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ABSTRACT

The JET Active Gas Handling System (AGHS) was designed, built and commissioned to handle safely radioactive tritium gas mixtures, to supply tritium (T_2) and deuterium (D_2) to the JET torus, to process the exhaust gases with the main purpose to enrich and re-use T_2 and D_2, to detritiate tritiated impurities and to keep discharges far below the approved daily release limits. In addition, the AGHS had to supply the necessary ventilation air streams during maintenance or repair inside or outside of the AGHS building.

During the first Deuterium-Tritium Experiment (DTE1) at JET in 1997 the AGHS fulfilled all these tasks in an excellent manner. No unauthorised or unplanned tritium releases occurred and no operational delays were caused by the AGHS. In fact, this was the first true demonstration that quantities of tritium in the tens of grams range can be processed and recycled safely and efficiently in a large fusion device.

At the start of DTE1 20 g of tritium were available on the JET site. About 100 g of tritium were supplied from the AGHS to the users which necessitated the recycling of tritium at least five times. Approximately 220 tritium plasma shots were performed during DTE1. Large amounts of tritium were temporarily trapped in the torus.

This overview presents the performance of the whole AGHS during DTE1 as well as general aspects such as the preparation for DTE1; the quantities of gases supplied from the AGHS to the users and pumped back to the AGHS; tritium accountancy; interlock systems; failure of equipment; and gives detailed information of the gas processing in each subsystem of the AGHS.

As a consequence of the performance of the AGHS during DTE1 we can state confidently that the AGHS is ready for further Deuterium-Tritium Experiments.

1. INTRODUCTION

The JET tokamak and the connected gas handling systems were designed and built for the study of fusion reactor relevant operating conditions including the use of deuterium-tritium gas mixtures for plasma fuelling. Therefore, the design had to make provisions for remote maintenance (due to activation of components) and for the processing of radioactive tritium gas mixtures.

JET has successfully performed two tritium experiments, one at the end of 1991 with 0.2 g on site, designated Preliminary Tritium Experiment (PTE) [1] and one during the months May/June and September to November 1997 with 20 g on site, designated Deuterium-Tritium Experiment (DTE1) [2].

Tritium was injected for the first time into a large tokamak during the experiment in 1991, where the tritium was recovered and stored on uranium beds. In the DTE1 experiment, the amount of tritium gas injected into the torus was the highest achieved to date on a fusion research facility and the tritium on site was fully processed and recycled several times.

This paper will discuss the processing and the recycling of the tritium at JET.

1.1 The Active Gas Handling System (AGHS)

A special plant, designated the JET Active Gas Handling System (AGHS), was constructed to process and recycle the gases from the torus and Neutral Injectors. The AGHS is located in a separate building equipped with its own ventilation system and connected with the Torus via long gas transfer and pumping lines.

The gases collected from the Torus and the other systems are mainly the six hydrogen molecular types (H_2, D_2, T_2, HD, HT, DT); helium; other gases added to the plasma for temperature profiles and power control density; impurities such as hydro-carbons (mainly methane), generated by the interaction of the plasma with the first wall or by the interaction of the atomic tritium (generated by the tritium decay) with carbon on the surfaces of the primary containment; and water, nitrogen, oxygen, and argon from leaks.

The main processing steps of the gases in the AGHS are:

1) to pump the gases from the torus and Neutral Injector (NI) systems,
2) to separate impurities from hydrogen isotope mixtures,
3) to recover tritium from tritiated impurities,
4) to isotopically separate hydrogen isotope mixtures into pure T_2, D_2 and H_2, the former two for recycling to the torus and NI systems and the latter for discharge into environment
5) to store pure deuterium and tritium in uranium beds for further re-use,
6) to re-supply deuterium and tritium to the torus and NI systems.

2. GENERAL DESCRIPTION OF GAS PROCESSING AND RECYCLING IN ACTIVE GAS HANDLING SYSTEM (AGHS)

A schematic overview of the various gas streams from the torus and NI systems to AGHS, inside AGHS and back to the users is shown in Fig. 1.

The gases from the torus and Neutral beam Injection Boxes (NIBs) are pumped via the torus crown (ML1) and NIB crown (ML2), respectively, by either the Cryogenic Forevacuum (CF) or Mechanical Forevacuum (MF) systems. Tritium and oxygen in these gases can be monitored by tritium specific detectors and combustible gas monitors. During warm-up of the cryopumps of CF a separation of the pumped gases by distillation into helium, hydrogen and impurities is achieved. Helium and impurities are moved into Impurity Processing (IP) system for detritiation of tritium containing gas compounds. Hydrogen pumped by CF as well as the hydrogen recovered in IP are moved to the Intermediate Storage (IS) system prior to injection into one of the two hydrogen isotope separation systems: Gas chromatography (GC) and Cryogenic Distillation (CD). The product tritium and deuterium from the two separation systems are sent to the Product Storage (PS) system to be supplied to Neutral beam Injection Box at Octant 8 (NIB8) or to the tritium Gas Introduction Module on the torus (GIM15).

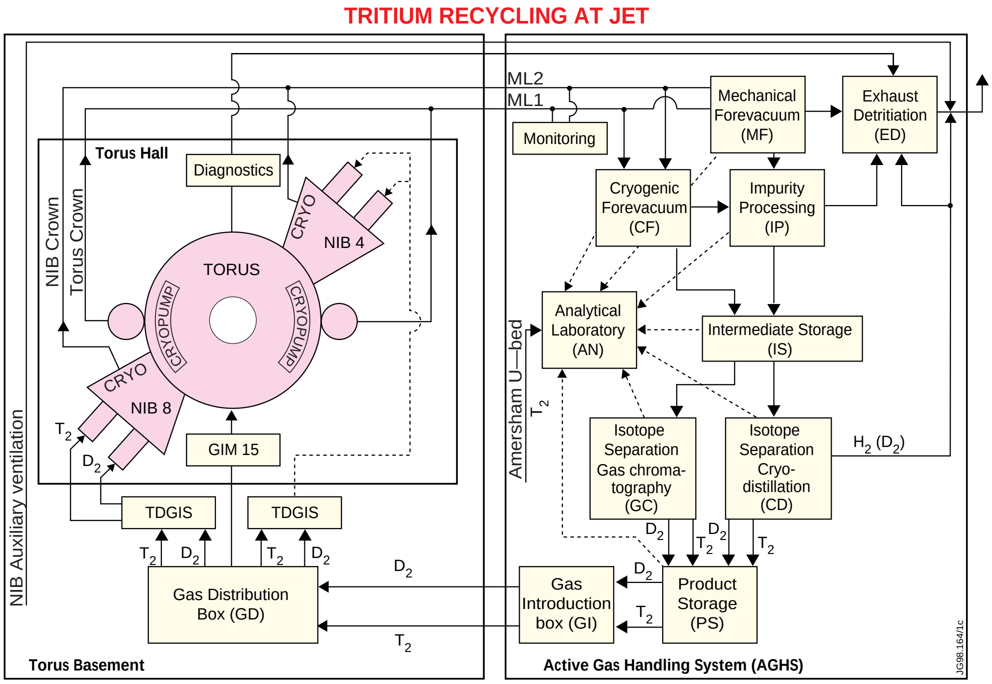


Fig. 1 Schematic flow diagram of torus systems and Active Gas Handling subsystems.

The Analytical Laboratory (AN) is connected via sampling lines to most of the subsystems of the AGHS and is used for characterisation of the various gas compositions in AGHS. In general, detritiated gases have to pass through the Exhaust Detritiation (ED) for further and final tritium removal before their discharge into the environment. On the other hand, detritiated hydrogen from CD can be discharged directly into the environment depending on its final tritium contamination.

All these systems with the exception of ED have their own secondary containments and some components even tertiary containments. The purpose of the secondary containments at JET is to capture any permeated or leaked tritium and to transfer the tritium to ED for adsorption on molecular sieves.

As a further aid to containment the AGH building has dedicated ventilation systems for normal operation and emergency situations.

2.1 Various Subsystems of the AGHS

This Section gives a short description of each AGH-subsystem by mentioning the main process and main components. Operational experience on some of the systems is detailed in companion papers in this volume.

i) Cryogenic Forevacuum (CF) System

Normal pumping of torus systems is done by the CF-system which consists of ten separate cryopumps; large storage and assay volumes (600 and 100 L); and the associated automatic UHV-valves, pressure gauges, thermocouples, and other instrumentation.

All gases except helium are pumped by cryo-condensation at 4 K. To pump helium, four of the cryo-pumps are equipped with activated charcoal sorption panels.

Controlled warm-up of a cryo-pump allows the separation of the pumped gases into three streams of helium, hydrogen and impurities.

ii) Impurity Processing (IP) System

Helium and impurities are sent to the IP-system where residual amounts of tritiated gas species are cracked on hot uranium (U) beds or burnt to water by the addition of small batches of oxygen in the presence of a platinum de-oxo catalyst.

Hydrogen and tritium are recovered by cracking water on hot U-beds. The residual gas left contains mainly helium, CO and CO_2 and can be discharged via the Exhaust Detritiation (ED) system (see below).

The main components of IP are: one 2 m^3 mixing tank; two Normetex pumps (150 m^3/h); one recombiner; one cold trap; four JET uranium beds; and two iron beds.

The operational experience with this system is detailed in [3] in a companion paper.

iii) Intermediate Storage (IS) System

The hydrogen from CF and IP is sent to the Intermediate Storage system for temporary storage prior to injection into one of two isotope separation systems.

IS contains four JET U-beds which are located in an evacuated secondary containment. JET uranium beds can contain up to 4.284 kg of uranium and can store up to 27 moles (605 NL) of hydrogen if loaded fully, but normally they are filled only to two thirds of their total hydrogen capacity.

iv) Cryogenic Distillation (CD) System

Hydrogen from IS can be sent via two feed lines to the CD system. Three product lines exist where the products (protium, deuterium, tritium) can be withdrawn with very high purity if the CD system is operated correctly and the tritium amount is near to its optimum inventory of approximately 33 g. For the product protium (H_2) the contamination level of tritium is below 1 ppm which makes direct discharge into the environment possible. The deuterium and tritium products are sent to the Product Storage (PS) system.

The main components are three packed distillation columns; expansion volumes; siphon pumps; and associated flow and pressure transducers.

The operational experience with this system is described in detail in [4] elsewhere in this volume.

v) Gas Chromatographic (GC) System

Displacement gas chromatography is used to enrich tritium and deuterium from the six hydrogen molecules. The packing material used is palladium (Pd).

Displacement gas chromatography is a batch process. At the end of every separation run the hydrogen molecule (H_2) with the highest affinity to Pd has to be desorbed. This is done by heating the columns to about 200 C. The deuterium and tritium products are sent to the Product Storage (PS) system.

The operational experience with this system is detailed in [5] in a companion paper.

vi) Product Storage (PS) System

The isotopically pure gas products of CD or GC are collected and stored in U-beds of the PS-D_2 and PS-T_2 systems. The PS-T_2 U-beds contain only about 1 kg of uranium per bed. In the case of the PS-T_2 U-beds, in situ determination of the tritium inventory can be performed by quasi-adiabatic calorimetry. In addition, the gas content of the U-beds can be determined by gas desorption into 100 L or 700 L reservoirs and (PVT-c) measurements.

Metal getter beds are a safe storage technique for tritium. In addition, in U-beds the decay helium stays trapped in the uranium. Temperature cycling of the uranium and removal of the helium in the gas phase produces tritium with a very low helium-3 concentration, an important consideration when supplying a neutral beam injector [6].

A disadvantage of uranium getter beds is that inert gases which are not absorbed by the getter material can lead to blanketing effects. The absorption of hydrogen by the uranium slows down because the hydrogen has to diffuse through ‘inert’ gas layers surrounding the getter material. A simple remedy against blanketing is to circulate the gas through the U-beds by means of a pump; Normetex and metal bellows pumps are installed for that purpose in the PS-system.

vii) Gas Introduction (GI) System and Gas Distribution (GD) System

Deuterium and tritium are supplied from the PS-D_2 and PS-T_2 systems via GI and GD to the users: for Neutral Beam Injection via Octant 8 (NIB8) and for gas puffing directly into the torus via the Gas Introduction Module 15 (GIM15).

The long transfer lines are surrounded by secondary containments in the same way as the other systems of the AGHS.

The accountancy of the gases supplied to the various users is mainly done in the GI-system via (PVT-c) measurements.

The Gas Introduction system for the NIB8 neutral beams is described in more detail in a companion paper [6] in this volume.

viii) Mechanical Forevacuum (MF) System

The MF-system has the following roles: to pump the Torus and NIB-cryo-pumps from atmosphere; to pump the Torus and the NIB cryo-pumps during normal operation when CF is not available; to supply the necessary backing pressure for the Torus turbo-pumps during helium glow discharge; and to discharge gases from the various AGH-subsystems via the Exhaust Detritiation (ED) system.

The following pumps are installed in MF: one 600 m^3/h Normetex pump; two 150 m^3/h Normetex pumps; and one 1000 m^3/h roots pump.

ix) Exhaust Detritiation (ED) System

Almost all gases (except the protium product of the CD-system and the exhaust gases of the analytical gas chromatograph) are sent through the ED-system prior to their discharge. Also in case of emergency (e.g. after a window rupture on the Torus or after a tritium leak into one of the rooms on the active side of the J-25 building) the air from the Torus or from the rooms would be pumped into the ED-system and detritiated.

The ED-system is a conventional tritium removal system where tritium and tritiated gas species are burnt to water. The water is trapped on dry molecular sieve. Wet molecular sieve beds are regenerated by heating, the desorbed humidity is collected in coolers and finally stored in drums if the tritium concentration is high.

The system is designed to reduce the incoming tritium concentration by more than a factor of 1000.

x) Analytical Laboratory (AN)

The AN is connected via small bore pipework with most other subsystems of the AGHS. In this way samples from other subsystems can be analysed by the three analytical techniques available in AN: analytical gas chromatography; mass spectroscopy (Omegatron and quadrupole); and ionisation chambers. In addition, the CD-product streams protium and deuterium are analysed by sensitive katharometers.

The analytical tool most often used is the gas chromatograph: six detectors are available to study the composition and tritium concentrations in the gas mixtures as follows: one thermal conductivity detector (TCD); one flame ionisation detector (FID); two ionisation chambers (IC); and two flow proportional counter detectors (FPCD).

The operational experience with the AN is described in detail elsewhere [7] in this volume.

xi) Over/Under Pressure Protection System (O/UPPS)

All process lines of the active gas handling system where tritium process gas is handled at higher pressures are surrounded by secondary containments. These containments are either evacuated or filled with nitrogen or argon and kept a few mbars below atmospheric pressure, and are intended to retain the tritium in case of a primary containment failure.

3. OPERATIONS AND STAFF TRAINING ON THE AGHS

3.1 Operations

During DTE1 the AGHS was permanently manned by four four-man shift teams which worked to a 12 hour shift pattern. Each shift team consisted of an Operation Engineer, Plant Supervisor, Control Technician and Analytical Technician. At all times two shift team members who were on rest days remained ‘on call’ to cover any short term absences during the operations period.

3.2 Training

An extensive training programme was carried out prior to DTE1 in order to ensure that members of the AGH-group were sufficiently experienced to operate the plant safely and also that the members of the groups interfacing with the AGHS operations were familiar with the operating procedures that would be followed. This training programme complemented the practical experience of operating the AGHS during Trace and Full tritium commissioning.

3.2.1 Training of the AGH Group staff

A training grid was devised depicting the various topics which needed to be known for each of the four operational roles in the AGHS against the individuals within the group. Staff were then trained by practical demonstration and/or lecture. At the end of the training period a review panel met to consider the level of training and achievement of each member of the group. Staff were then officially appointed to one or more of the four roles in the AGHS organisation.

3.2.2 Training of external personnel

A two day course was devised to familiarise members of other groups at JET. The course consisted of an overview of the AGHS followed by a plant tour and then a detailed description of the various subsystems within the AGHS. The courses were tailored to suit the group being lectured e.g.: highlighting the Gas introduction system for the Neutral Beam Operations group.

In return these external interface groups provided lectures on their systems and operating procedures for the members of the AGHG.

3.2.3 Practical Training

Prior to DTE1 the AGHS supported the machine operations for several months as described below. During this period the shift teams gained practical experience of many of the operations which would be carried out during DTE1 but using deuterium only. It also enabled the interface procedures for gas feed and recovery to be tested.

At the end of the training period four shift teams of four men each were sufficiently trained to safely operate the AGHS.

4. COMMISSIONING OF THE AGHS

The commissioning of the AGH-plant was performed in five phases:

- Inactive commissioning;
- Trace tritium commissioning;
- Full tritium commissioning;
- Inactive commissioning of Interface systems; and
- Final preparations for DTE1 (expanding the tritium boundary).

4.1 Inactive commissioning

The performance of the subsystems of the AGHS was tested with inactive gases, the functioning of tritium specific equipment being tested with gamma sources wherever possible. Leak tightness of the systems was tested with helium leak detectors. Subsystems of the AGHS passed these tests only when their total leak rate did not indicate any leak in the 10^{-9} $Pa.m^3.s^{-1}$ range. During this phase AGHS was used occasionally to pump the torus to test the performance of the MF and of the CF systems. Results of the inactive commissioning are discussed in the 'Inactive commissioning report' and in various publications [8] - [14].

4.2 Trace tritium commissioning

Trace tritium commissioning was performed with the tritium gas used during the PTE-experiment and stored in U-beds located in the JET U-bed safe store. The total tritium amount was about 30 TBq (800 Ci or 0.08 g) in $166kPa.m^3$ of hydrogen. All AGH-subsystems were trace tritium commissioned with the exception of the systems interfacing with the torus such as MF, CF, GI and GD. This was done to prevent accidental tritium introduction into the torus. These systems functioned as a buffer between AGHS and torus systems. In addition, no trace tritium gas was directly injected into the Exhaust Detritiation (ED) system. The first tritium tests were done with gas treated in Impurity Processing (IP) system and injected into ED with the purpose of further detritiation. The performance of ED was monitored and checked during those injections.

At the end of trace tritium commissioning three objectives were completed: a) the systems were leak tested with trace tritium gas; b) tritium sensitive detectors were exposed to trace tritium gas and their expected response confirmed; and c) the trace tritium gas was processed in the Cryogenic Distillation (CD) system, tritium was enriched and most of the total gas amount was discharged to the stack.

Results of trace tritium commissioning have been published elsewhere [15].

4.3 Full tritium commissioning

Full tritium commissioning was performed with about 3 g of tritium supplied through the Canadian Fusion Fuels Technology Project (CFFTP) in an Amersham U-bed (containing 320 g of uranium). With approximately 1 g tritium the GC system for isotope separation was tested and very good product purity obtained. Altogether, the AN, PS, IS and GC systems were tested with pure tritium and results of full tritium commissioning have been reported previously [16].

4.4 Inactive commissioning of the interface systems

Before the start of the DTE1 phase the GI and GD systems were tested with deuterium. In the same way the CF system was tested for weeks during normal operation of the torus to assure that the CF system could handle the various gas loads from regenerations of the cryopumps of the NIBs and Pump Divertor (PD).

4.5 Final Preparations for DTE1: expanding the tritium boundary.

The systems GI, GD, and CF were tritium commissioned very shortly before the commencement of DTE1. First the tritium boundary was expanded into these systems and they were tritium leak tested with a 1% tritium-99% deuterium mixture. After no leaks were detected, GI and GD were tested with pure tritium. Again no leaks were found which clearly demonstrated that the inactive commissioning had been done very carefully. CF was not tested with pure tritium because only subatmospheric pressures were achievable with the available tritium amount due to the very large volumes in CF.

All torus and NI operations for DTE1 were carried out in accordance with approved Operating Instructions (OIs). These procedures were checked in the final preparation phase for DTE1.

5. SUPPLY OF DEUTERIUM & TRITIUM TO TORUS AND NEUTRAL INJECTOR SYSTEMS DURING AND AFTER DTE1

The DTE1 phase started officially with the supply of 1% tritium-99% deuterium mixture to the Neutral Beam Injectors.

Tritium and/or deuterium were supplied to the users in weeks 21 to 47 of 1997 excluding weeks 25 to 36 due to the intervention to cure a small leak on the NIB8 system [17] and the subsequent restart.

Prior to DTE1 the tritium gas amount on site was increased from the 3 g, used for the full tritium commissioning program, to 20 g. The 17 g were supplied by CFFTP in four Amersham U-beds.

After arrival at JET the tritium content of these U-beds was measured by precision calorimetry [18]. The determined tritium content was compared with the value stated by the supplier. In all cases the agreement between these values was better than 0.3%.

5.1 Tritium purity supplied to JET

Table 1 gives the results of analytical gas chromatography performed in Chalk River National Laboratory (CRNL) and at JET in atomic ratio. The results are in good agreement, the main difference occurs for D. An explanation for this difference is that the Amersham U-bed supplied by JET for transport and the JET PS-T_2 U-beds had all been activated with deuterium. A small amount of deuterium is not removable from the uranium even after extensive heating and pumping. This deuterium can lead to dilution of the tritium. The tritium sample at JET was determined after absorption of the tritium on a PS-T_2 U-bed.

CRNL ANALYSIS	JET ANALYSIS
Atomic ratio in %	Atomic ratio in %
0.36 H	0.22 H
0.155 D	0.41 D
99.485 T	99.37 T

Table 1: Purity of the tritium gas measured at CRNL and at JET

5.2 Transfer of tritium from Amersham U-beds to PS-T_2

The Amersham U-beds were connected to the pipework of the Tritium-Make-up Box in the analytical laboratory. After leak tests of the new connection, the Amersham U-beds were heated to approximately 500°C and the desorbed tritium was moved to one of the four U-beds of the Tritium Product Storage System. During the transfer the tritium amount was again determined via (PVT-c) measurements using well calibrated volumes and high accuracy pressure gauges. The concentration c was obtained from the analytical gas chromatographic (AN-GC) system after absorption on a PS-T_2 U-bed. For very pure tritium gases two fully independent analytical techniques of the AN-GC are employed: thermal conductivity detector and ionisation chamber [7]. The results of both techniques showed very good agreement.

During the transfer of the tritium from the Amersham U-bed to PS very high tritium concentrations were observed in the N_2 atmosphere of the Make-up Box due to permeation of tritium through the hot walls of the U-bed. These commercially available Amersham U-beds have no secondary containment to capture permeated tritium. Amersham U-beds are used because they are part of a licensed transfer package for tritium. The tritium contamination levels in the Make-up Box due to the transfer were by far the highest values (approximately 1000 DAC in the Tritium Make-up Box) seen until now in any of the AGHS containment boxes.

After transfer the Amersham U-beds were disconnected from the pipework inside the Make-up Box and re-examined by precision calorimetry. Small residual levels of tritium (‘heels’) were observed in the uranium. The heels were negligible (approximately 0.1 - 0.2%) compared to the tritium inventory supplied. Because the same procedure for the transfer of tritium from the Amersham U-beds to the AGHS was followed, the heels left in individual Amersham U-beds were very similar.

The two methods used - precision calorimetry and (PVT-c) measurements - gave a very accurate total tritium gas amount in the AGHS. The relative agreement was better than 0.5%.

The tritium amount available at the 15 May 1997 12:00, just before the start of DTE1, was 20.448 g or 8260Pa.m^3 at 20°C.

The Amersham beds with their small tritium heels (0.033 g) are stored in the JET U-bed Safe Store.

5.3 Production and use of a 1% tritium-99% deuterium mixture

A gas mixture of approximately 2 10^4Pa.m^3 of 1% tritium-99% deuterium was produced by mixing appropriate gas amounts of very pure tritium and deuterium. The actual atomic composition of the gas mixture achieved was 0.12% H, 98.96% D and 0.92% T.

This gas was used

a) in the expansion of the tritium boundary to leak test the GI, GD, the NIB8 Tritium-Deuterium Gas Introduction System (TDGIS) [6], the NIB-crown (ML2) and CF.

b) to supply the users with a 1% tritium-99% deuterium gas mixture for various plasma experiments.

After the performance of the 1% tritium-99% deuterium plasma shots the residual gas mixture was separated again into pure tritium and deuterium using the preparative GC-system.

5.4 Supply of deuterium and tritium from Product Storage to the Neutral Injector and Torus systems

Figure 2 shows in a schematic diagram the supply of deuterium and tritium from PS via GI to the users NIB8 and GIM15. During DTE1 only the three lines shown in Fig. 2 were used for D_2 and T_2 supply, but in reality ten transfer lines are installed which allow the connection with Neutral Injector Box at Octant 4 (NIB4 -shown in Fig. 1 by dashed lines), Pellet Injection system and other gas introduction modules. These are foreseen for use in future Deuterium-Tritium Experiment at JET (DTE2) [19].

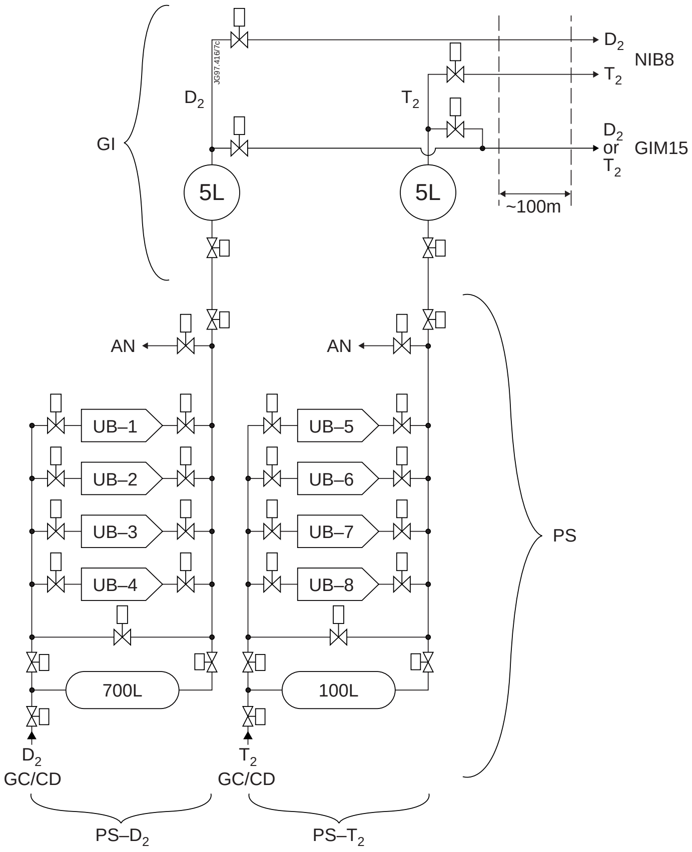


Fig. 2 Schematic flow diagram for deuterium and tritium supply from Product Storage (PS) system via Gas Introduction (GI) and Gas Distribution (GD) to the users: Neutral beam injection Box (NIB)8 and Gas Introduction Module (GIM)15.

Pure deuterium and/or tritium gas was supplied to GI by heating U-beds of PS-D_2 and/or PS-T_2 to about 450 °C. In GI the gas amount was determined in well calibrated volumes, its pressure measured with highly accurate capacitance manometers and the temperature measured with PT-100 precision resistors. The valves above the 5L volumes in Fig. 2 have to be enabled by keys before they can be operated via the automatic control system. In this way the users have full control over these valves. With the key removed no compressed air is applied to the actuators of the valve and opening is not possible either by malfunction of the control system or by operator error.

From GI the D_2 and T_2 gases were supplied via long transfer lines (>100 m) to the Gas Distribution (GD) Box and from there to the users: NIB8 TDGIS and GIM15.

At the end of a day's operation the gas amounts left in the pipework of GI and GD were determined again and pumped back to the U-beds of PS. The difference of the two measurements gives the total amount of gases supplied to the users. A large effort was made to establish the tritium gas amounts supplied to the users accurately. These values are listed for tritium and deuterium in the Table 2 and 3 as a function of week numbers in 1997.

Table 2: Quantities of pure tritium supplied to NIB8 and GIM15

TIME Year 1997	pure T_2 to NIB 8 (kPa.m^3 at 20° C)	pure T_2 to GIM15 (kPa.m^3 at 20° C)
week 21	1.2065	0.0031
week 22	3.3964	0.0199
week 23	——	2.2339
week 24	——	2.3007
week 25 to 36	NIB8 intervention and restart	
week 37	——	0.02
week 38	2.7358	0.879
week 39	2.2981	0.5618
week 40	3.8553	1.6341
week 41	2.5310	1.9911
week 42	2.0023	0.8646
week 43	2.5517	0.4989
week 44	2.4864	0.7122
week 45	1.8070	1.5405
week 46	1.4634	1.3235
week 47	——	0.0066
week 48 to 49	Torus Clean-up and return to post DTE1 experimental programmes	
week 50	——	0.0035
	$\Sigma = 26.3303$	$\Sigma = 13.8023$
	$\Sigma = 40.1326$	

Table 3: Deuterium amounts supplied to NIB8 and GIM15

TIME Year 1997	D_2 to NIB8 (kPa.m^3 at 20° C)	TIME Year 1997	D_2 to GIM15 (kPa.m^3 at 20° C)
Week 21 - 46	96	Week 21 - 49	8.5

Deuterium and tritium are stored in uranium beds (UB) 1 to 8 of PS. The PS system can be divided into three sections. Only two are shown in Fig. 2.

a) PS-D_2: The product storage system for deuterium contains four U-beds with 4.282 kg of uranium each and a 700 L reservoir. PS-D_2 has interconnecting lines to GC, CD, AN and GI and connections to PS-T_2 and the pumps of PS (not shown in Fig. 2).

b) PS-T_2: The product storage system for tritium contains four U-beds with 1.19 kg uranium each and a 100 L reservoir. The design and dimensions of the PS-D_2 and PS-T_2 U-beds are identical. The only difference between them is that the PS-T_2 U-beds contain about a quarter of the uranium of the PS-D_2 U-beds. Due to the limited amount of tritium expected to be handled during DTE1 the uranium amount for PS-T_2 beds was reduced. This also minimises the heel of tritium in a U-bed and makes a larger part of the tritium on site available for re-use. PS-T_2 has interconnecting lines to GC, CD, AN and GI and connections to PS-D_2 and the pumps of PS (not shown in Fig. 2).

The third section of PS not presented in Fig. 2 contains combinations of pumps with the main purposes to achieve good vacuum conditions in primary, secondary and tertiary containments and to circulate gases through U-beds or tanks with the purpose of removing blanketing gas. The Pumps are: turbo-molecular pump; getter pump using SAES-707 material; sputter pump with Fe instead of Ti to achieve selective pumping for inert gases but not for hydrogen; Normetex pump; and metal bellows pump.

During the DTE1 phase tritium and deuterium were supplied to NIB8 and GIM15. NIB4 and all other gas introduction modules used their own gas supplies. Table 2 gives the amounts of pure tritium supplied to NIB8 and GIM15 as a function of weeks.

According to Table 2 more than 99 g of tritium were supplied to the users. This means that the total tritium gas amount available at JET was recycled to the torus at least four times. If one also considers that a large fraction of up to 11.5 g of tritium supplied to the torus was temporarily trapped there [20], the tritium available and handled in the AGHS was recycled at least five times.

The AGHS system was specially built for this reprocessing purpose and is the first tritium handling facility in connection with a fusion research machine used for recycling large amounts of tritium.

Table 3 shows the gas amounts of deuterium supplied to NIB8 and GIM15 during DTE1 and up to week 49. After week 46 the D_2 gas supply to NIB8 and GIM15 from the AGHS was stopped. NIB8 was reconnected to its own gas supply independent of AGHS.

It is of interest to compare the tritium use at the Tokamak Fusion Test Reactor (TFTR) in Princeton during their D-T experimental campaign [21].

At TFTR 78 g of tritium were supplied from the tritium handling facility to the neutral beam injection boxes of which 5 g were injected into the tokamak. In the last month of TFTR operation, 8.2 g of tritium were reprocessed by means of a cryogenic distillation system especially built to achieve a small total tritium inventory. 7 g of the 8.2 g were sent to the neutral beam injection boxes. The total amount of tritium handled in the tritium handling facility at TFTR was 98.99 g. 21 g of tritium were used for various tasks inside the tritium handling facility (e.g. calibration) or were immediately sent back to the supplier because the tritium purity did not fulfil the specifications.

6. GASES PUMPED FROM THE TORUS AND THE NI SYSTEMS DURING AND AFTER DTE1

Figure 3 shows a simplified flow diagram of the torus, NIB8, NIB4 and the CF and IS systems of the AGH-plant. NIB4 and NIB8 vacua are separated from the torus vacuum by Rotary Valves (RHVV). The torus, the NIBs and the interspaces of the rotary valves are evacuated by turbo-molecular pumps which exhaust into the torus and NIB crowns. These are connected via long (>100 m) vacuum pipes (ML1 and ML2) with the Cryogenic or Mechanical Forevacuum systems of the AGH-plant.

6.1 Cryogenic Forevacuum (CF) System

During normal plasma operation the torus is continuously pumped by four turbo-pumps (only one shown in the simplified Fig. 3) and one of the four charcoal equipped cryogenic pumps of CF works as the forevacuum system for the turbopumps. During that time the valves between the NIB cryo-pumps and the NIB turbo-pumps are closed and the NIB crown with its 6.8 m^3 acts as a storage volume being pumped down by CF from pressures of order 10Pa to pressures below 0.1Pa.

At the end of a day's operation, mainly overnight (22:00 until 6:00), the helium panels of the NIB and torus cryo-pumps were regenerated routinely one after another depending on total gas and tritium amounts on the various cryo-pumps, and the requirements of the operational program. The cryo-pumps were warmed up to 77 K with the valves on top of the turbo-pumps and the

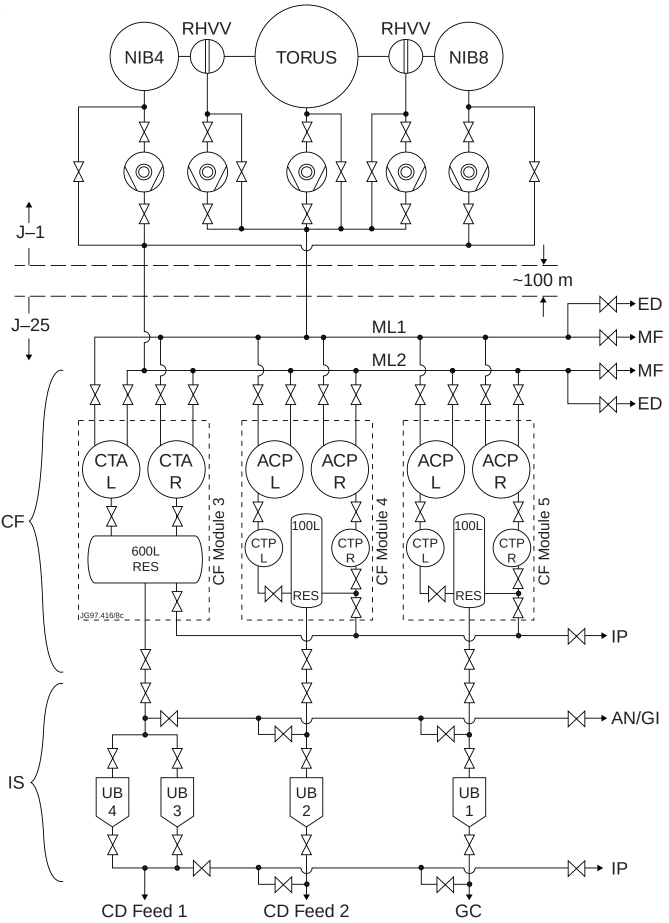


Fig. 3 Schematic flow diagram of the torus systems, cryo-pumps in Cryogenic Forevacuum (CF) system and uranium bed in Intermediate Storage (IS) systems. RHVV: rotary valve; CTA cryo-transfer accumulation pump; ACP: accumulation cryo-pump; CTP: cryo-transfer pump; L and R: left and right hand side; UB: uranium bed.

by-pass valves closed. The gas was expanded into the corresponding crown by opening the by-pass valve. The total gas amount released is determined by (PVT) measurement using the connected volumes of torus, torus crown or NIB4, NIB8, NIB crown and experimentally determined effective temperatures. The tritium concentration was established with ionisation chambers directly positioned in the crowns. In addition, the tritium concentration could also be established in the Exhaust Monitoring System (EMS) which allows filling of the ionisation chamber with hydrogen of higher pressures to avoid extrapolation of the amplification factor from very low pressures up to 1 bar. These measurements were the first indications of the tritium concentrations in the various systems.

A ‘fresh’ cryopump of CF cooled down to 4.2 K was connected to the corresponding crown and was capable of pumping all gases by cryo-condensation on the cryo-surfaces with the exception of helium. Helium was cryo-sorbed by charcoal at 4 K with a storage capacity of approximately 2800Pa.m^3 for helium.

Six cryo-pumps in CF are available for pumping ML1 or ML2 and accepting the gases from torus and NIB regenerations, but only four are equipped with charcoal. These cryo-pumps are located in module 4 and 5 (see Fig. 3). These four were mainly used to pump the torus, because the torus gas can contain larger amounts of impurities, e.g. helium, etc., depending on the special plasma shots performed.

The two cryo-pumps without charcoal in module 3 were mainly used to pump gases which were known not to contain helium, e.g. gases during D_2 glow discharge (GDC) or gases from NIB4 or NIB 8 regenerations.

During the main DTE1 phase, when tritium was supplied to the torus and NIB8, the NIB8 and PD cryo-pumps were regenerated to 77K almost every night.

The gas from the NIB8, PD and NIB4 regenerations were cryo-pumped by separate cryo-pumps in CF. In many cases the gas from the PD regeneration was added to the gas already pumped during the day. But on special occasions the gas was pumped with a fresh CF cryo-pump to establish the gas amount gettered on the PD cryo-pump. Under these conditions 4 of the six cryo-pumps in CF which are available for pumping on the ML1 or ML2 lines were in use. The regenerations had to be planned carefully because NIB4 and NIB8 regenerations could not take place at the same time due to the shared crown and the capacity of the cryoplant. In addition, one of the remaining two cryo-pumps had to be available for further pumping of the torus after its regeneration. The last cryo-pump was not to be used. It was kept as back-up in case one of the cryo-pumps in use suddenly warmed-up or became otherwise unavailable.

Gases pumped by the CF-cryo-pumps equipped with charcoal were transferred to further cryo-pumps (called cryo-transfer pumps) without any sorbent. In this way, helium could be moved through this cold cryo-pump and all other gases were cryo-condensed again. Furthermore, the second cryo-pump has a far smaller volume and was used for single pass batch distillation at 20 K to separate hydrogen from all other impurities. But the gas amounts received from

NIB8 or PD regenerations during the main DTE1 phase were in most cases too small to use this distillation process. In almost all cases the CF cryo-transfer pumps were allowed to warm up to 77K and connected to larger volumes for PVT measurements at 77K. A disadvantage was that impurities are also released and the separation into hydrogen and impurities was not achieved. Under these conditions eight of the ten cryo-pumps in CF were in use during a night shift.

These (PVT) measurements together with the tritium concentrations from the EMS gave first results of the total gas amounts and the tritium inventories received back from the NIBs and PD.

The operation of these ten CF cryo-pumps required an almost daily liquid helium top-up from the JET cryo-supply system. The cryo-plant for the liquefaction of helium coped very well the liquid helium needs of the CF system during the DTE1 phase.

In total 77 PD, 38 NIB4 and 58 NIB8 regenerations were performed in the weeks 21, 1997 to week 6, 1998 and the regenerated gases pumped with the cryo-pumps of CF.

6.2 Gas amounts pumped from torus systems during and after DTE1

Table 4 presents the gas amounts in Pa.m^3 pumped by the AGHS. The gases are listed depending on their origins.

Table 4: Gas amounts pumped from torus, NIB4, NIB8 and glow discharge by AGHS

Gas pumped by AGHS	TORUS (Pa.m^3)	NIB4 (Pa.m^3)	NIB8 (Pa.m^3)	GDC (Pa.m^3)
Weeks 21 to 24, 1997	4.22 10^4	9.52 10^4	1.95 10^4	2.95 10^4
	NIB-8 intervention			
Week 33, 1997 to week 6, 1998	15.94 10^4	53.05 10^4	37.49 10^4	7.99 10^4
	$\sum$=2.016 10^5	$\sum$=6.257 10^5	$\sum$=3.944 10^5	$\sum$=1.094 10^5
	$\sum$ = 1.3311 10^6			

A comparison of the Tables 2, 3, and 4 shows clearly that the gas amounts pumped by AGHS are far larger than the ones supplied from the AGHS to the users. The reason for that is that NIB4 and the other torus gas introduction modules, exception for GIM15, used their own gas supplies. NIB8 was reconnected to its own gas supply after week 46.

The AGHS, the users and the torus form an almost closed gas loop only with respect to tritium, because tritium was supplied only from the AGHS. The loop is not closed with respect to the other gases, e.g. deuterium and protium, although closure with respect to deuterium would be possible if needed.

The AGHS had to process all gases received. The main part of the gas was processed in the AGHS with the intention to remove the tritium from the hydrogen gas mixtures and to detritiate gas species containing tritium (e.g. hydro-carbons, water, etc.) to such low concentrations that direct discharge into the atmosphere or via ED would be possible. Only a small part of the collected and purified deuterium gas was recycled via NIB8 and GIM15. All other gases were finally discharged whenever possible.

Table 4 shows that the original 20 g or 8080Pa.m^3 tritium were significantly diluted by other gases, mainly deuterium, totalling to approximately 1.33MPa.m^3 (up to week 6 of 1998). The main and most difficult task of the AGHS has been to enrich the diluted tritium to 100% purity and to discharge the bulk of the deuterium to atmosphere. At certain times this task was made easier when tritium of high purity was pumped from NIB8 thus requiring only one-stage separation in GC.

A large fraction of the 1.33MPa m^3 of gas measured were discharged by means of the CD-system (see Section 7.2.2).

7. PROCESSING OF GASES INSIDE AGHS DURING AND AFTER DTE1

7.1 Intermediate Storage (IS) System

The gases warmed up in the CF system to 77 K are transferred after (PVT) measurements in the 100 or 600 L volumes of CF to U-beds of IS. The three interconnecting lines between CF and IS shown in Fig. 3 are used for this transfer.

The gas transfers from CF to IS take time due to various reasons. The pressures in CF are small due to the large volumes, the temperature of 77K and the small gas amounts handled in one day’s operation. Furthermore, the interconnecting lines between CF and IS are more than 20 m long and of an inner diameter of only 1 cm. No pumps are installed in these lines to pump the gases from the large volumes and compress them into the U-beds. In addition, blanketing of the U-beds can occur frequently, especially at low pressures, by helium, argon, and hydrocarbons. This blanketing gas must be removed by a Normetex pump which can be connected to the common outlet manifold of the IS U-beds (not shown in Fig. 3).

The transfer of gas from CF to IS takes approximately 24 hours and needs accurate attention of an operator to remove any blanketing gas. In fact, these transfers are the bottlenecks in the tritium processing routes of the AGHS.

During these gas movements it was particularly difficult to judge transfer completion, because the pressure gauges in CF and IS are of the strain gauge type with relatively large zero point fluctuations and drifts.

The transfers of gas from CF to IS were arranged so that gas with the highest concentration was sent to UB-1 and gas with the lowest concentration to UB-3 or UB-4. Intermediate concentrations were sent to UB-2. The pipework is arranged in such a way that the inventory of

UB-1 can be moved directly to GC (and used immediately for a GC isotope separation run) whereas the contents of UB-2, UB-3 and UB-4 can be directly injected into CD or by using the U-bed outlet manifold into GC. Gas streams of different concentrations are thus segregated and inadvertent mixing is avoided.

Time permitting, the hydrogen composition of these IS U-beds was again assessed with AN-GC. This involved heating the U-bed to achieve a pressure of approximately 1 bar(a), filling the pipework to the AN-GC with the sample, injection of a sample into the AN-GC, performance of an analysis, and re-absorption of the gas in the pipework into the same U-bed after the U-bed was cooled down to near room temperature.

As long as tritium was supplied to NIB8 the gas regenerated from this cryopump, which had very high tritium concentrations, was moved via the cryopumps in module 5 of CF to IS UB-1 and finally directly injected into a GC column for final enrichment to 100%. The gas from torus (PD) regenerations with moderate tritium content was transferred via CF module 4 to IS UB-2 and injected into GC by using the IS U-bed outlet manifold. During the clean-up phase the highest tritium concentrations were observed in the torus gas which was then collected in module 5 of CF for direct transfer to GC.

7.2 Gas Chromatography (GC) and Cryogenic Distillation (CD) systems

The AGHS contains two hydrogen isotope separation systems.

7.2.1 Gas Chromatography (GC) system

A detailed description of the performance of the GC system during and after DTE1 is given in [5].

The principle of the GC system is displacement gas chromatography. The material used is 20 weight% palladium deposited on porous α-Al_2O_3. Hydrogen in contact with palladium shows a very large isotopic effect. The lighter hydrogen atoms are preferentially absorbed in the Pd, whereas the heavier molecules remain mainly in the gas phase. When a hydrogen isotope mixture is added to a Pd filled column, separation starts at the beginning of injection. After the column is filled with the gas mixture up to a quarter of its total capacity, protium is used as displacement gas to push the partially separated gas mixture through the column. Protium has the highest affinity to Pd and is capable of replacing tritium and deuterium in the Pd and of forcing them into the gas phase. As a consequence, at the column exit tritium arrives first followed by deuterium and the eluant gas protium. These three products are separated by small interfractions $He+T_2$, T_2+DT+D_2, and D_2+DH+H_2.

A simplified flow diagram of the JET GC system is shown in Fig. 4. Only one column out of the four is presented. U-bed1 is used for scrubbing and U-bed2 for storage of gas mixtures to be separated in internal GC runs. U-beds 3 and 4 contain the eluant gas protium. The pumps (Normetex- and metal bellows pump) compress helium into the 80 L reservoir and are used to circulate helium through the columns during the regeneration of the columns after a separation

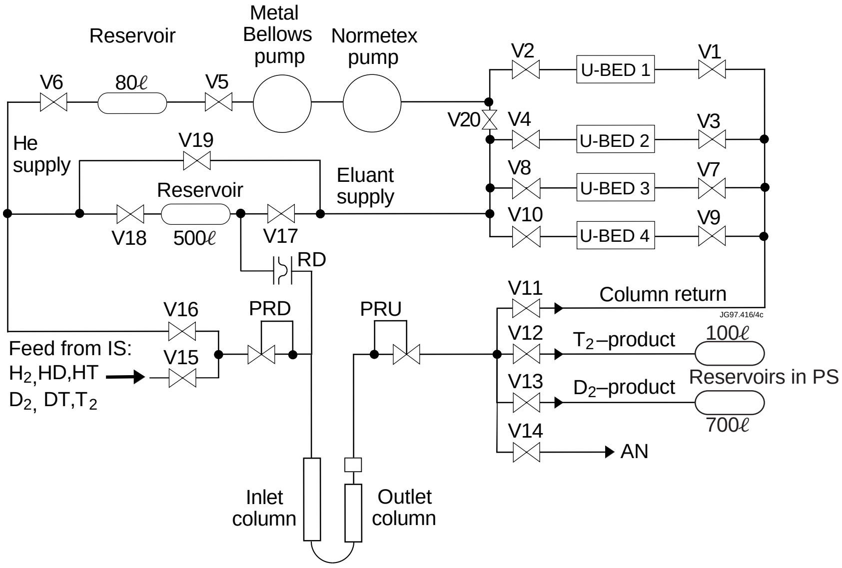


Fig. 4 Schematic flow diagram of the Gas Chromatographic (GC) system.

run. The gases exiting the column are observed by two main diagnostics: katharometer and ionisation chambers. During automatic runs the switching of the valves V11, V12, V13 is controlled by these instruments.

The GC system was generally used to enrich tritium in gas mixtures with tritium concentrations higher than 0.2%.

More than 160 separation runs were performed with the preparative GC system during DTE1 and the consequent clean-up phase up to the start of the remote tile exchange. Approximately 470kPa·m^3 of hydrogen isotope mixtures with 64.6kPa·m^3 (160 g) of tritium were injected and processed in the GC columns. The recovered tritium and deuterium amounts were 96 g and 440 g, respectively. Tritium was produced for operational use no fewer than 40 times. ‘Pure’ tritium as well as ‘pure’ deuterium were generated in 24 runs and tritium alone was produced in 16 runs. Under these conditions the enriched deuterium product was added to the T_2+TD+D_2 interfraction.

The gas mixtures after DTE1 contained tritium with less than 2%, so pre-enrichment was necessary. 105 separation runs were performed to pre-enrich tritium from low tritium-hydrogen gas mixtures and to cut deuterium and 15 runs to clean-up the eluant gas protium. These pre-enrichment runs were necessary because the injection of 3kPa·m^3 of tritium gas mixture with tritium concentrations < 2% gives a tritium product of less than 60Pa·m^3. Since 70Pa·m^3 tritium are needed for the He-T_2 and T_2-D_2 interfractions no pure tritium can be obtained. The deuterium cut from these runs was moved to CD for final detritiation before the discharge to stack. Protium was collected as eluant gas. If too much eluant gas was found in U-bed 3 and/or 4, part of the protium was sent to CD for final detritiation and discharge to stack. Large amounts of tritium were re-cycled through the GC-columns to achieve the final enrichment.

The largest tritium amount separated in a single run in one column was 8 g.

Best tritium purity is achieved with gas mixtures of high tritium concentrations because of the wide pure tritium band at the column exit. The transitions helium to tritium, tritium to deuterium and deuterium to protium were found to be very sharp and independent of the composition of the injected gas mixture. Typical purities of the tritium product and of the deuterium product of the GC-systems are listed in Table 5 and compared with the requested specifications. The achieved purity exceeded the requirements. Furthermore, the tritium purity achieved in GC was even better than the purity of the tritium as originally supplied to JET.

Table 5: Required and achieved gas compositions of deuterium and tritium

ACHIEVED GAS COMPOSITIONS			
	H / %	D / %	T / %
D_2 gas	0.34	99.62	0.04
T_2 gas	0.07	0.05	99.88
REQUIRED GAS COMPOSITIONS			
	H / %	D / %	T / %
D_2 gas	<1	>98	<0.25
T_2 gas	<0.5	<1	>98

Although the tritium concentration in the deuterium product was in most cases below 0.05%, and the tritium concentration in the protium gas used as eluant was even lower, in both cases the tritium concentrations were too high to allow discharge to atmosphere. Both gases were sent to the CD system for further detritiation.

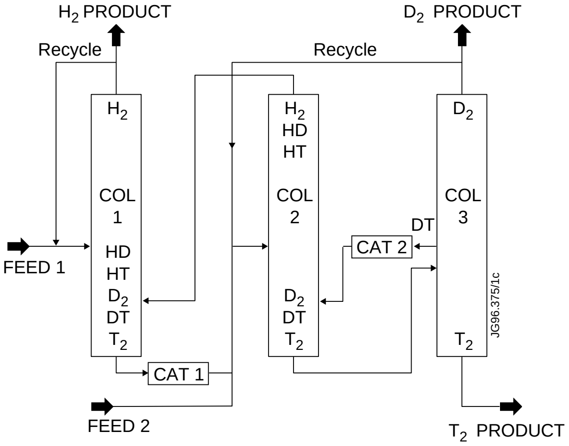
The tritium concentration determined with the AN-GC and the total gas absorbed in the PS U-beds were used for accountancy purposes and to characterise the quality of the performed separations.

7.2.2 Cryogenic Distillation (CD) system

A detailed description of the performance of the CD system during and after DTE1 is given in a companion paper [4].

The principle of hydrogen isotope separation by cryogenic distillation relies on the relatively large isotopic differences in concentrations between liquid and saturated vapour phases. The less volatile isotopes are enriched in the liquid phase and collected at the bottom of column, whereas the more volatile ones stay preferentially in the gas phase and are extracted from the top of a column.

The main components of the JET CD system are three columns filled with packing material, one boiler at the bottom and one condensor at the top of each column with an intermediate boiler in column 3 to reduce the tritium inventory, two catalysts at room temperature to split the mixed hydrogen molecules into H_2, D_2, and T_2, one feed each to column 1 and column 2 for addition of gas mixtures with low and high tritium concentrations, respectively, and three extraction points, at the top of column 1 for ‘pure’ protium, at top of column 3 for ‘pure’ deuterium and at the bottom of column 3 for ‘pure’ tritium. If no products are extracted, the system can be put into recycle mode. Figure 5 shows these components schematically. In addition, the various hydrogen molecules are listed at the top and bottom of the columns to indicate their principal destinations.



TOTAL INVENTORY	1700barl
20.5% H, 79.5% D, 200ppm T	

	H_2 product	D_2 product	T_2 product
H	83.4%	<100ppm	<100ppm
D	16.6%	100%	96%
T	3.6ppb	18ppb	4%

Fig. 5 Schematic flow diagram of the Cryogenic Distillation (CD) system. ‘CAT’ indicates catalysts

The CD system is far more complex and many components are not shown in Fig. 5 such as siphon pumps to circulate the gas, large expansion volumes to avoid high pressure in case the liquid in the condensors and in the columns were to evaporate, automatic valves, the gaseous helium refrigeration system, heat shields as well as secondary containment, etc.

The JET CD system was designed for a tritium inventory of 33 g tritium. With only 20 g tritium present at JET during DTE1 it was clear that the full performance of the CD-system with respect to tritium purity could not be achieved. In fact, the maximum tritium inventory in the CD system until now has been below 1 g.

Generally only gas mixtures with tritium concentrations smaller than 0.2% were transferred to CD. In this way the tritium inventory and contamination of the CD system was kept as low as possible. Under these conditions no pure tritium product can be obtained. The maximum tritium concentration observed at the bottom of column3 was approximately 30% tritium in deuterium.

The CD operating inventory is about 220kPa (a) in $0.8m^3$ at room temperature. On cooling to ≈21 K the pressure falls to 110kPa due to hydrogen condensation in the condensors and the packed columns. At the start of DTE1 the CD pipework and expansion volumes were used as a temporary storage for tritium-hydrogen gas mixtures which could not be treated by the GC-system due to their low tritium concentrations until the CD operating inventory was reached.

During the DTE1 phase, the CD system was used to enrich tritium at the bottom of column 3 and to produce protium or deuterium at the top of column 1 with sufficiently low tritium levels for direct discharge to atmosphere. The tritium enriched gas mixture from the bottom of column 3 was transferred to the GC-system for final enrichment to 100%. Deuterium gas from the top of column 3 was transferred to PS-D_2 U-beds for temporary storage before injection to NIB8.

Only pure hydrogen gas must be injected into the CD system because otherwise blockage due to frozen impurities can occur. In the AGHS U-beds are used as a source for CD, providing ideal gas purity - hence no freeze-up occurred.

As mentioned above the volume of the CD system was used at the start of DTE1 first as a storage volume. During the NIB8 intervention the gas was processed in CD, and discharged via various routes and the CD system emptied again for the second phase of DTE1. CD was used during the second part of DTE1 in a very similar way.

The performance of the JET CD-system allowed discharge of protium and deuterium to atmosphere. This discharge route was very important because without it the storage capacities of the AGHS for deuterium and protium would have been exceeded.

In summary, 1.364MPa.m^3 of hydrogen gas were treated in CD during and after the DTE1 phase, 0.948MPa.m^3 were discharged to the stack and 2.2 g (880Pa.m^3) of tritium were extracted.

The hydrogen compositions achieved with the CD system at the various product extraction points show that in the H_2 and D_2 product extraction there was < 1 ppm tritium, this was sufficiently low to allow discharge of 1 m^3 of this gas within a few days.

The analysis of the product deuterium from top of column 3 showed very pure deuterium with < 50 ppm (the detection limit) of protium. The purity of the deuterium produced in CD is therefore far better than commercially available deuterium which shows as the main impurity HD of concentrations of about 0.15%.

7.2.3 Complementary operation of and comparison between GC and CD

Deuterium product of the GC system which was not re-supplied to the users was transferred to CD for further detritiation and for discharge to stack.

Tritium product from the CD system was sent to GC for final enrichment.

Deuterium and protium product of the GC system contained tritium concentrations too high for direct discharge and were therefore sent to CD for detritiation and subsequent discharge to the stack.

CD performance allowed discharge of protium- and deuterium-rich mixtures from the top of column 1 to stack.

The operation of the GC system is simple. The switching of the valves can be done either automatically or manually. Production runs for large amounts of tritium were done only in automatic mode. The GC system is operational within approximately one hour. The GC process is a batch process and requires regeneration of the columns at the end of each run.

The operation of the CD system is complex, as cascaded control loops lead to interdependence of operating parameters. The system can be operated automatically or manually. In many cases the system was operated in a mixed mode, meaning many parameters were in automatic mode with a few fixed manually. Starting of the CD system and achievement of equilibrium conditions can take time. The CD-system can be used in batch or continuous mode operation.

Both hydrogen isotope separation systems were vital to cope with the gas quantities and the total tritium inventories during the DTE1 phase. The GC system was used very often during the ‘hot’ (D-T plasma) phase of DTE1, whereas CD was very important during the end of the DTE1 phase, the clean-up period and the time of the return to D-D plasma experiments. The GC-system was necessary to produce the required tritium purity and the CD system to produce gas mixtures with tritium concentrations sufficiently low for direct discharge to stack.

7.3 Impurity Processing (IP) System

Gases which are not absorbed by the JET U-beds need to be detritiated because they contain tritiated methane, higher hydrocarbons, etc., in addition to helium, argon, neon, nitrogen, etc.

The tritium in these impurities has to be recovered for re-use and to avoid tritium emission to the environment. The removal of tritium from tritiated compounds is done in the IP system. A simplified flow diagram of IP is shown in Fig. 6.

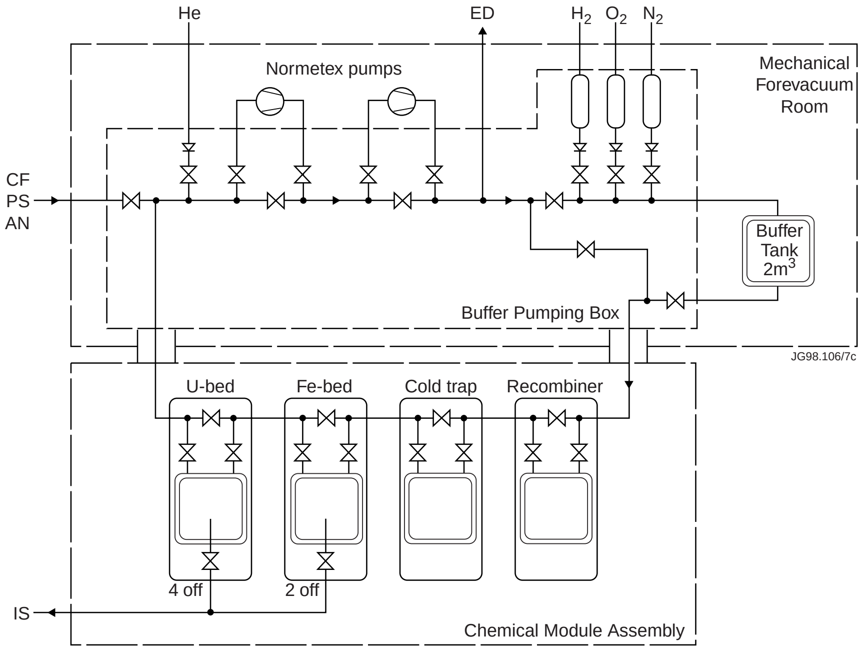


Fig. 6 Schematic flow diagram of the Impurity Processing (IP) system.

Gases which were not absorbed by U-beds in other subsystems of the AGH-plant were collected, transferred to IP and compressed via the Normetex pumps into the 2 m^3 tank or into the manifold bypassing the tank if the gas amount to be processed was small.

Various methods exist for detritiation but the sample composition should be determined beforehand in the analytical laboratory to select the best processing technique:

a) Circulation of the gas mixtures through a cold U-bed (at room temperature):

This method can be used when hydrogen forms a large part of the gas mixture.

Hydrogen will be absorbed by the U-bed when the gas mixture is circulated through the cold U-bed via the Normetex pumps. The removal of hydrogen can be observed by a decrease of the pressure in the manifold and the reduction of the tritium concentration by an ionisation chamber.

b) Circulation of the gas mixture through a hot U-bed (~800 K)

If large amounts of hydrocarbons and only small amount of hydrogen are present in the gas mixture to be processed, circulation over a hot U-bed will crack most of the hydrocarbons and hydrogen will be liberated. Finally an equilibrium between the generated hydrogen and the final composition of hydrocarbons will be reached, which can only be changed further by absorption of the generated hydrogen in a cold U-bed. (See next Section).

c) Circulation of the gas mixture through a hot U-bed (~800 K) and a cold U-bed (at room temperature) in series:

This method can be used when the gas mixture contains hydrogen and hydrocarbons.

Hydrogen already existing in the gas mixture is absorbed by the cold U-bed. The higher hydrocarbons are cracked by the hot U-bed creating uranium carbide and hydrogen gas which is absorbed in the cold U-bed. In this way the cracking of the hydrocarbons higher than methane continues quantitatively because the generated hydrogen is immediately removed.

d) Addition of oxygen and catalytic combustion:

This is used if further detritiation of the gas mixture (e.g: with respect to methane) is needed.

Figure 6 shows the possibility to add various gases such as H_2, O_2, N_2, to the 2 m^3 tank.

The purpose of oxygen addition to the tank is to burn combustible impurities (hydrocarbons, hydrogen, etc.) in the hot recombiner to water and CO/CO_2. A disadvantage is that large amounts of water are created and the U-beds used for cracking the water are used up by the irreversible reaction to uranium oxides.

To avoid the generation of explosive gas mixtures via the addition of oxygen, helium is added first to the gas mixture and oxygen only in small batches. On the hot recombiner hydrogen and hydrocarbons are burnt to water and CO/CO_2. The water is collected in a cold trap at 160 K. The process of detritiation and collection of the water on the cold trap can be seen by the drop of the ionisation chamber signal. The detritiated gas mixture containing inert gases, N_2, O_2 and CO/CO_2 is finally discharged via ED to the stack.

The cold trap is slowly warmed up, the water vapour cracked on a hot U-bed and the liberated hydrogen absorbed on a cold U-bed.

Hydrogen gas recovered and stored in a IP U-bed was transferred to one of the IS U-beds and fed to one of the two hydrogen isotope separation systems for isotopic separation.

Four U-beds are available in IP to crack water, hydrocarbons and to store hydrogen (see Fig. 6). The hydrogen capacity of these U-beds was checked again after the Remote Tile Exchange was started and most of the gases in AGHS were treated. High reductions of hydrogen absorption capacities of up to 83%, 48%, 22% and 3% were observed for UB-1, UB-2, UB-3, UB-4.

An effort was made to determine the concentration of impurities in the gases pumped from the torus systems during the second phase of DTE1 (week 38 to week 47 inclusive). The total gas quantity of impurities collected from the torus systems and AGHS was 7640Pa.m^3 which corresponds to 3.7 % of the total gas processed during that period. The compositions for the impurities are listed in Table 6. The impurities were determined with the analytical gas chromatograph. It must be noted that the Flame Ionisation Detector used in the Analytical Gas Chromatograph [7] underestimates the concentrations of tritiated hydrocarbons and that also very broad peaks were observed with very high retention times which could not be assigned to the available gas mixtures. These peaks are believed to be caused by hydrocarbons C_nQ_m with n > 3.

A more detailed description of the performance of the IP system is given in [3].

Table 6: Composition of impurities pumped from the torus systems from week 38 - 46 in 1997.

Impurity	Concentration vol %
He	1.61
N_2	0.25
O_2 + Ar	0.022
CO / CO_2	0.039
water vapour	1.2
CQ_4	0.394
C_2Q_2	0.036
C_2Q_4	0.029
C_2Q_6	0.031
C_3Q_8	0.048
total	**3.7**

7.4 Mechanical Forevacuum (MF) system

The Mechanical Forevacuum was used to pump the torus, NIBs and AGH-subsystems from atmosphere to low vacuum and to transfer gases between various AGH-subsystems. Furthermore, MF was always ready to start evacuation of the torus or of the NIBs in case a major leak occurred [22], [23].

Figure 7 shows schematically how the various pumps, Normetex pumps (PUNs) and roots pump (PUR) are interconnected. Depending on the operational needs the pumps of MF can be run in parallel or in series to achieve a large throughput or a very low base pressure.

About 14 and 8 hours were needed to pump down the torus and NIB volumes from atmosphere, respectively. Normally pumping was started with two 150 m^3/h Normetex pumps in parallel (see Fig. 7). If the pressure in the torus or the NIB was below 70kPa, only the 600 m^3/h pump was used until the pressure is below 20kPa where one of the 150 m^3/h pumps is turned on to back-up the 600 m^3/h pump. Below 100Pa the 1000 m^3/h roots pump with a 150 m^3/h Normetex pump and the two other Normetex pumps were used in parallel (see Fig. 7).

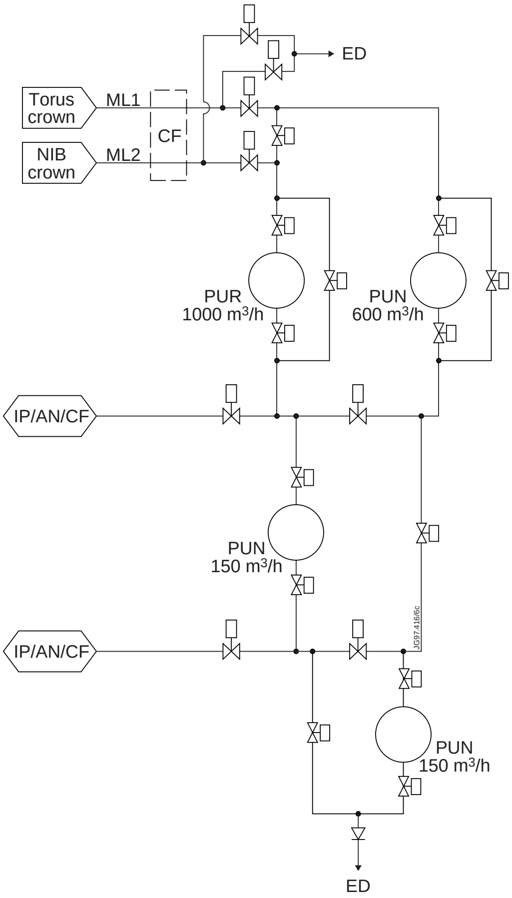


Fig. 7 Schematic flow diagram of the Mechanical Forevacuum (MF) system.

MF was very heavily used during the NIB8 intervention [17]

a) to pump the water vapour from the NIB8 cryo-pump,

b) to pump N_2 from NIB4 and NIB8 after extended soak times before their opening,

c) to purge NIB4 and NIB8 with air,

d) to keep the interspaces of the rotary valves between NIB4/NIB8 and torus differentially pumped,

e) to evacuate the NIB4 and NIB 8 after the NIB8 intervention.

MF and ED were the subsystems of the AGHS which were most heavily involved in the NIB8 intervention. Both systems coped very well the various demands and contributed to the very efficient and timely completion of the intervention.

7.5 Analytical Laboratory

Gas samples from almost all AGH-subsystems can be moved to the analytical laboratory via connecting pipework for analysis with different methods: ionisation chambers for low and high tritium concentrations, omegatron, residual gas analyser (quadrupole), katharometers and analytical gas chromatograph.

The main part of the analytical laboratory is the analytical glove box which is subdivided into three separate containments: The analytical section houses the ionisation chambers and the analytical gas chromatograph. The Make-up box houses the katharometers for checking the product quality of CD and allows connection of the Amersham U-beds for transfer of tritium to the process pipework of AN. These two compartments are the only ones in the AGHS permanently equipped with gloves. In the third section all pumps necessary for the mass spectrometers are located. The Omegatron and the quadrupole are placed inside a ventilated hood. This was permitted because due to the very low pressures the risk of a tritium release is very low. In addition, the air in the fume hood is monitored by an ionisation chamber. Upon observation of tritium concentrations slightly above detection limit in the hood, the extracted air would be switched to ED for detritiation.

318 analyses were performed with the analytical gas chromatograph (AN-GC) during and after DTE1 up to the start of the remote tile exchange. The analytical laboratory played a very important role in characterisation of the various products and processes. Detailed description of the AN-GC and of results obtained are published elsewhere in this volume [7].

7.6 Exhaust Detritiation (ED) system

Almost all gases to be discharged from the AGHS have to pass through the Exhaust Detritiation system for further detritiation. The ED system has a design detritiation factor of 1000. A detailed design overview of the ED system is given in [24].

The detritiation is achieved by burning hydrogen and hydrocarbons in hot recombiners to water and by trapping water on dry molecular sieves. The humidity levels of the gas exiting the driers is continuously monitored. When the humidity reaches a dew point of (-60 °C) the standby drier unit is switched in and the saturated drier is regenerated. At various places, e.g. before and after the recombiners, water condensors are installed with the purpose to reduce the air dew point to 4 °C in order to minimise the water load on the driers.

Under normal circumstances (e.g. no maintenance performed in AGHS and no elephant trunk used) the capacity of one drier bed was sufficient for up to 3 weeks of operations.

The ED system can be bypassed by discharges through a 10m^3 tank B4. This was often done for the exhaust gases of the analytical GC system [7] and for protium gas from top of column 1 of CD (see Section 7.2.2). In both cases this bypass was only selected when the tritium concentrations were known to be very small. In addition, the tank B4 is equipped with an ionisation chamber and software and hardwired interlocks which would switch the discharge route to ED on a high ionisation chamber reading.

Operational experience on the ED system has been discussed in [25].

Until now the ED system was used very heavily during the NIB8 intervention and the Remote Tile Exchange which followed operations in February 1998 [26]. During the NIB8 intervention the driers had to be regenerated sometimes after only about 8 to 12 hours. To increase the duty time of a drier the driers were run with dew point far higher than (-60 °C) and were changed depending on the increase of the ionisation chamber reading at the outlet of the ED system.

Very sensitive ionisation chambers monitor the tritium levels at the inlet and the outlet of EDS. High tritium concentrations were observed in the inlet with almost no tritium concentrations above background at the outlet.

The water generated in ED is collected in a 4 m^3 tank. Low tritiated water (< 5 GBq/m^3) is filled into a special bowser and the water handed over to the JET Waste Management Group. Highly tritiated water up to 800TBq/m^3 is filled into 200 L drums for shipping to CFFTP in Canada for detritiation. Even higher tritium concentrations must be diluted before any removal from the 4 m^3 tank.

At present a design study is in progress to explore the possibility of treating aqueous tritiated waste on-site by addition of a Combined Electrolysis Catalytic Exchange (CECE) module to existing equipment (CD, GC, ED).

7.7 NIB8 Intervention

During DTE1 on the 4 June 1997 a small water leak was observed in NIB8 which stopped further operation of the neutral beam injection. Manual intervention was necessary. At that time about 11 g of tritium had been supplied to NIB8. The intervention is described in detail in [6], [17].

NIB8 cryopump was warmed up to 77 K and the gases released at 77 K were pumped with CF. After a warm-up of the NIB8 cryopanels to ambient temperature, the moist air was pumped with MF directly into ED. A N_2 stream was added in MF to purge the water at the outlet of the Normetex pumps to ED and to avoid condensation at the outlet of the pumps due to the atmospheric pressure.

The torus was filled with 15kPa of pure nitrogen to avoid any ingress of air after opening the NIBs to atmosphere due to potential leaks in the rotary valves separating torus and the NIBs. During the whole NIB8 intervention the interspaces of the two rotary valves were almost continuously pumped by MF.

NIB4 and NIB8 were filled first with nitrogen gas, allowed to soak for certain times and then evacuated again by MF into ED. This allowed to establish the tritium concentrations. Afterwards air was used instead of nitrogen and finally NIB4 and NIB8 were purged by turns for hours. During these purges the MF system was bypassed and flows of generally more than 250 m^3/h were achieved by the blowers of ED.

The Injector central column [6] of NIB4 which carries the deflection magnets and the ion dumps and which was not directly exposed to tritium was moved into a ventilated plastic tent in the main assembly hall and the more contaminated column of NIB8 transferred to NIB4 where the existing Injector Box envelope acted as the secondary containment. Access for repair inside NIB8 was made via a specially constructed access cabin [17]. Access in pressurised suits was allowed for tritium concentrations <100 DAC.

During this repair work which lasted five weeks, ED supplied the necessary ventilation and detritiation of the air. Daily regeneration of the drier in duty were necessary. The water amount collected by ED was about 50-60 kg per day. The total tritium activity collected during the NIB8 intervention was 29 TBq in 1.78m^3 water. The total tritium release due to the NIB8 intervention was a few percent of the monthly discharge authorisation for HTO.

7.8 Secondary containments of the AGHS

Process pipework of the AGHS and in the supply lines/gas distribution modules in the Torus basement (Fig. 1) with internal operating gas pressures larger than 100 mbar is surrounded by secondary containment. The purpose of the secondary containment is to capture tritium leaked or permeated from process pipework and to protect workers and environment. Only the long evacuation pipework between the torus systems and CF/ MF are not secondary contained because the normal operating pressure is below 1Pa and during regenerations of the torus and NI systems cryo-pumps pressures are limited to 1kPa.

Secondary containments on the JET AGHS are either evacuated or filled with nitrogen, helium or argon. If a whole room functions as the secondary containment, e.g. the room containing the large Normetex pumps and the Exhaust Monitoring System (EMS), air is the atmosphere of the secondary containment.

The most common secondary containments are the N_2 filled valve boxes which do not contain any gloves. These boxes are kept at a pressure between -3kPa and -1.7kPa with respect to atmosphere. Downstream and upstream ‘Donkin’ valves are used to keep the pressures between these limits. If the pressure goes below -3kPa, N_2 is allowed to enter the box; if the pressure goes above -1.7kPa the upstream pressure regulator opens and gas is moved to ED.

Only the analytical glove box and the Make-up box have gloves to allow operator manipulation inside the boxes. The N_2 atmosphere is controlled between -400 and -200Pa.

In the CD system the secondary containments of the instrument and valve box are filled with helium of 180-220kPa (a). Due to the very high leak tightness of the secondary containment the pressure in these boxes stays constant. Alarms are created on the annunciator panel if the observed pressure deviates from the set value within certain limits.

After installation and connection of the boxes in the AGHS they were leak tested to the specification that starting at a pressure of -3kPa, the pressure rise observed during 24 hours must be smaller than 1kPa. During these tests correction was made for temperature and atmospheric pressure changes.

The boxes were purged once per day with N_2 to dilute possible inleakage of air. The oxygen level in the boxes was checked at regular intervals and found to be less than 0.5%.

The N_2 filled secondary containment boxes are equipped with JET designed ionisation chambers with Overhoff preamplifiers [27]. The lower detection limit is about 0.1 to 1 MBq/m^3. Any tritium leak rate is integrated for one day due to the selected purge interval of 24 hours.

Due to the very high leak tightness of the process pipework no tritium leaks into secondary containments of N_2 filled boxes were observed during the DTE1 phase which would have required operator intervention.

Major tritium concentration of up to 1000 DAC have been observed only in the secondary containment of the Make-up box of the AN glove box during the transfer of tritium from licensed Amersham U-beds to PS-T_2. The Amersham U-beds have no secondary containments. After a certain time of heating depending on the history of the U-bed and on the tritium pressure inside the U-bed a high permeation rate of tritium is observed which caused the high DAC values and internal contamination of the box. The Make-up box of AN is the only N_2 filled secondary box of AGHS which shows internal tritium contamination.

8. TRITIUM ACCOUNTANCY

The tritium amounts transferred to the AGHS were measured very accurately with precision calorimetry and (PVT-c) measurements. The relevant numbers were given in Section 5.

The tritium amounts moved via GI and GD to the users were also determined very accurately by (PVT-c) measurements.

The tritium amounts pumped back from the torus and the NIB cryo-pumps were also determined, but due to the very large volumes involved, different temperatures of the gas streams (room temperature and 77 K), small total gas amounts and the use of ionisation chambers at low and varying pressures (IC-current is a function of many parameters including pressure, gas composition, and applied voltage) the accuracy of these measurements was limited. They were used however to give a daily information of the tritium inventories in various subsystems.

For accurate determination of the tritium inventory during DTE1 the total tritium inventory in the AGHS was determined at least every second week in the following way:

a) Tritium gas mixtures were enriched with the GC-systems to nearly 100%. The enriched tritium was collected in one of the PS-T_2 U-beds. The result of this undertaking should be that only small amounts of tritium gas mixtures exist in various subsystems, mainly the GC system, because the interfractions are an unavoidable by-product of a GC separation run.

b) The tritium content in the PS-T_2 U-bed was determined by desorbing its content and performing (PVT-c) measurements using the 100 L assay volume with precision thermometer, pressure gauge and AN-GC analysis.

c) The tritium content in gas mixtures of the other subsystems was also determined via (PVT-c) measurements.

Best results are obtained with the above methods when most of the tritium was moved into GC for isotopic separation and almost no gas needs to be determined under section c).

The main finding was that a significant fraction of the available tritium (20 g) was not recovered in the AGHS, but was trapped in the torus systems [20].

Table 7 shows the tritium inventory calculated for torus and NIBs by subtraction of the measured tritium inventory in the AGHS from the total decay corrected inventory on site as a function of various dates when the inventory snapshots for the AGHS were performed. 6.2g of tritium were still retained in the machine at the start of the Remote Tile Exchange (RTE). Most of the tritium was held up in the torus internal surfaces [20], with very little in the NIB [6].

Table 7: Tritium Inventory in Torus and NIBs

DATUM	**Tritium in torus/NIBs in g**
11 July 97	2.9
14 September 97	2.3
27 September 97	3.3
6 October 97	5.3
13 October 97	7.8
21 October 97	7.5
28 October 97	7.6
4 November 97	8.4
11 November 97	10.0
21 November 97	8.4
10 December 97	7.3
14 January 98	6.8
27 January 98	6.2

In-situ transient adiabatic/isothermal calorimetry [28] can be performed with the PS-T_2 U-beds. Additional thermocouples are installed for determination of the temperature rise due to the tritium decay heat. Transient adiabatic conditions are observed because the primary process volume is surrounded by an intermediate and secondary containment which are both continuously evacuated. Isothermal conditions are achieved after cooling the U-beds for long times (15 hours) with gaseous nitrogen of room temperature. After cooling has stopped the temperature rise is observed for a few hours and the tritium content determined from the slope of the temperature rise. During the cooling and measurement phases no other work is permitted in PS-T_2 to avoid any temperature changes which means that PS-T_2 is not available for other tasks during these times. Due to these facts the in-situ calorimetric determinations were performed more out of scientific interest than operational necessity. The agreement between the calorimetric results and (PVT-c) measurements was generally better than 10%.

9. CONTROL AND INTERLOCK SYSTEMS OF THE AGHS

9.1 AGHS control system

The main control system of the AGH-plant is a Distributed Control System (DCS). In addition, two AGH-subsystems (CD and ED) are operated by Siemens PLC.

These control systems are used to control the various processes, to recognise process parameters which are drifting outside normal operating boundaries, to bring those parameters back into totally safe conditions or to stop these processes. 436 static software interlocks are installed in the DCS.

9.1.1 Distributed Control Systems (DCS)

The DCS from Fischer and Porter is connected to 3600 inputs and outputs. There are 414 analogue inputs. Control of the plant is split up between 17 Distributed Control Units (DCU-2000s). Within these DCUs, there are 140 automated sequences and 51 analogue PID loops.

Each DCU controls its section of plant independently. If there is a communications failure, or a failure of one control unit or miniframe, control for the rest of the plant is unaffected.

Four additional controllers, μDCI-4000s, are connected to the GC columns, and are used for fast switching during hydrogen isotope separation runs. They communicate to one of the DCU-2000s via an RS-485 serial link.

The DCUs are connected to a dual ETHERNET highway. The DCUs are interrogated by four PDP-11 miniframes, DOC 2500s, which each drive two operator consoles (total of eight consoles).

There are 123 graphics which can be accessed from any of the eight consoles. These are used to monitor and operate the plant.

Analogue inputs are recorded on trend displays. These displays are split up between the DOCs. There are 343 displays, trending a total of 975 points.

Part of the system consists of a new DCS, a SYSTEM SIX UNIX miniframe (the AP-6400 from Elsag-Bailey). This has been connected to the ETHERNET highway and has 24 trend displays, trending a total of 90 points. The AP-6400 drives two UNIX terminals, which display graphics and trends.

Another PDP-11 miniframe (CEU-2500) is also connected to the highway. Both the AP6400 and the CEU-2500 periodically schedule programs written in C to perform calculations such as the conversion of the measured ionisation chamber current into tritium concentrations, and tritium inventory calculations.

Complex sequential control that is deemed to be non-real-time and non-safety critical, is also carried out by periodically scheduled C programs in the CEU-2500, and sequences in a SYSTEM SIX Distributed Control Unit. (DCU-3200).

The Control and Data Acquisition System (CODAS) is a large UNIX based system custom built by JET [29]. It acts as a site wide control system. The AP-6400 has a dedicated

ETHERNET TCP/IP link to the CODAS system. Customised software enables two-way transfer of data between the AGHS plant and plant elsewhere on the JET site.

9.1.2 Stand-alone PLCs in AGHS

There are two Siemens S5-135U PLCs, which control the CD subsystem and the ED subsystem. Both have a single screen which can be used to display simple graphics and trends. These PLCs communicate to the Fischer and Porter system via separate RS-485 serial links.

9.2 Hardwired Interlock System of AGHS

A special hardwired interlock system was installed to turn off equipment (e.g. pumps, heaters) or to put valves into their fail-safe position on approaching process parameters exceeding defined operating limits and to alert the operator via audible and flashing alarms on a annunciator board in the AGHS control room. 159 hardwired interlocks are used in the AHGS. All hardwired interlock latch and continuation of the work is only possible after cure of the wrong process parameters. The hardwired interlocks can be split into three categories and are distinguished by their colour on the annunciator panel: red for imminent or actual tritium release requiring immediate operator action; yellow for potential tritium release; and white for warning only.

The hardwired interlock system employs only very simple electrical circuits such as relays to achieve a very high reliability of the system. Programmable integrated circuits were not permitted.

The hardwired interlocks were tested at least annually. If the operations program allowed the tests were performed every 6 months.

Every hardwired interlock is used to back-up a software interlock. The setpoints of the software interlocks were chosen such that the software interlock cuts in earlier than the hardwired interlock. In this way hardwired interlocks are almost never triggered.

10. SERVICES SUPPLIED TO THE AGH BUILDING

10.1 Ventilation system

The AGH-building has a once through ventilation system which holds the building under a slight under-pressure (-100 Pa) with respect to atmosphere. Extracted air is discharged to atmosphere via a monitored stack at a normal flow rate of 11 m^3/sec resulting in about 10 air changes in the main hall per hour. Containment between rooms is maintained by varying the underpressure to provide air flow from clean areas towards less clean ones.

If a tritium leak is observed in the main hall of the AGHS an emergency fan is added to the normal running fan to provide an enhanced air change rate of double the normal (20 air changes per hour). To provide the increased air flow dampers open in the building envelope.

The building ventilation also provides the ventilation for the air lock to move large equipment in and out of the building, for slightly tritiated waste stored in front of the AGH-building and for the NIB auxiliary ventilation system (see Fig. 1).

Several tritium handling facilities have an emergency clean-up system where the building air is circulated through a dedicated tritium clean-up system after a tritium release into the building. These clean-up systems are large to achieve tritium removal in a short time to reduce contamination of the building.

At JET this philosophy is only taken up partly for the small rooms which contain the impurity processing system, the analytical laboratory, product storage and the large Normetex pumps. In case tritium is observed in one of these rooms, the ventilation of this room is stopped and the room connected to the ED system via an existing elephant trunk ventilation duct. The air of the room is moved to ED for detritiation and then discharged into the environment.

10.2 Other services supplied to the AGHS

The AGH-building uses the following services supplied by other groups at JET:

i) Electrical power

The electrical power supply feeds to the AGH-building comprises three power distributions: a) to AGHS process equipment, b) to AGHS building services, ventilation, air compressors and chilled water equipment, and c) to the un-interruptable power supply (UPS).

The following AGHS essential equipments are supplied by more than one power supply feed to improve availability in the event of power supply interruptions: a) AGHS UPS, b) ED system, and c) air compressor control panel.

ii) Chilled and cooled water

Two water cooling circuits are used in the AGHS, one with chilled water at 4 C and one with cooled water at 16 C.

Chilled water is used in the various water condensors in MF and ED and to cool-down secondary containments. Low water temperature is needed in the condensors to achieve a low humidity of the air leaving the condensors and therefore a low water load on the driers.

Cooled water is used for various pumps, the turbines of the CD He-refrigerator and the aftercooler of its He compressor,

iii) Compressed air

Compressed air of 8 bar is supplied by three compressors, one always on duty, one in standby, and one as reserve or in maintenance. In addition, if all three fail, a backup system is available at 6 bar which needs to be connected manually.

iv) Nitrogen gas at 400kPa

Nitrogen at 400kPa for U-bed cooling, purge of secondary containments, etc., is available from a nitrogen ring manifold which is supplied by boil-off gas from liquid nitrogen.

v) Liquid nitrogen

Liquid nitrogen from the JET cryoplant is supplied via long cryo-transfer lines to the 0.5m^3 storage tank in the AGHS hall and from there to the various systems using liquid nitrogen such as CF, IP and AN-GC.

vi) Liquid helium

Liquid helium from the JET cryoplant is supplied via long cryo-transfer lines to the 2m^3 storage tank in the AGHS hall and from there via the liquid helium distribution box to the ten cryopumps of CF.

11. FAILURE OF EQUIPMENT IN AGHS DURING DTE1

In general, operation of the AGHS was highly reliable during the whole of 1997 and 1998. In the following only repairs performed during the main DTE1 phase whilst D_2 and/or T_2 were supplied to the users are discussed.

11.1 Bearing problem of one of the three blowers of ED

A blower/fan in the ED system became very noisy and showed strong vibrations.

The blower was dismantled and the new bearing installed, but the new assembly failed again because the old bearing had slightly worn out the bearing sleeves. The complete replacement of the bearing and housing solved the problem.

11.2 Butterfly valves in ED

Butterfly valves are used in ED due to limited space. The open/close mechanism of these valves was found not to function correctly and finally the valve seats became almost immobile.

Examination of the valves revealed corrosion effects due to high humidity with the effect that the valve actuating mechanism became stiff and finally seized. In one of the valves the shaft which operates the sealing disc was found to be broken. As a short term solution these valves were exchanged on all driers of ED with new ones, but the long term solution will be to use a different type of corrosion resistant valve. A totally new valve means a modification of the ED system which has to be assessed and approved by the modification approval procedure [22].

Before the breach of the process pipework the ED driers had to be purged thoroughly. No tritium contamination of the interior pipework was observed by smear test as well as no airborne tritium activity.

11.3 Oil circulation pump of the GC system

The columns of the GC system are regenerated by heating the heat transfer fluid (a special oil) normally to 200° C and in special cases to 300° C. This is done by circulation of the oil through a heater and a heat exchanger by means of a dedicated oil circulation pump.

On one occasion it was found that the oil pump could not be started. The drive motor was found to be the problem, but due to the construction of the pump the motor could not be exchanged.

The oil was checked for contamination with tritium with a null result. This was expected from the design which had separated the Pd filled columns from the oil filled columns by a 1 mm wide gap filled with the nitrogen. As a result the oil pump could be removed without the establishment of a controlled area.

A new pump was ordered and installed within a few days. The DTE1 program was not delayed by this problem.

11.4 Exchange of a Helicoflex seal in one of the Normetex pumps of IP

A tritium leak was observed at the outlet of one of the IP Normetex pumps. The leak was finally identified by using a He leak detector. The leaking Helicoflex seal was exchanged.

With the new seal installed the Normetex pump was again leak tight. The occurrence of this leak was probably caused by high humidity at the outlet of the pumps (in the IP process water is created by design) which caused corrosion of the helicoflex seal liner (aluminium). A new helicoflex seal with a Ag liner was installed to prevent repetition of the problem.

11.5 Leak in a valve of PS-T_2

Just before the start of DTE1 a small leak was observed in the PS-T_2 U-bed outlet manifold with tritium pressures above 150kPa (a). The bellow of the boundary valve of UB-5 (see Fig. 2) was identified as the cause of the leak. The maximum leak rate observed with a He leak detector was in the 10^{-9}Pa.m^3.s^{-1} range. The valve was not replaced due to the imminent DTE1 phase, but the usual Cajon seal was replaced by a blind disc and the compressed air supply to actuate the fail closed valve was removed. In this way the leak of the bellow could not come in contact with any tritium. The disadvantage was that only three of the four PS-T_2 U-beds were available for the DTE1 phase with UB-5 (see Fig. 2) acting as a back-up.

12. SUMMARY OF THE EXPERIENCE WITH THE AGHS DURING DTE 1

12.1 General

All subsystems of the AGHS performed very well during and after DTE1. The AGHS fulfilled all requirements (such as supply of pure tritium, tritium storage, pumping, hydrogen isotope separation, detritiation of impurities, purging, pump down from atmospheric pressure, discharges of protium and deuterium, etc.) during normal operation of the torus and during repairs of equipment connected to the torus. A further very important point is that all subsystems designed, constructed and commissioned were in fact used during DTE1 and were necessary for the functioning of the whole AGHS and the processing of the gases.

This is the result of a good design, careful inactive and active commissioning, the installation of necessary modifications and a well trained and dedicated staff.

The shift teams were able to maintain the plant. The highest dose received by one member during one of the maintenance jobs was 85 μSv [27].

No unauthorised or unplanned tritium releases occurred inside the AGHS or via the stack. Any tritium discharges were far below the approved daily tritium release limit.

The AGH plant can therefore supply with confidence the requested services for further future deuterium tritium experiments (e.g. DTE1b, DTE2).

The AGHS demonstrated for the first time that tritium in large amounts can be processed and recycled in an efficient and safe way during a tritium phase of a large fusion machine. This is an important step on the way to the use of fusion machines for energy production.

12.2 Tritium Releases From JET Site

Tritium released into the environment is measured in the various stacks at JET. From 7 May 1997 (before start of DTE1) until 9 February 1998 (after start of remote tile exchange) 1.6 TBq of HTO and 1.49 TBq of HT and other tritiated gases were discharged from the AGH-building into the environment. These numbers are to be compared with the annual (monthly) discharge authorisation of 90 TBq (20 TBq) for HTO and 110 TBq (25 TBq) for HT and others.

The discharges were from gas streams where further detritiation was not practicable (e.g. contaminated gas from impurity processing system, product from top of column 1 of CD, samples analysed in AN-GC), and from repairs on torus systems.

12.3 Areas Of Improvements In AGHS

12.3.1 Accountancy

Day by day accountancy, especially of the gases pumped back from the torus systems was inaccurate due to the pressure gauges used, small gas quantities and the very large volumes involved.

Improvements could be made by the use of capacitance manometers which would also be of advantage in various AGH-subsystems.

12.3.2 Ionisation Chambers

The interpretation of ionisation chamber readings was found to be difficult due to their dependence on pressure.

This could be corrected for by using ionisation chambers in combination with pressure gauges and implementing correction factors in the software.

However, further ambiguities arising from the gas compositions, dependent sensitivity and contamination effects would still remain a problem.

12.3.3 Transfer of gas from CF to IS

The transfer of gas from CF to IS was the main bottleneck in the AGHS.

Installation of pumps in the three transfer lines between CF and IS to evacuate the large CF volumes and to compress the gas into the IS U-beds would reduce the time needed for transfer drastically.

12.3.4 Restricted use of manifolds

A few manifolds, e.g. the PS U-bed outlet manifolds, were used during the day’s operation to supply gas to the users and during the night shift to pump the unused gas back to PS. At the same time these manifolds were needed to remove blanketing gas from U-beds in PS used to absorb gas enriched in CD and GC. These processes could not be done at the same time.

Installation of new pipework in PS and other systems would help to solve this problem.

12.3.5 Impurity Processing system

One of the main disadvantages of the JET impurity processing system is the consumption of uranium by cracking water and/or hydrocarbons and the formation of uranium-oxide and/or carbide. For further processing in IP the spent U-beds are to be replaced by fresh ones. The consumed beds have to be treated as special waste due to their uranium content and the additional contamination by tritium.

In recent years large progress has been achieved in the processing of tritium containing impurities. Total detritiation factors of up to 10^8 seem to be possible for integral process concepts in ITER [30].

As mentioned in Section 7.3 high reductions of hydrogen absorption capacities of up to 83%, 48%, 22% and 3% were observed for UB-1, UB-2, UB-3, UB-4 in the JET IP system. Both UB-1 and UB-2 need replacement before the start of the next tritium experiment.

The best solution is to modify parts of IP such that modern techniques can be used which do not need any U-bed replacement.

12.3.6 Further Enhancements Of The AGH-Plant

The full operation of all AGH-subsystems highlighted the possibility of simple installations which can accelerate and simplify the processing of the various gases.

Only a few of these possible enhancements will be mentioned here. They include the installation of: new pipework in CF to by-pass the large expansion volumes; mass flow controllers in GC to achieve constant flows during separation runs; ionisation chambers of higher sensitivity and lower contamination memory effects in CD; a new interconnecting line between bottom of column 3 of CD and GC for transfer of not fully enriched tritium; a new pumping circuit for PS-D_2 to avoid cross contamination between the deuterium and tritium systems of PS; more accurate flow meters and new non-corroding valves in ED to avoid the regular exchange of the valves now installed; and new liquid helium transfer lines to the JET cryoplant to reduce helium consumption.

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