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ABSTRACT
The Active Gas Handling System (AGHS) of the JET Facilities has been operating in conjunction with the JET machine since it was connected in Spring 1997. Initial estimates of the period of time that the AGHS would be needed to detritiate the machine exhaust gases was of the order of a year. However tritium emanation from the machine and the in vessel inventory has meant that the AGHS has operated continuously since this time. It has therefore been necessary to continue operations whilst also carrying out plant development and maintenance.

1. INTRODUCTION
The AGHS is designed to detritiate the exhaust gasses of the JET machine, to separate out hydrogen species from these gasses and to isotopically enrich the tritium, ready for re- injection into the machine as part of D-T experiments. This ability to operate with D-T plasmas is unique to the JET machine.

2. THE HISTORY OF THE AGHS
Construction of the AGHS started in 1989 and the process plant was installed and inactively commissioned [1] up to 1995. The system was then actively commissioned with first 0.1g and then 3g tritium [2]. For the DTE experiment [3] in 1997 20g of tritium was transferred into the system. This experiment concluded in December 1997 and after a period of clean-up [4], the vessel was vented to atmosphere and the MKIIA divertor was removed and replaced with the MKII GB divertor. At the beginning of this Remote Tile Exchange [5] (RTE) 6g of tritium remained within the machine. The Exhaust Detritiation System (EDS) was used to provide detritiating ventilation during this operation [6] recovering 2g of tritium from the machine in the form of tritiated water. Machine Operations continued from September 1998 through to May 1999 [7] when the machine was again vented to atmosphere to install an inboard Pellet Injection (PI) track (PIT shutdown). A short period of operations then occurred before the plant was put into a benign condition at the end of 1999 and handed over to the UKAEA. In the new organisation the UKAEA operate the JET facilities under the European Fusion Development Agreement (EFDA). Four successful plasma campaigns have been carried out under the new organisation and a major series of modifications undertaken including the remote removal of the septum from the divertor (SRP shutdown).

3. OPERATIONS
The manning levels in the AGHS are determined by the nature of operations being carried out. During tritium operations it was required that the plant was manned 24hrs per day by shift teams composing of 4 men. Now with D-D operations it is only necessary to man the plant during plasma operations with a shift team of 2 men. Each shift must be lead by a qualified Operations engineer who is responsible for the safe operation of the plant reporting to the Group Leader and Authority to Operate (ATO) Holder for the AGHS. The ATO lists the constraints within which the plant may be operated. With AGHS unmanned the plant is monitored by main JET Control Room (J2) Shift Technicians who are present 24hr a day all year round. They monitor the AGHS remotely via a terminal connected to the

AGHS control system but situated in the main control room, via a series of hard wired alarms which appear on the J2 emergency desk and by routine tours of the plant. They also have the facility to monitor the AGHS main annunciator panel by Closed circuit television. The shift technicians have been trained to carry out some of the routine plant operations such as the switching of EDS driers and the regeneration of these dryers. The plant must be placed into a defined and safe state prior to hand over to the shift technicains and the duty Operations Engineer must provide a handover document that details the status of the plant and any monitoring requirements whilst the plant is unmanned. The Operations Engineer then remains on call until the plant is next manned.

11.5g of the original 20g inventory remain available for use within the AGHS. The discrepancy between these two figures is due to decay; tritium converted to tritiated water and tritium held in machine components such as flakes and tiles. The difference between the book value for the tritium on the JET site and the amount of tritium measured within the AGHS is defined as the Material in Process and represents the tritium external to the AGHS trapped in machine components. This includes the MKIIA divertor tiles removed from the Vessel during the RTE, the tritium content of which has been estimated as 60mg [8].

Figure 1 shows the way the Material in Process has varied since 1998.

A tritium accountancy report is filed annually and independent inspectors also visit the site whenever a significant change in the inventory is taking place e.g. transfer of more tritium into the AGHS from an external source. These inspectors also carry out an annual tritium inspection usually lasting two days. Here they inspect the tritium accountancy records and also request that a demonstration PVT measurement is carried out on the bulk of the pure tritium held within the Product Storage System.

4. PLANT RELIABILITY, REDUNDANCY AND FLEXIBILITY

The continuous operation of the AGHS since DTE1 has been facilitated by the built in redundancy and flexibility of the plant design. In most cases the failure of a single component in a system has not meant that the system itself has failed. The following are the more significant failures since DT operations started.

CRYOGENIC FOREVACUUM (CF)

Failure of Module 4 vacuum inter-space turbo pump. The pump was replaced from spares. CF is composed of five pumping modules. Modules 1 and 2 are liquid nitrogen cooled module 3, 4 and 5 are, liquid nitrogen and liquid helium cooled. Module 4 only was affected. Modules 4 and 5 are identical with two Accumulation Cryo-panels each therefore there was sufficient redundancy that there was no effect upon operations.

Failure of roughing pump in the vacuum inter-space backing line. The pump was replaced from spares. This pump provides backing for all the CF vacuum inter-space turbo pumps. Mechanical pumping of the torus was used whilst the pump was replaced therefore there was no effect upon operations however in DT operations this would have caused a delay in tritium injection until the fault was repaired.

Intermittent failure of the liquid helium level sensors. The level sensors of both the LHe dewar and the LHe valve box failed at different times. Both filling sequences for these two boxes are interrelated. Often the failure occurred when a certain LHe level was reached and so the set points in the control sequences could be changed so that filling took place before reaching this level. Thus enabling the continued availability of the system until it was operationally possible to replace the probe. This fault could lead to the spontaneous regeneration of a CF Cryo-pump, which could have led to gas being released back into the torus, thus preventing machine operations.

MECHANICAL FOREVACUUM (MF)

Failure of Normetex pumps. One of the most significant failures within the AGHS has been that of three Normetex pumps (2x150m3/hr and 1x 600m^3/hr) in the MF System. All three have exhibited the same failure mode namely binding of the pump scrolls. As a short-term solution to this problem the pipe work of one of the 150m3/hr Normetex pumps from the IP system was modified to connect it to the MF system. The Normetex Pumps are housed in the MF Casemate, a room that acts as secondary containment for the pumps and their associated pipe-work. It was therefore not possible to replace them during operations. Previous maintenance work has lead to the room becoming contaminated with tritium to 100Bq/cm^2 on average. This room was built around the pumps and therefore had to be dismantled to allow the pumps to be removed. This work was successfully carried out over the summer and the three pumps now sit in the AGHS main process area. From here they will be moved to the Beryllium handling Facility where they will be dismantled by operators wearing pressurised suits to precisely determine the mechanism of failure and investigate potential repair. The removal of these pumps was a significant achievement in a contaminated area with restricted access to the pumps. It should be noted that the pumps are relatively young in terms of operating hours (17,000) and it is speculated that the failure mechanism is due to internal corrosion caused by exposure to moisture from pumping atmospheric air after interventions and following water leaks. The defective pumps have been replaced with Leybold Duradry pumps which will be used for D-D operations whilst a permanent solution is found.

PRODUCT STORAGE (PS)

Failure of metal bellows pump. Pump to be replaced from
spares. Metal bellows pump provides backing to 15m3/hr Normetex pump therefore the system could continue to operate but at a reduced maximum pressure.

GAS INTRODUCTION (GI)

Failure of process tritium monitors

One particular unit showed multiple failures associated with the temperature rise in a cabinet densely packed with electronics. Cabinet cooling was improved to prevent this. A number (5) of these units have failed during operations. As they are readily replaced this does not cause a significant effect upon operations however since they are part of the hard wired interlock system and fail safe they do shut down the sub-system which they are monitoring and therefore cause a short term delay whilst they are replaced.

CRYODISTILLATION (CD)

Control card failure in programmable logic controller.

Replaced from spare

Δ**P cell failure**. Replaced from spares

Control valve failure of helium circuit. Valve removed and repaired.

Each of these failures caused the CD system to trip, shutting down the helium cooling loop. The major delay associated with the Cryo-distillation system is that if the helium cooling is lost and the system temperature rises above 50K then software interlocks prevent cool down until the whole system has reached ambient temperature. This is to prevent excessive thermal stresses occurring in the columns. Warm up to ambient temperature can take up to five days with an additional day for cool down. This could potentially impact on DT operations but had little effect upon DD operations as there is sufficient capacity in the IS Uranium beds to act as a buffer store until the system is warmed and re-cooled.

OVER/UNDER-PRESSURE PROTECTION SYSTEM (OUPS)

Failures of valve diaphragms. These were replaced routinely with no significant consequence for operations.

EXHAUST DETRITIATION SYSTEM (EDS)

Failure of blower bearings. Blower vibration monitored and bearings replaced when significant wear is indicated. The three identical dryer racks of the EDS system mean that such breakdown maintenance is possible without jeopardising operations.

Failure of Regeneration Phase II Vatterfly valves. Valves are replaced upon failure and a suitable alternative valve type has been identified.

Failure of Siemens Programmable Logic Controller (PLC) power supply cooling fan. This was a failure of a trivial component however it lead to EDS becoming unavailable for several hours whilst the cause was diagnosed and remedied. The EDS is one of the key safety systems permitting tritium plasma operations and consequently a number of hard-wired interlocks generate a pulse inhibit signal when EDS becomes unavailable. Two schemes have been proposed to prevent a loss of EDS should the PLC fail. Firstly the provision of a standby PLC which will take over control of the system in the event of the duty PLC failing and secondly the modification of EDS to permit manual operation of it’s valves heaters and blowers.

This is by no means an exhaustive list of equipment failures but covers those most significant to operations. An exercise is currently underway to analyse all plant and component failures associated with the AGHS and the machine to compare actual failure rates with those used for failure analysis.

BUILDING SERVICES.

One of the main causes of un-planned plant down time is the failure of building services such as compressed air, chilled water and electrical power. The AGHS was designed so that in the event of a loss of these services the plant would go to a fail-safe state and therefore in terms of safety the system is tolerant of these outages. Where such outages have occurred the root cause has been identified and where possible modifications have been carried out to prevent re-occurrence and improve the reliability of supply.

The loss of process chilled water occurred on several occasions. The main effects of this were the tripping of various water-cooled pumps. Perhaps the most important of which were the turbines in the CD compressor. The significance of tripping the CD refrigeration has been highlighted previously in this section. The Normetex pumps were also sensitive to a loss of chilled water and would tend to trip. The EDS system proved fairly tolerant to a loss of chilled water mainly due to the regenerative heat exchanger cooling the gas as it leaves the recombiner. However a dryer in regeneration would soon trip due to the high temperature at the blower inlet due to chiller becoming warm.

PLANNED OUTAGES.

There have been a number of planned outages of site power either for maintenance or for upgrades to improve the security of supply. These have needed to be managed to minimise discharges of tritium to the environment.

Before these outages an assessment was made by measurement of tritium out gassing rates from the various sources ventilated to EDS to determine the potential releases into the AGHS building or to the environment. In many cases the out-gassing sources were isolated prior to the outage. The plant was then placed in a safe state such that the outage would not cause plant damage, tritium release or a delay to operations once power was restored.

A similar but more extensive exercise was carried out for the handover from the JET Joint Undertaking to the UKAEA, which coincided with the turn of the millennium and the potential for problems associated with Y2K non-compliance.

5. MODIFICATIONS/UPGRADES/IMPROVEMENTS

A number of modifications have been proposed for the AGHS. Most significant to date has been the upgrade of the Impurity Processing System. The basis of this modification is the replacement of the IP iron beds with a nickel catalyst and palladium permeator combination and the replacement of one of the IP uranium beds. This modification has been installed and inactively commissioned and is detailed in another paper at this conference [9].

In addition to supporting the machine operations the AGHS is unique in being able to be used as a test bed for testing ITER tritium handling devices using gases from the exhaust of an operating tokamak and with tritium. Two such projects are proposed, the installation of a permcat reactor in the discharge line of the IP system and the installation of an ITER design cryo panel in the CF system shown in Figure 3.

Other upgrades to the AGHS have been proposed, designed and fabricated and will be installed prior to the next tritium campaign. Most notably a modification to the PS system to permit the coincident feed and absorption of tritium. During DTE1 it was considered that the potential for the mixture of in process gas being absorbed from the PS-T2 tank and gas being fed from another PS-T2 uranium bed was too high. The provision of another outlet manifold is considered to be sufficient to reduce this potential.

Another modification which arose from the experience during the DTE 1 experiment was to reduce the time taken to regenerate the machine cryo pumps. When the cryo pumps are regenerated from 4K to 77K the released gas is held in the machine for a period whilst the cryo panels come fully to temperature and measurement of the tritium and oxygen content of the released gases is carried out in the AGHS. This delay in pumping by the AGHS causes an increase of tritium permeation through the vacuum vessel which is heated to 320^{o}C. It is proposed to add mechanical pumps to the Exhaust monitoring sub system (EMS) which contains ion chambers to determine the tritium concentration of the regenerated gas in order to reduce this measurement time. A related modification was the provision of a calibration system for the real time west wing oxygen monitors [10] to reduce the time delay inherent in using the EMS.

6. TRITIUM RETENTION/ OUT GASSING

The residual levels of tritium remaining in the vessel from the DTE1 experiment and the associated out-gassing of tritium require that the AGHS continue to detritiate the exhaust gas of the machine and for the EDS to provide detritiating ventilation during machine interventions.

The typical rate of tritium release during operations in 2000 was 60GBq/day for the Torus, 36GBq/week for Neutral Injection Box (NIB) Octant 8 and 10GBq/week NIB Octant 4.

Similarly the tritium levels in the vessel when ventilated to EDS has fallen as shown.

CONCLUSION

The AGHS has operated continuously since spring 1997 with very few problems. The plant is sufficiently flexible in design that most of the component failures which have occurred have not caused significant operational delays. The AGHS will continue to detritiate the machine exhaust in order to minimise tritium discharges to the environment.

ACKNOWLEDGEMENT

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Table I: Tritium Recovered from Pumped Divertor Regenerations

Year	No of Regenerations	Days Operations	Total Gas Pumped bar litre	Total Tritium Pumped bar litre	Average Tritium Concentration percent	Tritium Recovered mg/day
1998	40	91	1566	0.31	0.0198	0.843
1999	64	159	1936	0.19	0.009	0.296
2000	53	150	2709	0.12	0.004	0.198
2001	42	61	2045	0.04	0.002	0.162

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Table II: In vessel tritium concentration compared to vessel tritium inventory and water collected in EDS during shutdown.

Shutdown	Average Tritium Concentration in Vessel MBq/m^3	Tritium in Vessel (MIP) g	Tritium collected at tritiated water g
RTE (1998)	117	6.2	2
PIT (1999)	55	2.7	0.27
SRP (2001)	23	1.6	Ongoing

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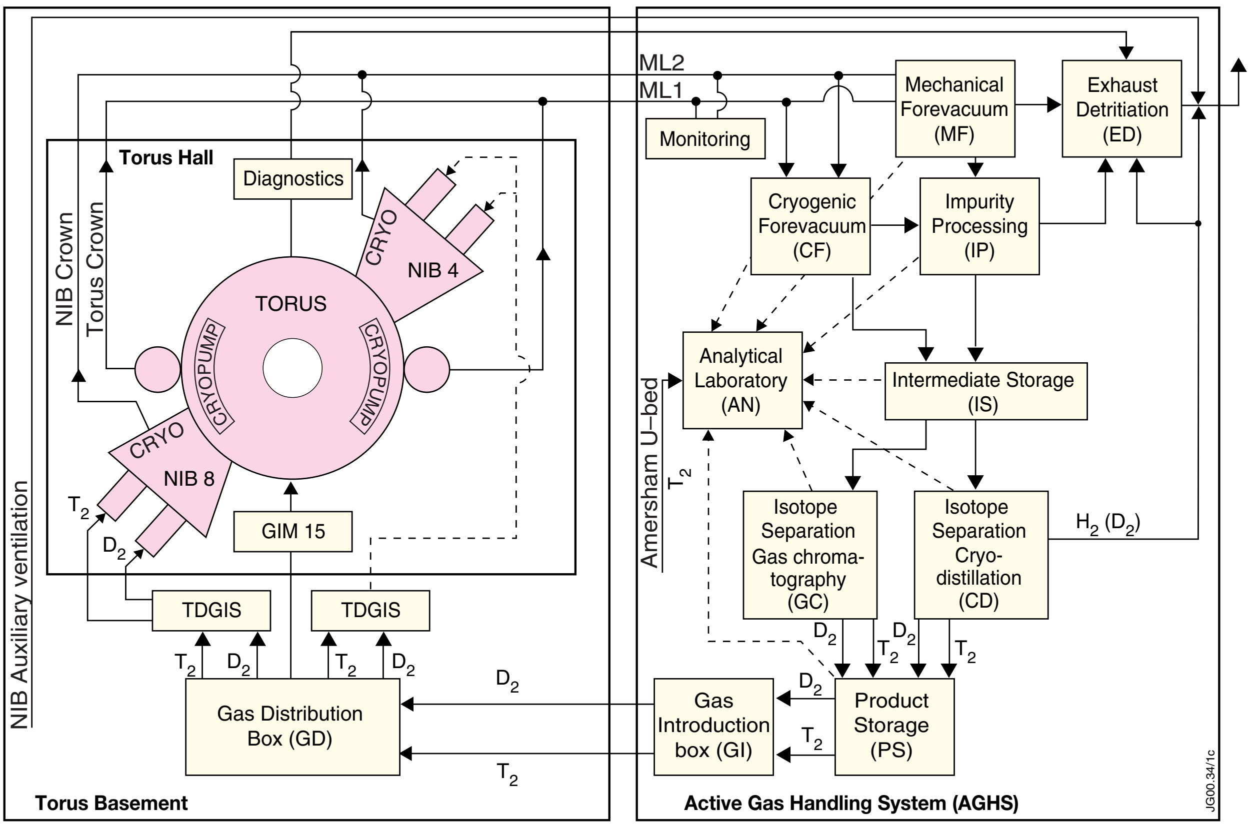

Figure 1: Tritium Recycling at JET.

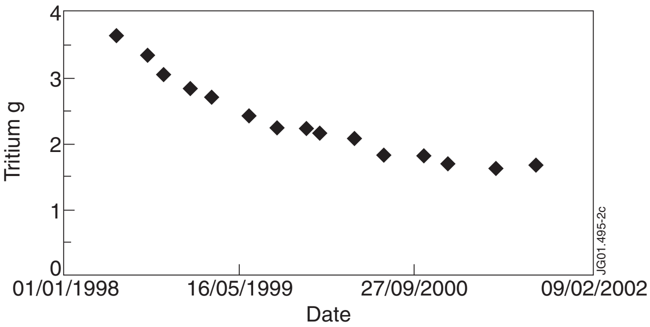

Figure 2: Tritium external to the AGHS.

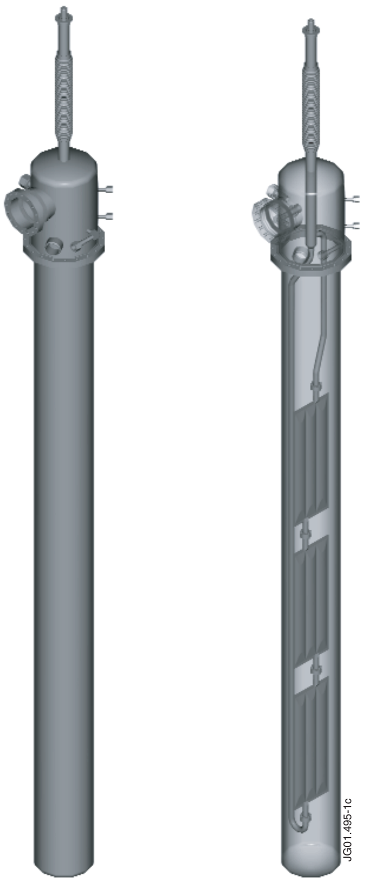

Figure 3: ITER Cryopanel in CF module 5.