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JET Tritium Inventory – Control and Measurement During DT, Shutdown and DD Operational Phases

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ABSTRACT

DT plasma operations took place at JET from May to November 1997. The site tritium inventory was 20 g and this was recycled several times using this Active Gas Handling System to recover tritium from mixed exhaust gases. The amount of tritium available for use at any time was determined by the hold-up in in-vessel components, in-process inventory, and losses via permeation and transfer to waste. It was therefore necessary to continually assess the tritium inventory through on-line and batch measurements.

During shutdown periods, tritium continued to be evolved from the machine and its trapped volumes. This meant that a large number of specific measurements were necessary to ensure that safety requirements were met and that waste could be properly characterised.

During DD operations, the exhaust gas from the machine contained quantities of tritium too great to be discharged to atmosphere and must continue to be processed by the AGHS. The techniques for tritium inventory assessment are reviewed, taking into account continuing uncertainties and plans for resolutions of these. The JET experiment is used to highlight issues of tritium inventory control which will apply to future fusion reactors.

1. INTRODUCTION

Following a successful Preliminary Tritium Experiment in 1991 [1], a second phase of DT experiments in the JET machine was carried out in 1997 (DTE1). Whereas the PTE used a "once-through" configuration for tritium fuelling with 0.25 g on-site, the DTE1 experiments, which occupied the period from May 1997 to November 1997 required up to several grams to be injected into the machine each day and recycling of tritium to minimise the inventory required and environmental discharges [2].

A plant, the so-called Active Gas Handling System (AGHS) had been constructed to permit recycling of tritium and to perform certain safety-related functions in respect of particular torus accident scenarios [3]. This plant was commissioned using 3 g of tritium in 1996 with a further 12 g being brought on site in preparation for DTE1 in 1997. However consideration of the planned experiments involving the loading of tritium into the wall of the vacuum vessel led to a further 5 g being delivered at the beginning of DTE1. A total of 160 g was recycled during the experiments.

The tritium was supplied by Ontario Hydro (now Ontario Power Generation) under a contract which specified that inspection and monitoring regimes were required to demonstrate that it was used in accordance with the contract. Ontario Hydro appointed Euratom to ensure that the tritium accountancy was being correctly performed. Although there are no treaty obligations for tritium accountancy and safeguards, the same standards of reporting were adopted as if it were. The difficulty of assessing the inventory of the torus was recognised and it was

agreed that JET would be a single Material Balance Area. The unit of accountancy was the gram and reporting precision of 1 mg was required. Yearly inspections by Euratom have taken place since 1997 which generally involve a specific inventory taking operation.

Tritium accountancy was also necessary to determine the influence of operating parameters on the retention in the machine and to ensure the assumptions on tritium inventory which were made if the safety case remained valid [4]. This also enabled the legal requirements of the UK Ionising Radiation Regulations to be fulfilled. During the tritium plasma experiments, up to 40 % of the injected tritium was retained in the vessel after each pulse and released slowly. An equilibrium of about 17 % of the injected tritium was eventually retained and progressively released during subsequent DD operation and shutdowns.

The continuing evolution of tritium from the machine after DT injection ceased has meant that the recycling plant has continued in operation in order to minimise the environmental impact. About 2 % of the injected tritium is currently estimated to remain in the torus and the presence of tritium in waste and as a hazard in the workplace remains an issue which affects procedures used at JET. The JET experience with tritium provides a number of valuable lessons in the handling of tritium accountancy and related issues in future DT fusion devices.

2. OVERVIEW OF TRITIUM FUEL CYCLE OF THE JET MACHINE

A schematic of the tritium and deuterium fuel cycle is shown in Figure 1. Tritium was delivered to site using Amersham Type B (U) uranium beds and loaded via the Analytical system into Product Storage (PS). Along with deuterium, it can then be supplied to the Neutral Beam Injector(s) and/or fed directly into the torus.

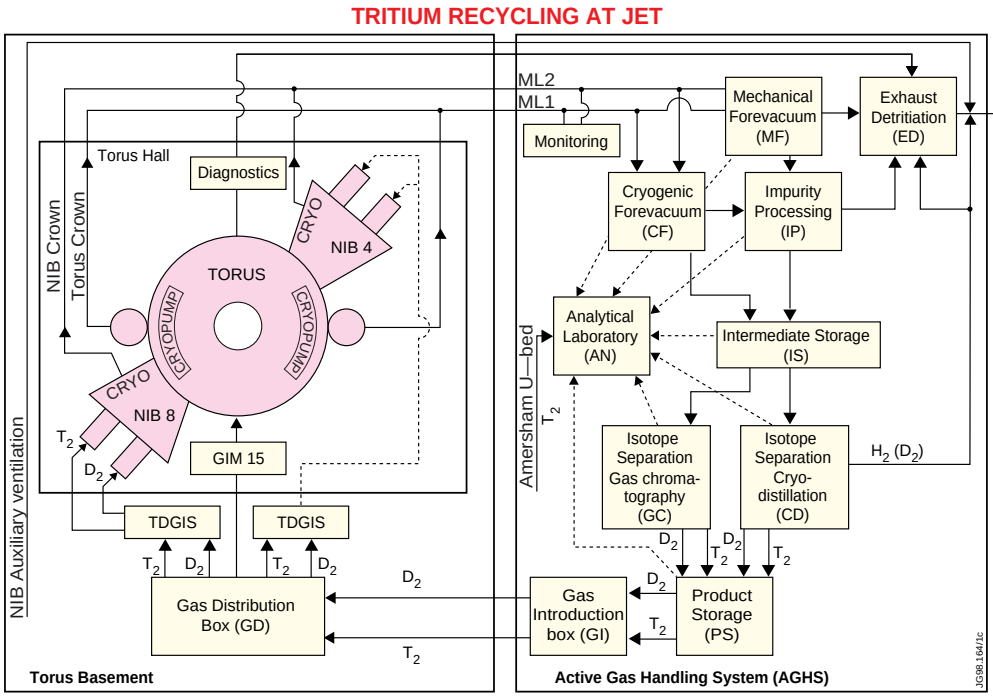

Figure 1: JET Tritium and Deuterium Fuel Cycle

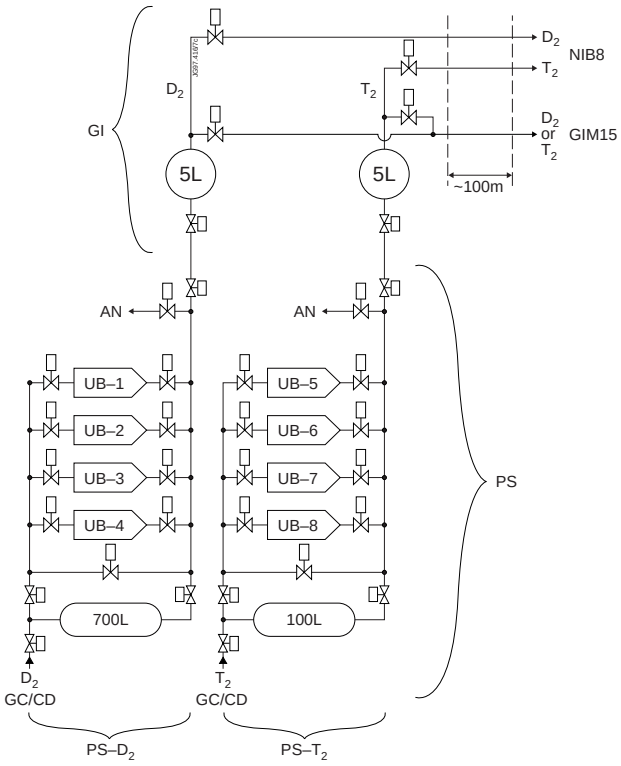

Figure 2: Gas Feeds from AGHS

During plasma operation gas is mainly pumped by the He cryopumps in the two Neutral Injection Boxes and in the Divertor [5]. These pumps are regenerated periodically and the gas transferred to cryopumps in the AGHS which provide the backing vacuum for the machine turbomolecular pumps. By selective heating and use of the hydrogen scrubbing ability of uranium beds in the Intermediate Storage (IS) system, mixed hydrogen isotopes are transferred to IS and impurities, including tritiated hydrocarbons, to Impurity Processing (IP) [6]. This system recovers the tritium from the impurities and transfers them to IS. In the case of mixed batches with high tritium content, a gas chromatography system purifies D and T to > 99.5 % and they are sent to PS where they are stored on uranium beds for resupply to the machine. 160 g of tritium have been processed through this route. Streams with tritium content <<1 % are directed to the continuously running Cryodistillation System [7] which can detritiate H and D streams to permit their discharge to atmosphere. This system is used particularly during DD operation and has processed around 20 m^3 to mid-2000.

In order to comply with the design safety principles of the plant, systems in which pressure can rise above atmospheric are doubly contained with the containment systems provided with tritium monitors and capable of being directed to the Exhaust Detritiation System (EDS) which collects tritium as tritiated water [8]. Storage of hydrogen isotopes in the AGHS is mainly in uranium beds (Figure 2) which are capable of storing 27 moles in the case of deuterium and 6 moles in the case of those dedicated to tritium. Uranium has the characteristic of releasing hydrogen isotopes at a pressure of around 1 bar when heated to 420 ºC whilst having a very low equilibrium pressure at room temperature. It is therefore well suited to pumping and storage [9].

3. GAS FEEDS TO TORUS

A schematic of the gas supply system from the AGHS is shown in Figure 2. The gas is supplied from the PS uranium beds. The gas from PS is passed through a measurement reservoir to a matrix of valves which supply a Tritium/Deuterium Gas Introduction System (TDGIS) for each of the two sets of eight NB injectors at octant 4 and octant 8 positions on the torus. A calibrated needle valve and pressure transducer enables flows to be computed [10].

The feed direct to the torus was also supplied from the AGHS valve matrix through a fast-acting Piezovalve [11] to the torus midplane or divertor region. Gas injected can be measured by the change of pressure in the supply reservoir. Unused gas can be pumped back to the AGHS from the torus and NB injection systems for re-use. The volumes of the systems and the measurement reservoirs in the AGHS were matched to the original requirements when the plant was specified. However changed experimental requirements involving higher torus injection rates required for wall loading meant that the transfer lines needed to be included as part of the supply reservoir, thus complicating the supply accountancy and valve sequencing.

A separate set of gas injection points on the torus could be used for deuterium and other non-active gases. This meant that there was always an excess of deuterium which was required to be detritiated and discharged via the CryoDistillation (CD) system.

4. ROUTES FOR TRITIUM LOSSES

There are two types of losses: those where tritium is lost from the fuel cycle in a form which does not permit it to be reused; and those where recovery is possible but the inventory is not available for immediate re-use. Together these determined the minimum operational inventory for the cycle. Apart from decay, those in the first category are losses to waste and ALARA considerations therefore apply. This means that possible options for recovery processes must be considered before a commitment to a particular disposal route is made. An important consideration has been the use of the EDS to comply with the ALARA principle. JET was authorised to discharge tritium to atmosphere and also through a pipeline to the river Thames set down in Table 1.

TABLE 1

Discharge Authorisations

Year	Gaseous (Annual)		Liquid (Monthly)
	HTO	Other Tritiated Species	
1991-1999	90 TBq	110 TBq	2 TBq
2000 onwards	50 TBq	50 TBq	0.5 TBq

The liquid route was justified on the basis that the critical group dose per unit release was less than that for HTO discharges to atmosphere [12]. Where practicable, the original design of systems directed most HTO discharges to EDS and provision was made for process elemental gaseous waste to be discharged directly. In addition, purging with process gas was intended to take place prior to maintenance so that the gas could be processed and tritium recovered. The experience during AGHS active commissioning which involved maintenance of processes systems which had surfaces exposed to mainly elemental tritium confirmed that this was practicable.

However the initial experience with torus systems maintenance was that the evolution was significantly greater and predominantly in the form of HTO. Even after purging with gas which could be processed, exposure to atmospheric air led to significant release [13] which if discharged, would have led to measurable tritium off-site. All routes for significant activity including the torus during shutdowns and gloveboxes handling high activity material were from then on therefore directed to EDS with the water collected. The arisings were much greater than the liquid discharge authorisations and, even for lower level streams, were above the concentration limit for discharge and would require excessive storage and dilution to permit discharge. A provision in the tritium supply contract for return of tritiated water, which had been made to cover arisings from large accidents, could however be invoked and the tritiated water sent to Canada where the tritium is recovered for re-use. The ability to process tritiated water has become even more important as a result of regulatory pressure to reduce discharges even around the insignificant level of 10 μSv.

Areas with high volumetric throughput such as the torus access systems where the intention is to minimise the tritium concentration and thus operator dose are vented direct to atmosphere as the throughput is beyond the EDS capacity and the cost of new plant and tritium recovery would be uneconomic. Solid waste becomes contaminated and the tritium lost from the cycle. This is not normally a significant loss except for the case of the highly tritiated dust and flakes with tritium/carbon ratios up to 10 % which arise from co-deposition in the divertor region of the vessel. This material has been segregated and will eventually be treated to recover the tritium [14]. A further source of loss was permeation and leakage into ancillary systems such as the baking plant and diagnostic interspaces and trapped volumes. These are generally not recoverable and being difficult to measure, lead to special precautions being required during maintenance. Where getter pumps were used for secondary containment pumping, around 95 % of the inventory could eventually be recovered by isotopic swamping and regeneration.

5. INVENTORY LIMITS DURING OPERATION AND PROCEDURES FOR CONROL

The main inventory limits are:

Environment Agency	90 g
Authority to Operate	20 g at present but likely to be increased to 50 g for a future tritium phase
AGHS Safety Case	30 g as free gas (less in some sub-systems)
Torus Safety Case	10 g as free gas and 20g in walls

For DTE1 most of these limits were complied with once the initial inventory was determined satisfactorily by calorimetry and PVT-c as 20 g being the maximum amount on site. The main inventory limit which required special procedures to demonstrate compliance was that of free (and immediately releasable) gas in the torus.

The procedures for transfer of tritium were defined as Tritium Transfer Operations (TTOs) and were all subject to review and approval. Each TTO defined the parameters which should be measured prior to, during and after the transfer and included a proforma for inventory determination. Some were backed up by automatic calculation which could be interrogated by the plant operators. TTOs were also performed for Euratom inspections.

TTOs did not apply to waste transfers or operations within the envelope of the JET machine. However a protocol for gas inventory assessment was run for each pulse so that the Engineer-in-Charge had confirmation that operation was within the limits.

6. TRITIUM MEASUREMENT SYSTEMS

There were several complementary techniques for measuring tritium within the fuel cycle which could be used to improve the overall confidence in the assessment of the inventory of the separate parts of the system and to eliminate any erroneous readings. There were three main types; those in which continuous measurements were possible, those which involved the taking of single "batch" measurements, and those in which the amount of tritium could be inferred from measurements made for another purpose. The second tended to be most accurate but introduced delays in the processing cycle. The precision of measurement was dependent on the instrument accuracy and was nominally about 1 %.

6.1 On-Line

6.1.1 NB Flow Measurements

The flows derived from inlet pressure in the TDGIS could be integrated to give tritium usage, taking into account the dead volumes and amount of gas pumped back.

6.1.2 On-Line Ionisation Chambers

An ionisation chamber was installed in each of the machine backing lines. As these were mounted directly on the lines, it was not possible to normalise the results to atmospheric pressure. In principle they could have been used to measure the activity transferred between batch regenerations but contamination meant that the background was too high for quantôtative results to be obtained from them.

Ionisation chambers were also installed on the baking loop. This loop maintains the vessel at its selected temperature up to 320 ºC and significant permeation into it could occur. A cleanup system using molecular sieves was installed with input/output ionisation chambers to measure, in conjunction with flow, the tritium removal [15]. Input/output ionisation chambers were also installed on the EDS. These suffered initially from water condensation-related contamination but, after improvements could be used as a reliable indicator of process discharges to EDS. For continuous low level measurements such as during torus man-access, they did not have sufficient sensitivity and bubbler type collectors were necessary. A number of AGHS systems incorporated Ionisation Chambers (IC) mainly for process purposes (e.g. GC output valve

switching). Some of these could be used for inventory measurements but in general contamination set a limit on accuracy for low-level transfers. This was particularly the case with the decontaminated CD streams where the IC could be used as a safety backup in case of process deviation but not for accountancy.

6.1.3 In-bed Calorimetry

The AGHS storage uranium beds are installed within a vacuum jacket as shown in Figure 3 and mounted in groups of four within a vacuum outer containment. The possibility of using the rate of change temperature of the bed as an indicator of tritium content was explored and initial results appeared promising [16]. However, in practice, the requirements for daily process operations involving heating of beds meant that the contribution from tritium decay was unable to be separated and the technique was unusable.

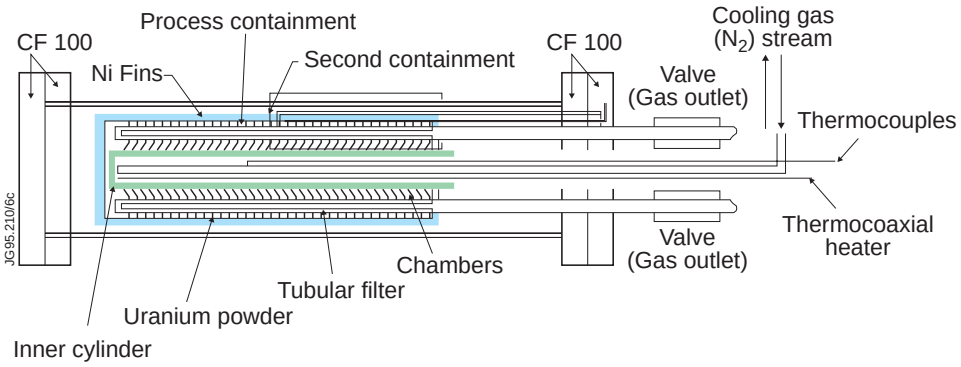

Figure 3: Uranium Bed

6.2 Batch

6.2.1 Off-line Calorimetry

This was carried out using an inertial calorimeter designed to accommodate an Amersham U-bed in a special calorimeter can [17]. It has a resolution of better than 1 mg with a measurement time of 1 day and was sufficiently accurate to distinguish the decay rate of tritium in a sample of less than 1 gram. After initial measurement of delivered tritium and the residue left in the U-beds after unloading, its main use has been for assay of dust and flake materials removed from the vessel.

6.2.2 Pressure, Volume and Temperature (PVT)-c

Calibrated tanks specifically for PVT measurement are installed in the PS system and these are used as the standard for accountancy for tritium once in the fuel cycle. Although they are provided with ionisation chambers, these are insufficiently accurate and the Analytical Gas Chromatograph (AN-GC) is used for precision measurements, including Euratom inspections [18].

The gas supply reservoirs supplying pure gas are also accurately calibrated and have capacitance manometers for pressure measurement and accurate temperature measurement using resistance thermometers.

The remaining volumes in the AGHS, for example the 4 m^3 tank in IP can also be used for PVT-c. As part of the commissioning procedures, a measurement, accurate to the standard of the installed capacitance manometers, was made of all the process lines within the system. This was a time consuming task involving several hundred measurements but was essential in enabling tritium transfer operations to be properly accounted.

6.2.3 Regeneration Measurements

Prior to tritium operation of the JET machine, the normal method for regeneration of cryopumps was to warm them to liquid nitrogen temperature and at the same time pump the evolved gases direct to atmosphere through a nitrogen purged line. However, with the use of the AGHS with a cryopumped first stage, one of the accidents identified in the safety analysis was the possibility of an undetected air leak leading to the cryopumping of an explosive mixture.

(This was of less concern in the machine cryopumps as a limit on gas inventory and larger volumes limited the maximum pressure achievable.) In tritium operation, the gas was almost fully released into the torus or NIB and the respective backing lines and then measured by an Oxygen Monitoring System (OMS) before being pumped.

By using ionisation chambers in the OMS, and pressure measurement, corrected for the effective temperature of the volume which included components at 77 K, room temperature and 600 K, the activity of the batch could be assessed.

As pressures were normally less than 1 mbar, a correction to compensate for ionisation chamber response would have been necessary but to obviate this, a series of inlets to the chamber were provided to allow introduction of hydrogen to bring the sample up to atmospheric pressure.

A comparison between the different techniques used for the same regenerations is given in Table 2. A further stage of assessment took place when the AGHS cryopumps were regenerated and a PVT measurement made using the expansion vessels at 77 K. This could confirm the quantity of gas but not its composition.

6.3 Inferential

A number of plasma diagnostics measure parameters which are related to the presence of D and T. For example the emission from a Penning discharge given D_ and T_ in proportion to the

TABLE 2

Comparison of Tritium Measurements of Regenerated Gas

Regeneration	OMS Value % T	On-line IC Value %T	AN-GC Value %T
PD89	8.6	26.5	7.6
PD90	3.4	9.4	1.8
PD91	2.8	8.4	2.3

species [19]. By suitable modelling, these can be used to predict the tritium deposition and recycling within the vessel and the proportions during regeneration of the cryopumps. The neutron ratio could also be used to determine the tritium content of the plasma and a residual gas analyser was also used [20]. The dynamic processes involved in tritium transport within the vacuum vessel meant however that these measurements were of limited value for accountancy.

7. WASTE ASSAY

Assessment of the gaseous and liquid discharges is straightforward and can be carried out to an accuracy greater than that required from an accountancy point of view. JET uses both on-line ionisation chambers and HT/HTO/CxHxT samplers for stacks. Stack flows are used to enable the discharge to be integrated for the on-line instruments. For the samplers, the flows are averaged. Liquid discharges are assayed by liquid scintillation counting at several stages depending on the route for disposal or recovery.

Solid wastes are more problematical because of the low UK limits for waste clearance (0.4 Bq/g) and for classification for burial at the Drigg engineered trench facility (<12 kBq/g). Accounting for waste can only be achieved by rigorous control of the routing of material in order that samples can be demonstrably representative.

In addition samples need to be sent off-site for combustion analysis and other techniques. For so-called housekeeping wastes, the option of using an empirically derived method taking air sample of drums can be used but this only applies to well defined and repeatable waste streams.

8. RESULTS

8.1 Deuterium Tritium Experiment 1 (DTE1)

In general tritium was supplied to the machine for four days each week with the remainder of the time spent processing gas and carrying out accountancy measurements. It was found essential to have a dedicated period for accountancy with no supply taking place. The original configuration of PS uranium beds used common manifolds and it would be impossible to keep track of supplied tritium. Modifications have been made since DTE1 and this now is less of a problem.

Daily meetings were held at which the results of gas supply and regenerations using the AGHS instrumentation were compared with those using the machine instrumentation and differences resolved both in terms of total gas load and individual components. Corrections had to be made for the fraction of gas supplied to NBI which was actually injected into the torus and an inventory model took account of the different pumping speeds and conductances of the various routes.

These values then gave the running inventory in the machine. Tables 3 and 4 show the typical differences in values (1 gram = 4.034 bar-litre @ 20 ºC) between the measurements made by the AGHS and by the “Users”. It can be seen that in some cases, particularly NB64 which came from NIB4 which had not been used for tritium injection, the AGHS value for tritium is higher,

indicating a higher torus NIB4 pumping speed than modelled or residual contamination in the backing lines. Once a week, the Figures were reconciled with the AGHS inventory taking and this was used as a new baseline for the torus inventory for the following week. The values over a typical period are shown in Table 5.

TABLE 3

Gas Supply

	User measurement (Bar-litre)		AGHS measurement (Bar-litre)	
Date	T2 to Gas Injection	T2 to NB Injection	T2 to Gas Injection	T2 to NB Injection
13/10/97	2.875	6.565	2.862	6.440
14/10/97	4.027	6.903	3.944	6.641
15/10/97	1.619	2.333	1.598	2.311
16/10/97	0.263	0.940	0.242	0.853

TABLE 4

Regenerations

		Gas Transferred (Bar-litre of mixed isotopes)			Tritium Transferred (Bar-litre)	
Date	Regen ID	Torus PVT	Inventory Model	AGHS PVT	Inventory Model	AGHS Measurement
13/10/97	PD61	3.6	3.20	4.14	2.77	2.82
14/10/97	NIB64	6.2	6.62	7.21	6.61	7.21
14/10/97	PD62	5.2	5.92	5.68	3.72	3.45
15/10/97	NIB65	8.75	9.57	10.24	7.10	7.31
15/10/97	PD63	3.3	3.72	2.18	1.54	0.93
16/10/97	NIB66	6.6	7.17	7.23	2.33	1.64
16/10/97	NIB67	96.7	117.78	98.85	0.08	0.25
16/10/97	NIB68	5.3	5.32	6.58	0.93	1.31
17/10/97	PD64	4.0	5.37	4.2	0.26	0.96
17/10/97	NIB69	3.42	3.87	4.63	3.87	4.43

Although the discrepancies were large and were up to 10 % of the torus inventory, there still remained sufficient margin to the safety assumptions to permit the experimental programme to continue as planned. Throughout the campaign, there appeared to be systematic differences between different methods of measurement. These could not be satisfactorily explained and no empirical corrections were made for them.

TABLE 5

Torus Inventory

Date of Inventory Taking	Torus Inventory (bar-ℓ) Assessed from Supply/Recovery	Torus Inventory (bar-ℓ) Assessed by TTOs	Torus Inventory (bar-ℓ) Measured by AN PVT-c	Difference in Period Since Last Inventory Taking	
				Supply/ Recovery	TTOs
27/9/97	13.31	---	14.80	1.49	---
6/10/97	19.53	---	21.47	1.96	---
13/10/97	30.47	---	31.47	1.00	---
21/10/97	29.83	31.92	30.27	0.44	-1.65
28/10/97	---	31.51	30.50		-1.01
4/1//97	31.76	35.15	33.78	2.02	-1.37
11/11/97	---	41.60	---	---	-1.33
21/11/97	---	35.90	---	---	-1.95

8.2 Shutdowns

There were three main shutdowns since mid-1997. These were the NIB8 shutdown when a water leak in NIB8 was repaired after it had been tritium commissioned [13], the Remote Tile exchange in 1998 when the divertor modules were replaced remotely and a considerable part of the tritium inventory removed with the old MKIIA divertor [21], and the pellet launcher shutdown in 1999 when man-entry to the machine was performed for the first time after tritium injection.

During shutdowns, virtually all the tritium evolved, apart from initial cleanup of the vacuum vessel was in the form of HTO with HT and other species typically < 1 %. The main issue was collection of high activity ventilation streams by the EDS. The activity measured in the ventilation line could be correlated with the activity measurement of the water collected in the EDS drain tank.

An important tritium “inventory” issue was knowledge of the location of leaked, permeated or pumped tritium particularly on the many machine diagnostics which were worked on during shutdowns. This was of particular concern because of the potential for worker exposure as a result of release on opening of trapped volumes and because of tritium evolution arising from reaction with moist air.

So-called Pump-Purge Rigs were developed to enable batch purging of containments to be carried out before maintenance. These include known volumes and a tritium monitor so that the tritium content of the system could be assessed against predetermined safety criteria.

8.3 Deuterium-Deuterium Operation and Current Position

In the periods of operation following the Remote Tile Exchange in 1998, tritium has continued to be evolved from the machine. The current value is 60 GBq/day. Although this is within the

Authorisation for discharge, previous experience would indicate that this would be detected above background off-site, so processing has continued albeit with less stringent accountancy and safety procedures. The AGHS also needs to continue to be connected because of the potential for a high temperature air ingress in the event of a vacuum failure and the release of some of the tritium held up in the vessel walls. During this period, more accurate estimates of some of the material removed from the vessel have been made using calorimetry and the small getters and secondary containment pumps in the AGHS have been regenerated to remove their inventory of gas mainly arising from permeation through u-bed containments. These inventory values had previously been calculated on the basis of experimentally determined permeation rates. However the inventory was found to be a factor of 10 lower than the calculated values.

The remaining uncertainties are associated with the limited measurements previously taken of the MKIIA divertor, the presence of flakes and dust in the divertor area and the inventory of the baking plant molecular sieves. The first is due to be improved by a sampling and analysis campaign to be undertaken in the second half of 2000, the second by further examination during the March 2001 shutdown, and the third when the IP systems modifications are completed to permit processing and recovery of the water which will be evolved.

The variation in the balance of unmeasured tritium (“Material in Process”) since the end of the RTE is given in Figure 4.

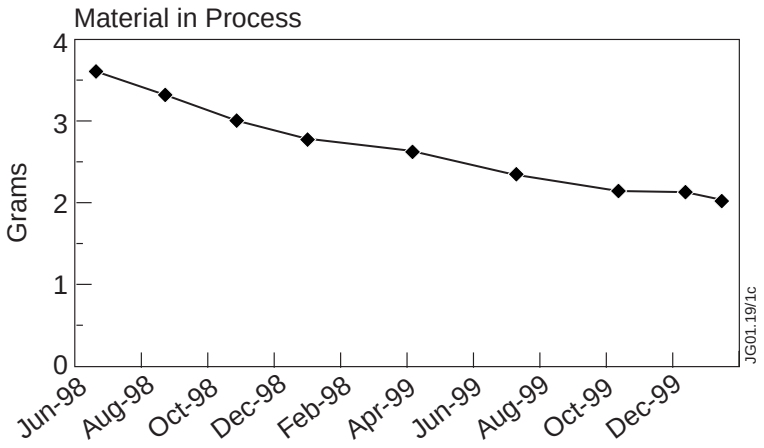

Figure 4: Tritium Balances

9. RELEVANCE TO FUTURE MACHINES AND FUTURE WORK

The scale of the JET fuel cycle plant is an order of magnitude smaller than a next step machine. However the individual process flows are comparable and useful conclusions can be made and the implications considered. JET was fortunate that weekly inventory taking coupled with the limited site inventory was able to demonstrate compliance with safety limits. The PVT-c measurements made of gas supply were adequate because of pure gases being used but similar techniques could not be used for gas received into the system so daily assessments of the retention in the torus were inaccurate.

JET had the advantage of a dedicated processing time and the daily throughput was never more than 20 % of the total inventory. It would be essential to have on-line inventory assessment where the throughput was several times the inventory. This would require the development of more accurate systems for measurement at backing line pressures. The use of the AN system for tritium measurement was time consuming and involved transfers of gas, leading to additional inaccuracies. In-bed calorimetry would have been advantageous but would have required a faster response or dedicated beds which could have been allowed to reach equilibrium. More development of techniques such as Laser Raman Spectrometry and process scintillation counters may be helpful. Calorimetry could also be developed further to enable it to be used routinely for waste sampling and for in-process measurement.A larger tritium phase is proposed for the end of the JET programme. The application of these techniques will be considered further at JET in connection with the operation of the machine and under the auspices of the EFDA/JET Task Force Technology.

10. ACKNOWLEDGEMENTS

The operation of JET under the JET Joint Undertaking ceased at the end of 1999. The JET Operating Contract is now the responsibility of UKAEA. A number of staff involved with tritium measurement and accountancy left the Project during the final period. This paper draws on their work and the authors wish to acknowledge their contribution. P Andrew, N Bainbridge, M Gadeberg, J L Hemmerich, R L K Lässer and L Svensson.

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