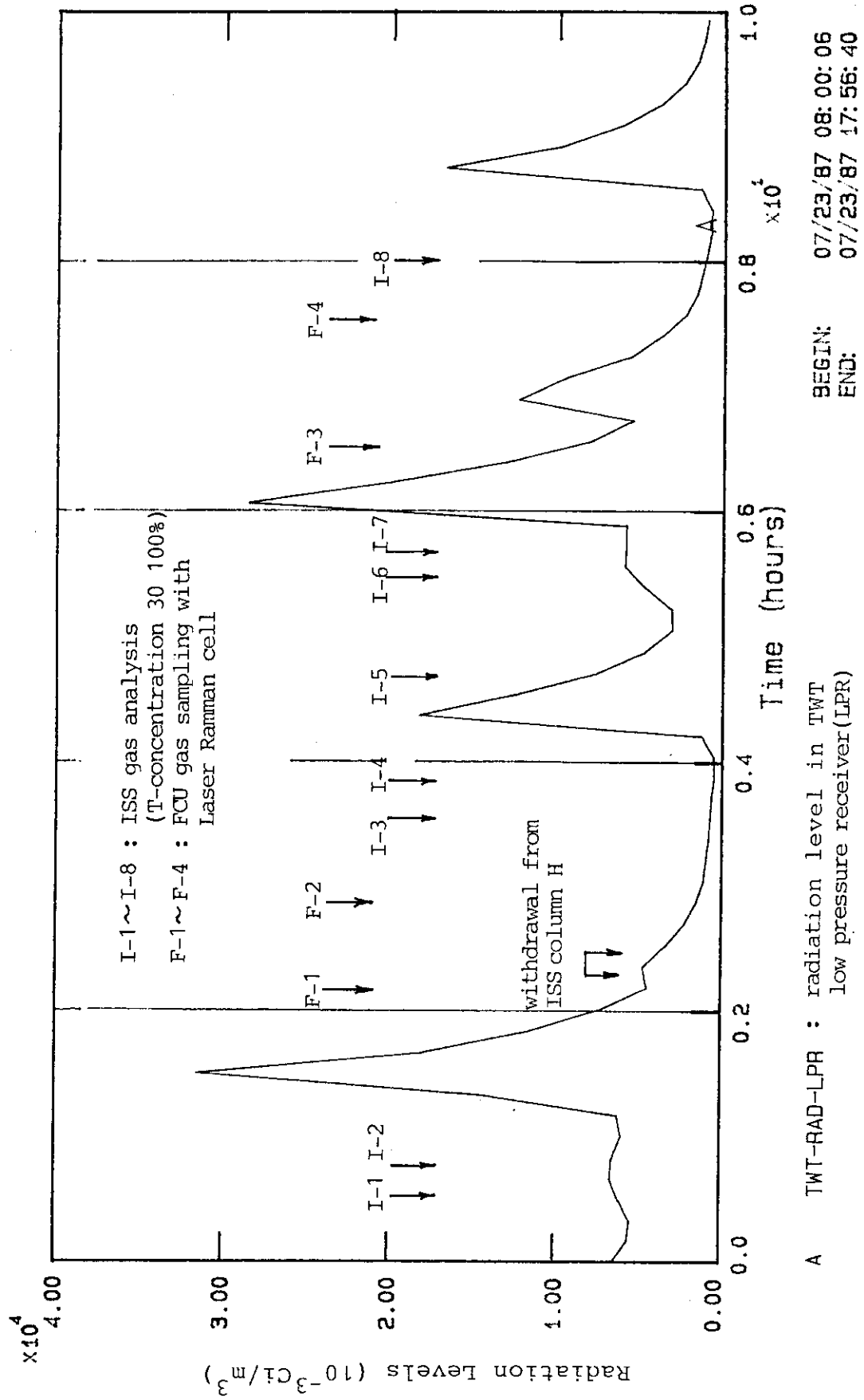


Fig. 3.16 Radiation levels in the TWT low pressure receiver at the gas analysis for the ISS and FCU

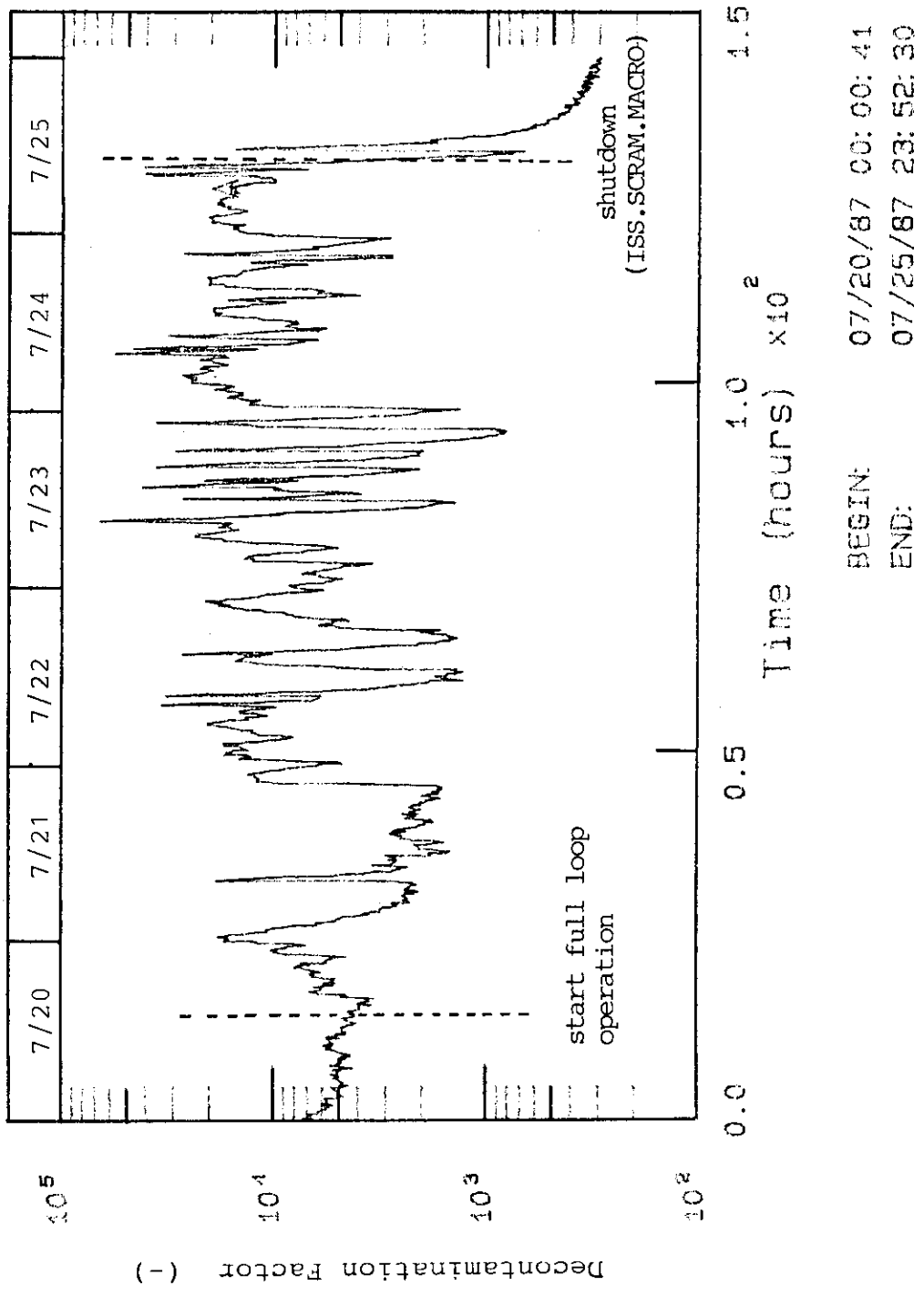


Fig. 3.17 Decontamination factor of the TWT during the run

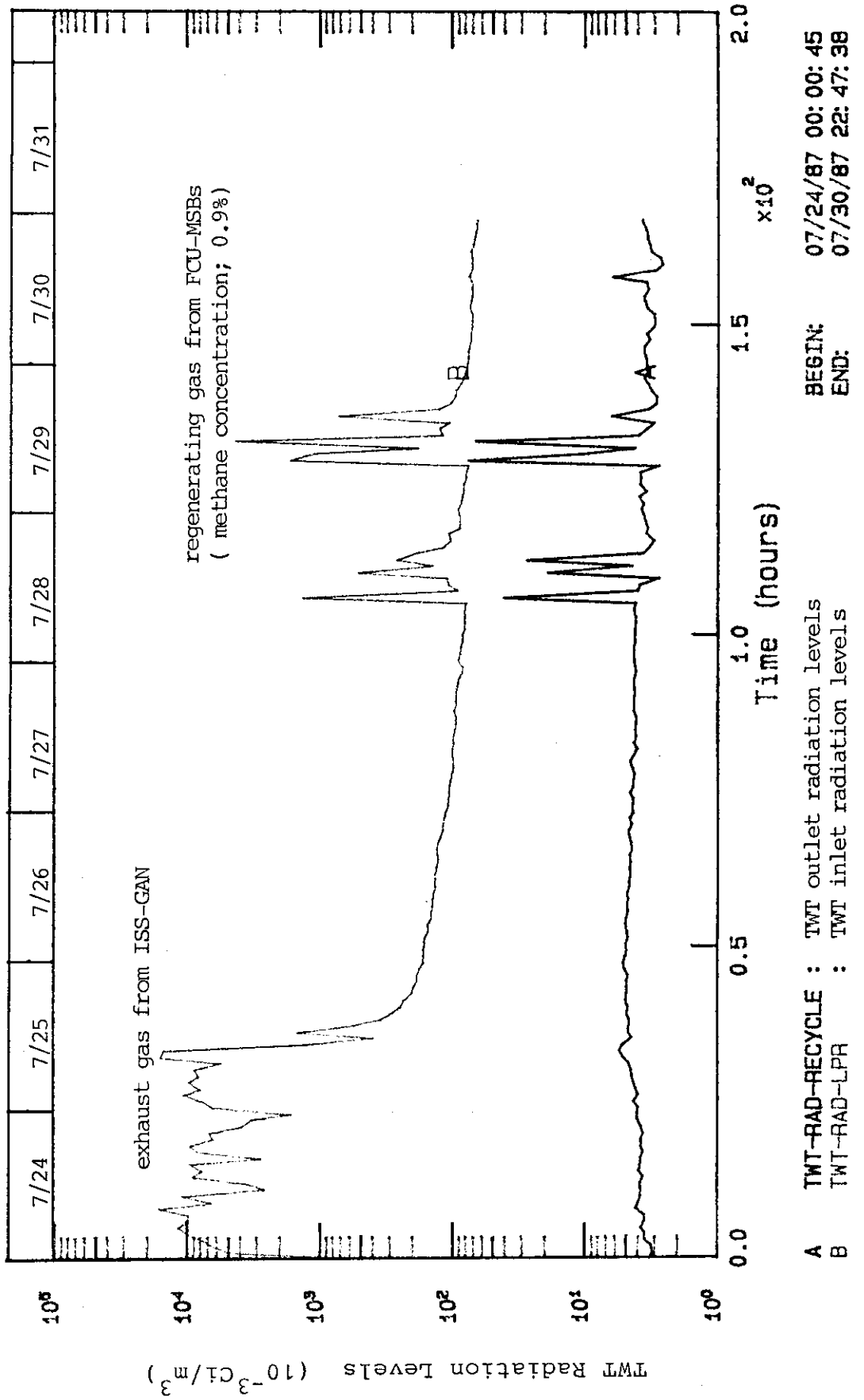


Fig. 3.18 Radiation levels at the inlet and outlet of the TWT

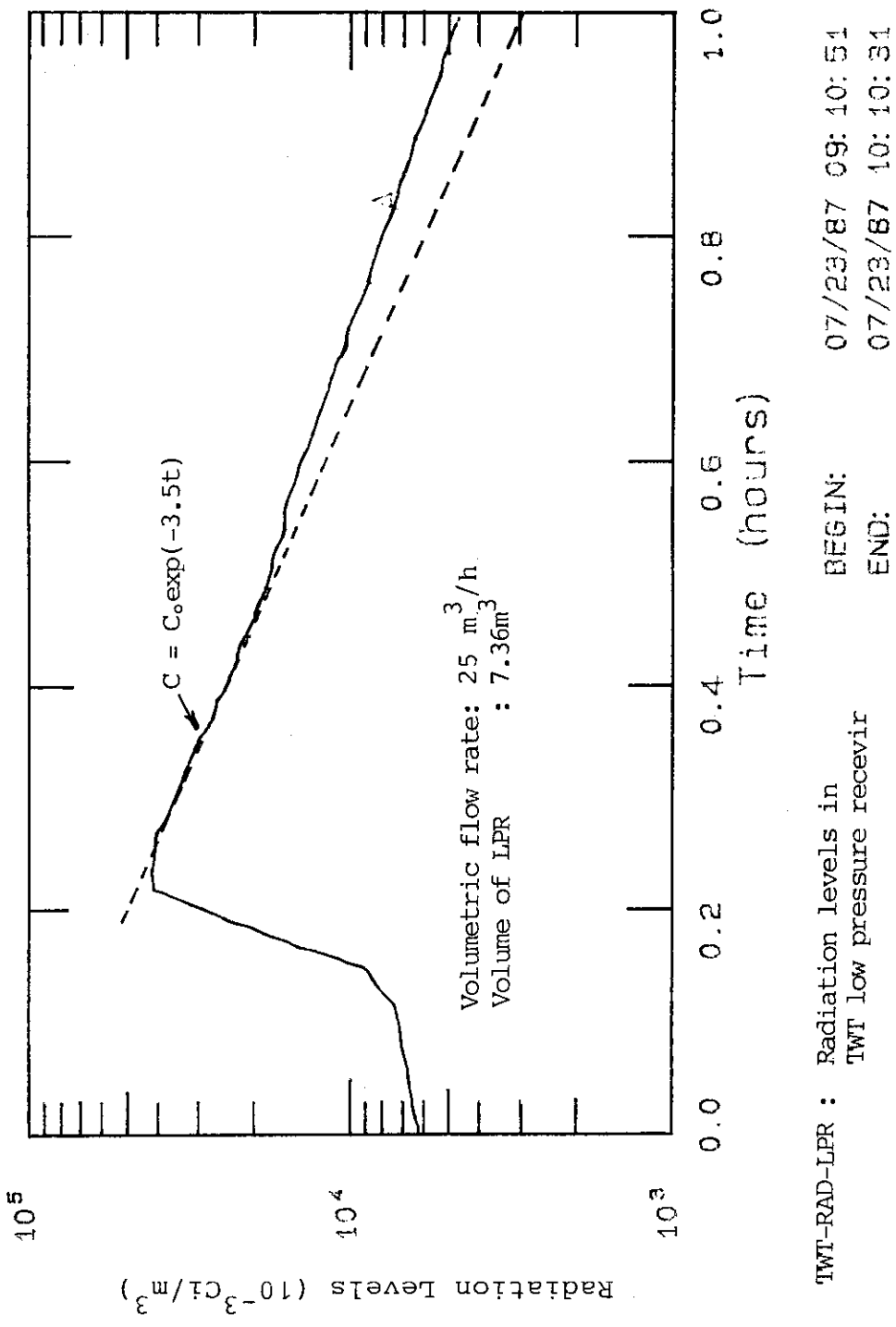


Fig. 3.19 Tritium reduction characteristics in the TWT low pressure receiver

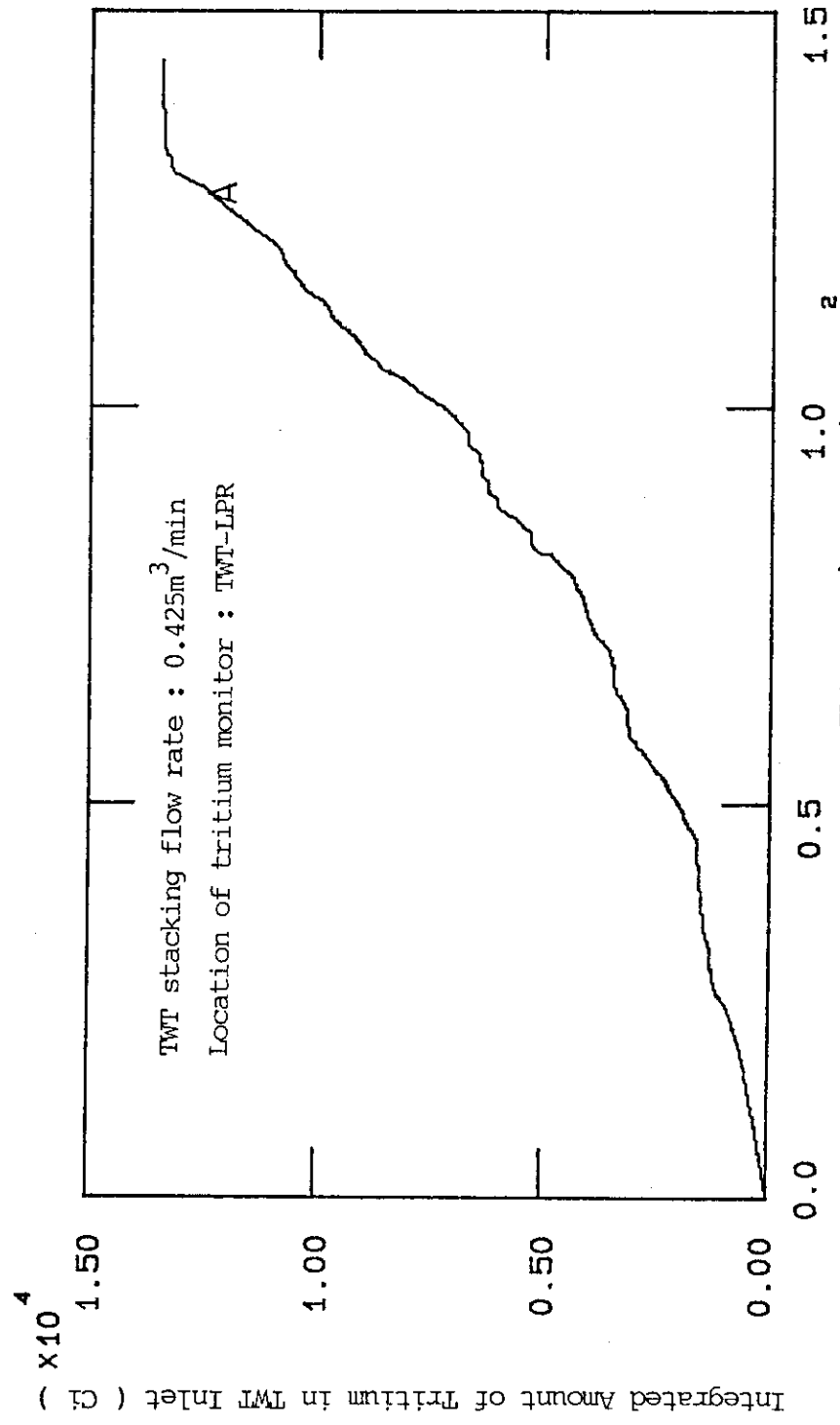


Fig. 3.20 Integrated amount of tritium in the TWT inlet

4. RESULTS OF SYSTEM SHUTDOWN

4.1 TEST OF EMERGENCY ISS SCRAM PROGRAM

Instead of the ordinary manual shutdown procedure for offloading H-D-T mixture in the ISS to the UTB, a test of the validity of the ISS.SCRAM.MACRO on the MDAC control program was performed. This scram macro program was developed for an ISS emergency scram in case of a serious problem such as the loss of cryogenic helium refrigerant.

The program is as follows(see Figure 4.1):

(i) Opening inter-connecting valves between ISS and UTB
```
set ISS-CD-EVIA open ;  column I to UB1
set ISS-CD-EVHA open ;  column H to UB2
set ISS-CD-EVDA open ;  column D to UB4 and 5
set ISS-CD-EVTA open ;  column T to UB3
```
(ii) Full opening of column inter-connecting valves by flow controllers
```
set ISS-CF-CLIA 5000 ;  column I top flow
set ISS-CF-CLDB 500  ;  column D bottom flow
set ISS-CF-CLTB 5000 ;  column T bottom flow
```
(iii) Turn off reboiler heaters of columns
```
set ISS-CW-HTIB  0   ;  column I heater
set ISS-CW-HTHB  0   ;  column H heater
set ISS-CQ-CLD  61   ;  column D heater
set ISS-CQ-CLT  61   ;  column T heater
```
(iv) Turn off condenser heaters
```
set ISS-CP-CLIA  0   ;  column I condenser
set ISS-CP-CLHA  0   ;  column H condenser
```
(v) Full opening of column inter-connecting valves by pressure controllers
```
set ISS-CP-CLDA  0   ;  column T top flow
set ISS-CP-CLDA  0   ;  column D top flow
```
(vi) Full opening of column inter-connecting valves by liquid level controllers
```
set ISS-CQ-CLI   0   ;  column I bottom flow
set ISS-CQ-CLH   0   ;  column H bottom flow
```

The procedures from (i) through (vi) were successively carried out with this scram macro after completion of some necessary preparation. They were:

(i) Because this is a functional test of the scram macro program, adjustment of inlet valves on the UTB was done to avoid migration of the uranium fine powder in the beds(UBs) due to the rapid flow of H-D-T mixture from the ISS,

(ii) The ISS process controllers on the local control panel were set to MDAC control,

(iii) The set value of the high temperature alarm on the helium refrigerator was changed to a higher value.

After execution of the ISS.SCRAM.MACRO the following complementary operations were performed:

(i) Scram TP3 to stop gas circulation (full loop),

(ii) Isolate ISS from the FCU and TP3 by closing

valves CLTA, CLTB AND CLIC,
(iii) Fully open manual valves on the UBs inlet paths,
(iv) Warm up reboilers of columns I and H by increasing reboiler heater power,
(v) Increase gradually the helium refrigerant temperature to enhance warmup of each column,
(vi) When the ISS pressures reached 300 Torr, reconnect the flow path between ISS and FCU and pumping H-D-T mixture in the FCU-MSBs(at liq.N_2 temperature) to the ISS,
(vii) Stop liquid nitrogen supply to the MSBs in the FCU and NBI, and make a flow path from MSB1 and 2 to the ISS surge tank through MSB3 to route mixture of impuriy and H-D-T desorbed from the FCU-MSBs.

4.2 RESULTS OF PROCESS SYSTEMS

The following figures shows variations of the major process parameters on the ISS, FCU and UTB during the shutdown operations.

Figure 4.2, outputs of the reboiler heaters in each column, shows that output of the columns I and D heaters were not turned off with the SCRAM.MACRO. The control switches of these heaters on the local panel might not have been previously changed to the computer control mode. The heater on column H was turned on soon after execution of the SCRAM.MACRO because its liquid level was much higher than the control level(60 mm). The heater output(approximately 40W) on column I was also maintained until its liquid level dropped to zero.

Figure 4.3 shows liquids in the reboilers of each column decreased to zero within 25 min after execution of the SCRAM.MACRO. The variation of the column D liquid level reveals electrical problems on this instrument.

Figure 4.4 shows that pressures of all columns immediately dropped 200-300 torr by execution of SCRAM.MACRO, but increased rapidly to 300-500 Torr(columns D and T) and to 1000 Torr(columns I and H) depending on the amount of liquid in each column. It can be concluded that process loop pressures of less than atmospheric pressure can be achieved in about 60 min.

Figure 4.5 shows pressures in the FCU and NBI. The pressure increase of the NBI molecular sieve bed after execution of the SCRAM.MACRO was caused by the pressure increase in columns I and H.

Figure 4.6 shows a rapid temperature rise due to the exothermic reaction between H-D-T mixture and uranium beds that occurred immediately after the execution of the SCRAM.MACRO. The temperature level on UB-3 connected to column T, which is the tritium enriching section in the ISS, was lower than that of the others due to a relatively small H-D-T inventory in this column. The UB-3 temperature remained constant because of the tritium decay heat from uranium tritide.

From this test, the ISS.SCRAM.MACRO was proved to be

effective as the ISS safety control program.

4.3 RESULTS OF SAFETY SYSTEMS

4.3.1 SECONDARY CONTAINMENT SYSTEM(SEC)

Figure 4.7 shows glovebox radiation levels of the FCU and ISS during process loop shutdown operation.

The radiation level of the FCU-GB1 slightly increased to 11×10^{-3} Ci/m^3 with increase of FCU pressures (up to about 1000 Torr) during preparation for the ISS.SCRAM.MACRO, and started to decrease after the execution of the ISS.SCRAM.MACRO (see Figure 4.5). The location of the tritium leak has been identified as a FCU process instrument(oxygen meter) and plumbing(rupture disc connection).

The first two peaks observed in the ISS-GB2 occurred during gas analysis of ISS. This analysis system(ISS-GAN) has unidentified tritium leaks in its gas sampling manifold. The decrease in the third peak (peak value; 8×10^{-3} Ci/m^3) resulted from pumping sampling the manifold residual gas(drawn from ISS column T bottom; atom fraction of T was 92%; pressure was 600Torr) to the TWT.

Even though the pressure of the column I increased to about 1000 Torr, no off-normal release occurred in the ISS-GB1 during the shutdown operation.

4.3.2 TRITIUM WASTE TREATMENT SYSTEM(TWT)

Figure 4.8 shows radiation levels in the TWT. While there were three major increases of inlet radiation level, no increase of the outlet(average 2×10^{-6} Ci/m^3) was observed. The sources of the first to third peak were exhaust gas from ISS-GAN, glovebox purge gas from ISS-GB1, ISS-GB2 and FCU-GB1, and pumped gas from ISS-GAN(sampled gas from ISS column T bottom), respectively. Because the reduction curves of these curves show almost the same rate, the reduction rate can be expressed by a function $C = C_s \exp(-2.8\ t)$. The value of exponential term, which is the volumetric change ratio of tritium in the TWT low pressure receiver LPR, determined from this figure is smaller by 20% than that determined from the flow rate of the TWT compressor(25.5 STP-m^3/hr) and the volume of the LPR(7.36m^3). This difference is considered to result from the measuring position of the tritium monitor installed in the LPR as well as the mixing conditions of tritium in the LPR. From the radiation peak from pumping the ISS-GAN manifold, the amount of tritium and the volume of the manifold can be determined as 70Ci and 40 cm^3(assuming the sampling manifold temperature was 298K), respectively.

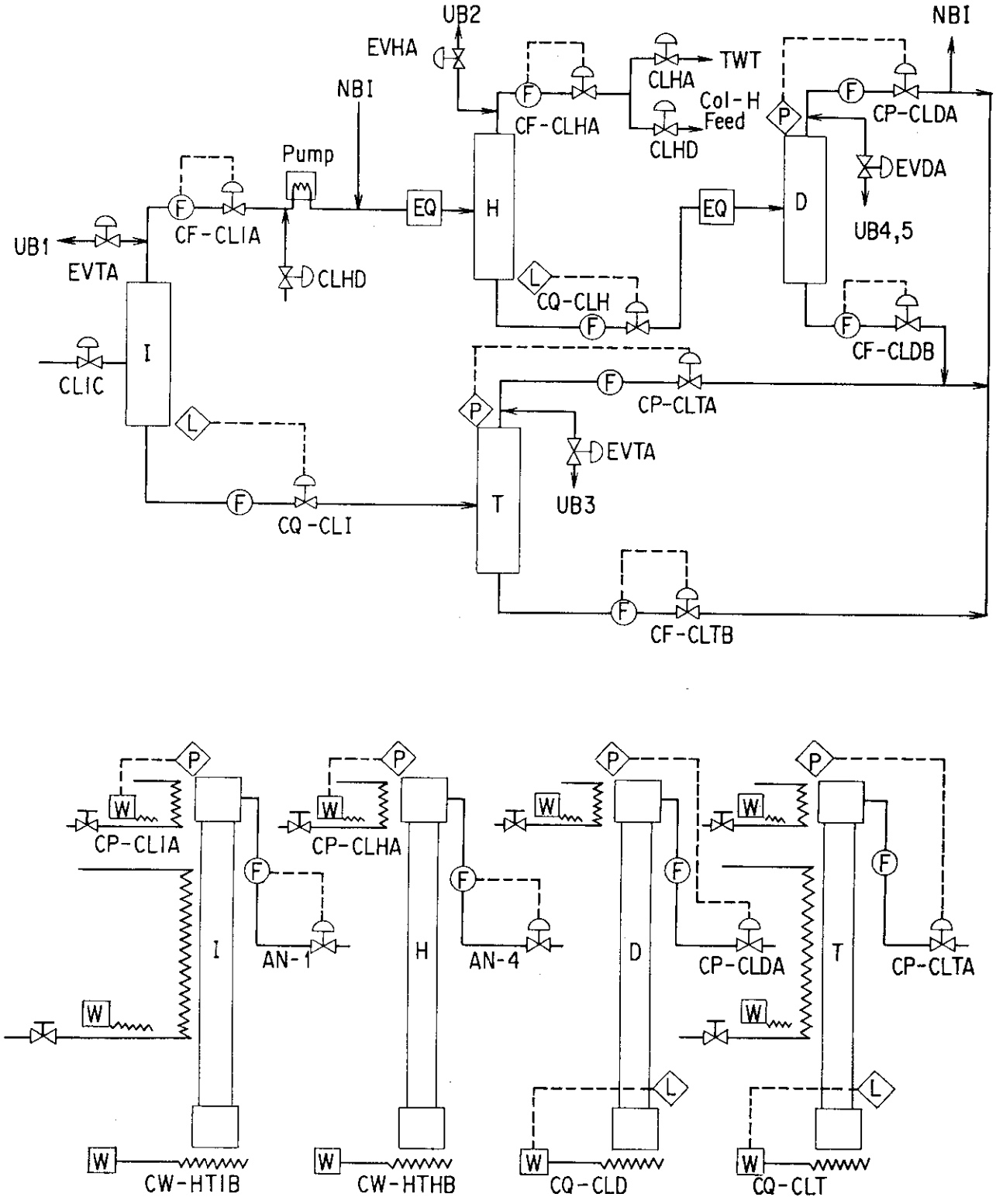


Fig. 4.1 Control system of the TSTA ISS

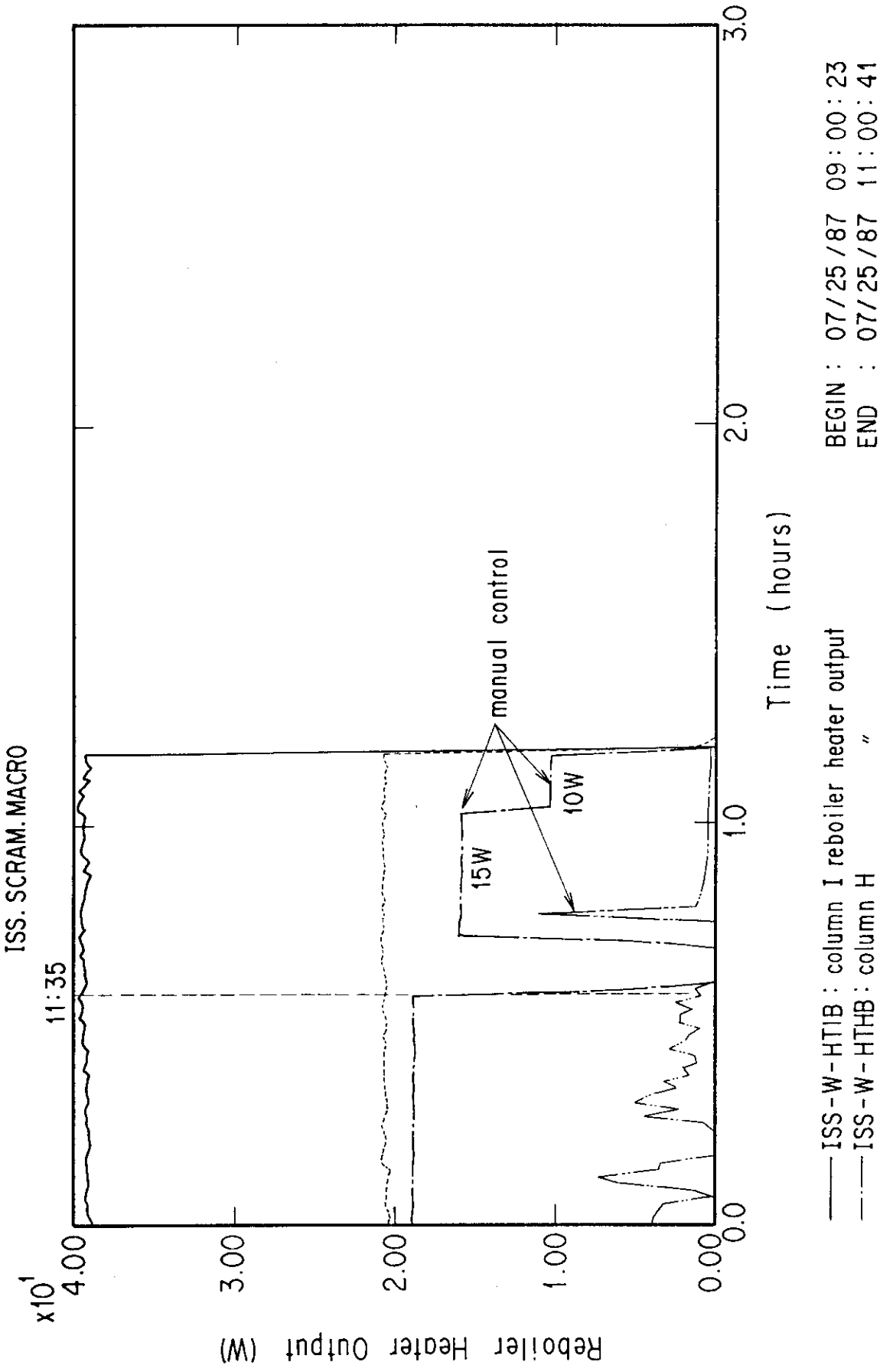


Fig. 4.2 Variation of the ISS reboiler heater output

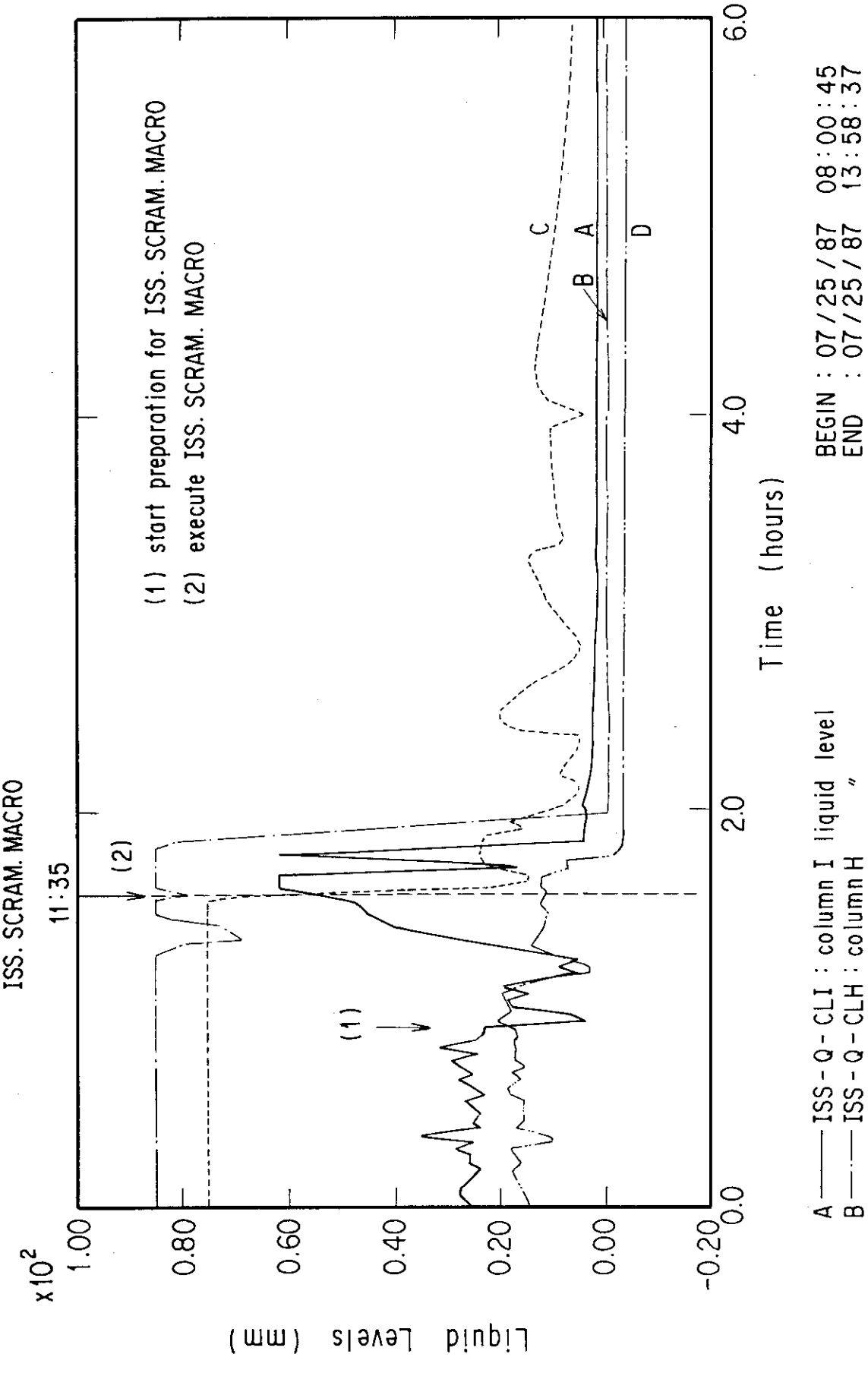


Fig. 4.3 Variation of the liquid levels in the ISS reboilers

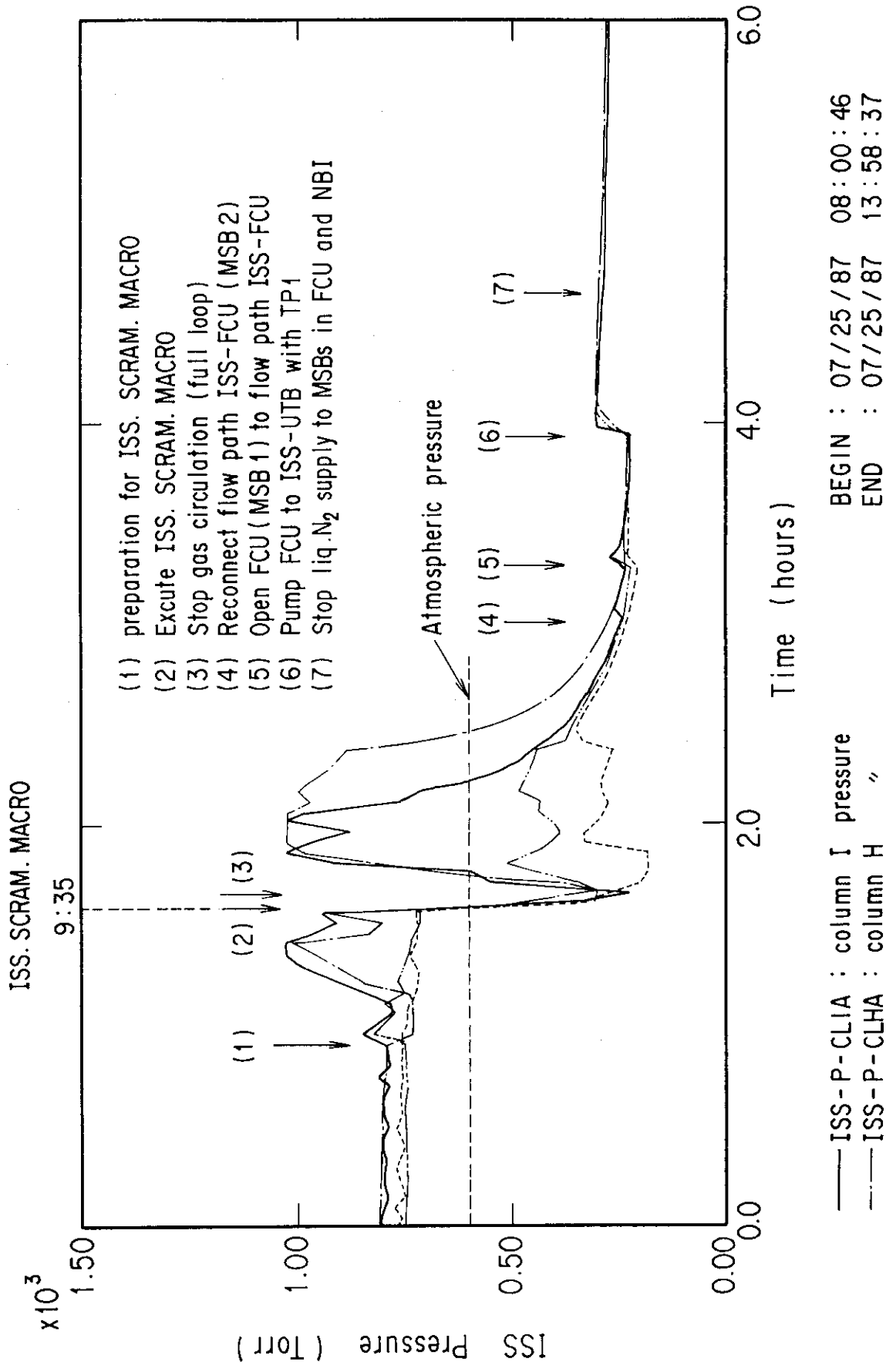


Fig. 4.4 Variation of the ISS column pressures

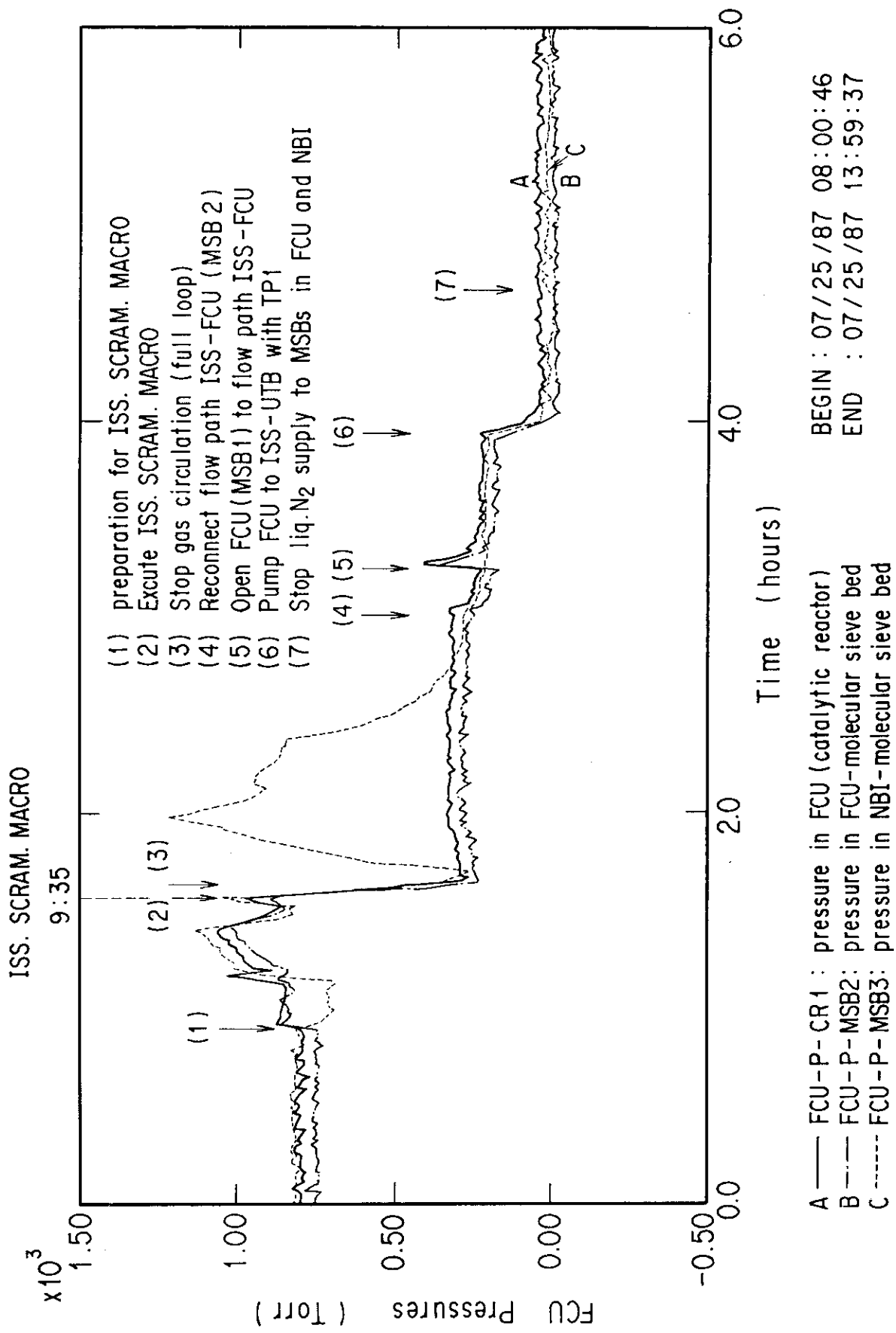


Fig. 4.5 Variation of the FCU process pressures

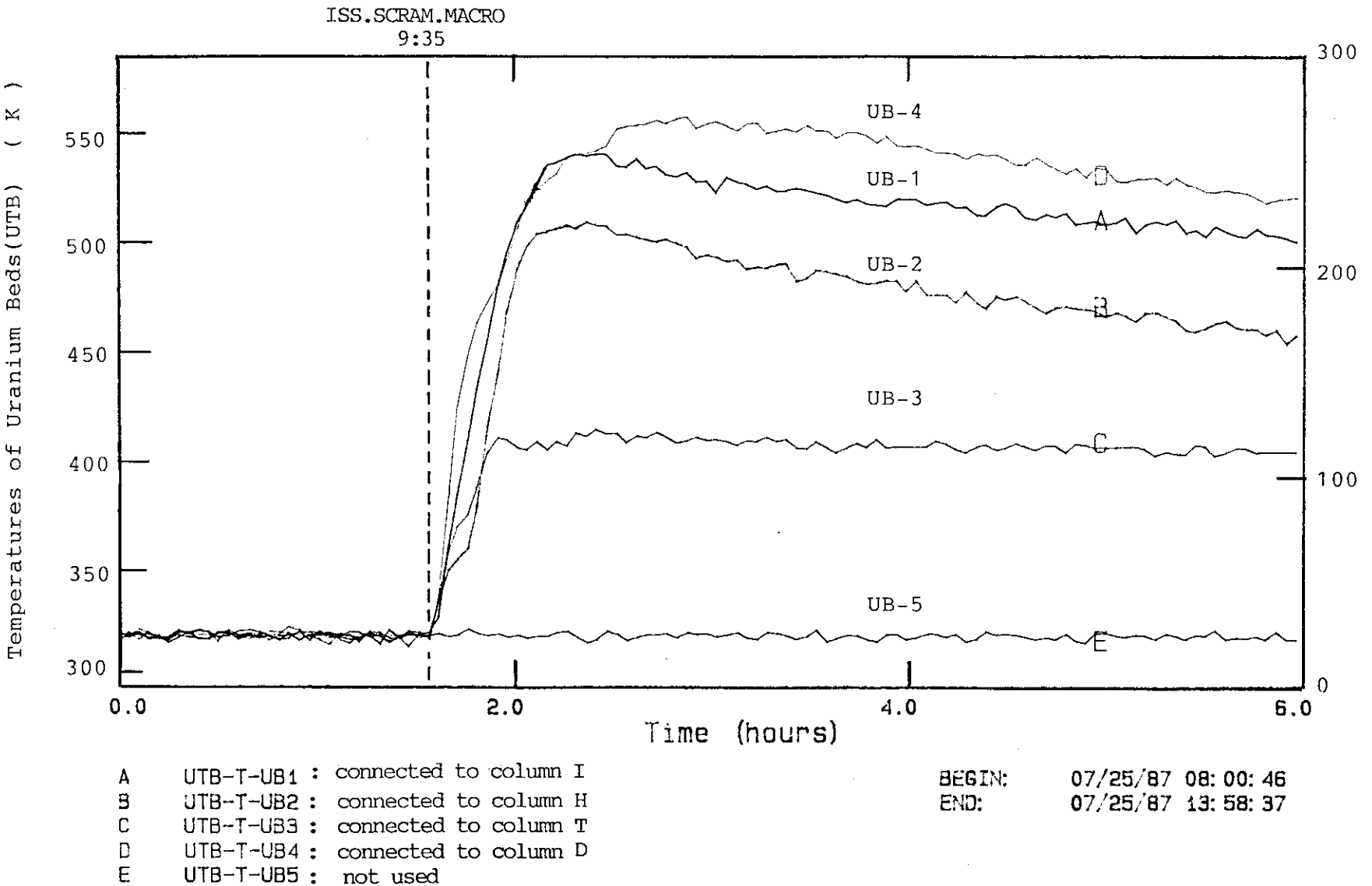


Fig. 4.6 Temperatures of the UTB at shutdown operation

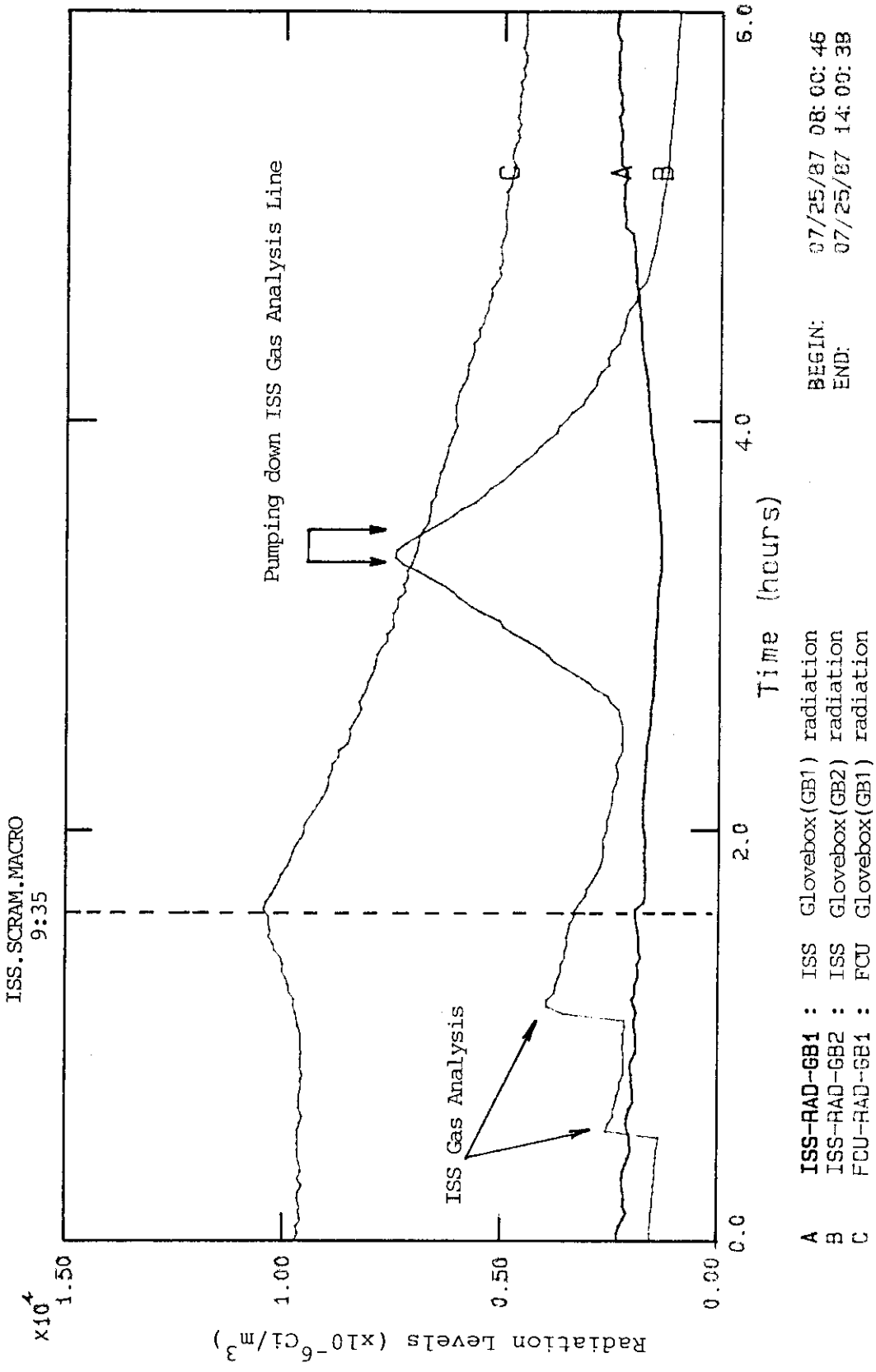


Fig. 4.7 Radiation levels of the ISS and FCU at the shutdown operation

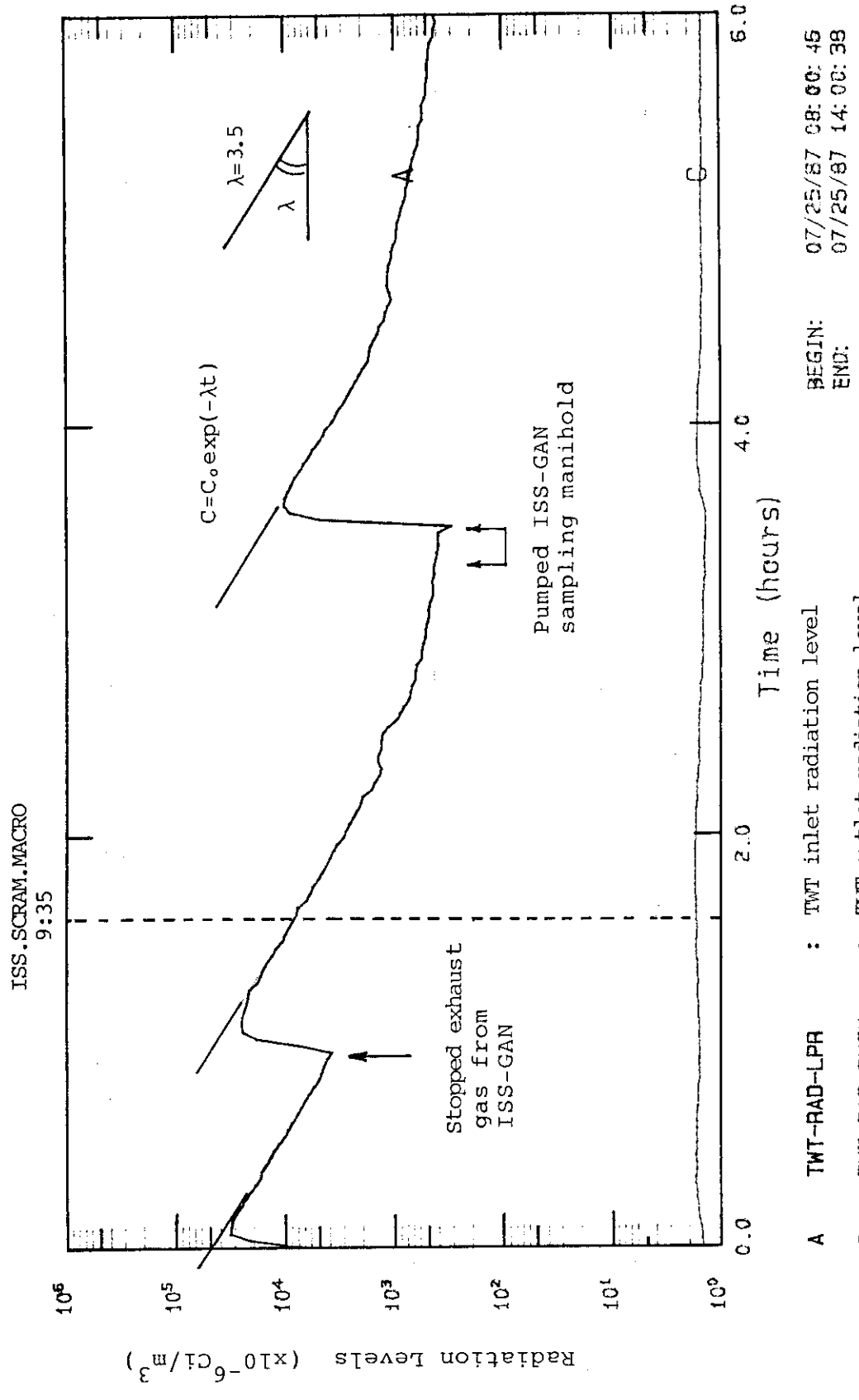


Fig. 4.8 Radiation levels in the TWT at the shutdown operation

5. CONCLUSION

This milestone run was performed as the resumption of the milestone run of June, which was halted due to mechanical failure of the cryogenic He refrigerator for the ISS. All primary objectives were achieved during this run without serious problems such as accidental release of tritium to the experimental room and the environment.

The major achievements on process systems are:

(1) Full loop operation with the FCU, NBI and ISS was performed with approximately 70g-mole of H-D-T mixture(tritium; 102g, D/T ratio; 1.7 - 1.3) for 115hrs.
(2) Impurity (nitrogen and methane) removal with the FCU frontend composed of cryogenic molecular sieve beds was successfully demonstrated. No plugging of the process loop at the ISS or FCU occurred during impurity injection for about 56hrs.
(3) The ISS was operated for 115hrs under cryogenic distillation conditions with the FCU and NBI return process. Withdrawals of ^3He, H_2 and HD from the top of column H, and D_2 from the top of column D were successfully carried out to adjust inventory of hydrogen and deuterium, and to remove ^3He from the process system. Pure tritium(5.5g-T_2) was recovered from the bottom of column T to a tritium gas cylinder(shipping container).

The issues of the safety systems are:

(1) There appeared several off-normal radiation levels in the process gloveboxes, but no tritium release into the experimental room was occured during the run. When the purge gas system of these gloveboxes was started(automatically), the tritium levels decreased with linearly. The reduction rate was expressed by the theoretical equation $C = C \exp(-0.5\ t)$, which can be derived from the perfect mixing model.
(2) The amount of tritium exhausted from the process loop to the TWT was estimated to be 7500 - 1300 Ci during this run. The amount of tritium exhausted from the ISS gas analysis was approximately 7500 Ci.
(3) There was no off-normal release of tritium from the TSTA process loop into the environment during this run. The total release measured with the stack monitor(bubbler system) was:
    July 16-22 ; HTO(240×10^{-3}Ci), HT(63×10^{-3}Ci)
    July 23-29 ; HTO(647×10^{-3}Ci), HT(624×10^{-3}Ci)

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