

TRITIUM ISSUES AT JET

A C Bell
EURATOM/UKAEA Fusion Association
Culham Science Centre, Abingdon
Oxon, UK
+44 (0)1235 464746

INTRODUCTION

The JET machine was originally planned to be capable of operation with DT plasmas with neutron production up to 10×10^{23} per year and the torus was therefore constructed within a massive concrete biological shield wall. As the experimental programme developed, numerous enhancements were made to the machine and its ancillary systems. Many of these were associated with tritium operation such as the construction of a plant to supply tritium and recycle it for re-use (The Active Gas Handling System, AGHS) and facilities to enable maintenance and modification to be carried out remotely.

Tritium experiments took place in 1991 and 1997 and required additional measures to be put in place to control radiological hazards and to handle tritiated waste.

Following these experiments, tritium retention in JET machine and other components and materials has been an important consideration and detritiation has been a key issue for study.

The following sections examine these issues.

TECHNICAL ISSUES RELATED TO TRITIUM OPERATION OF JET

The JET machine has been continually developed and enhanced since its commissioning in 1984 to meet the requirements of the European programme of fusion energy research. In particular the interior of the vessel has evolved from an iniconel first wall to the current arrangements with a number of additional heating systems, diagnostics, and pumped divertor with first wall cladding of mainly carbon/CFC tiles onto which beryllium is evaporated.

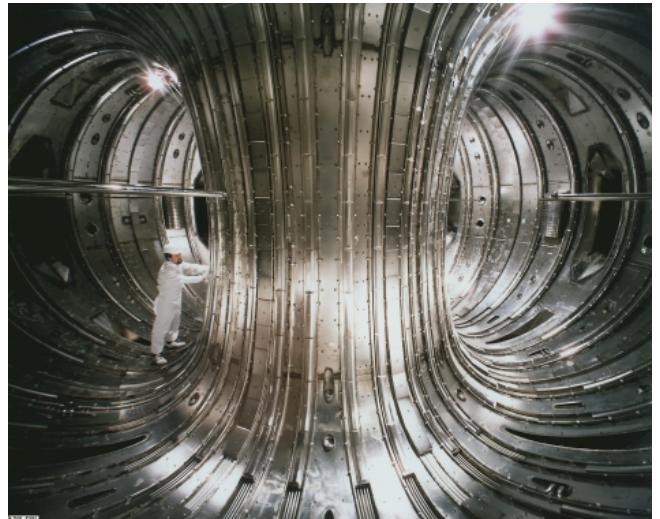


Figure 1: Initial Vessel Configuration

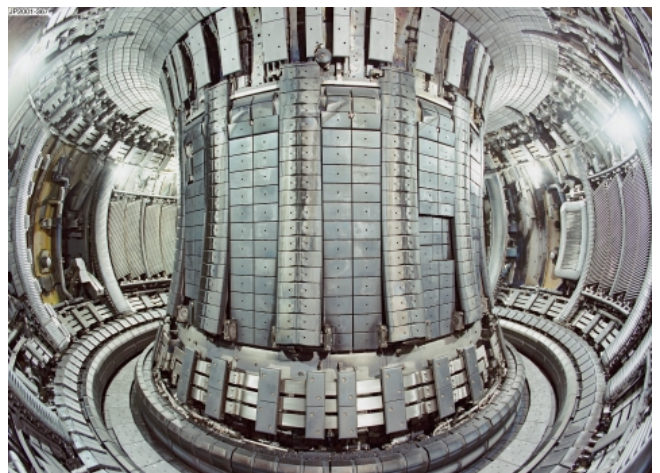


Figure 2: Current Vessel Configuration

These changes to the machine have been carried out either manually by personnel in suitable protective equipment, which since 1989 has been airline fed plastic suits as protection against tritium and beryllium, or by remote handling means involving remote master-slave manipulators and robotic arms. Because tritiated dust is produced in the form of co-deposited carbon during plasma operation, facilities have been built which dock onto the vessel to provide contamination control and enable waste to be safely consigned out.



Figure 3: Airline Suit Work

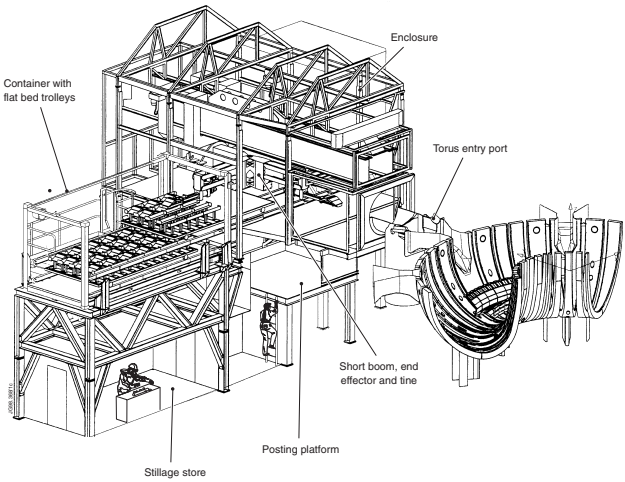


Figure 5: Tile Carrier Transfer Facility

The first tritium experiment in 1991, known as the PTE used 0.1 grams of tritium in a once-through mode. Tritium was supplied to the neutral beam injection system directly from a uranium bed and hydrogen isotopes were stripped from exhaust gases by another uranium bed after initial separation on a liquid helium cooled finger. The systems used for this experiment have been decommissioned.

Because of the significantly large amount involved recycling of tritium was required for the series of experiments carried out in 1997 (DTE1) and the more extensive programme planned at the end of the project (DTE2). The Active Gas Handling System was designed to cryogenically separate the torus exhaust gas to permit mixed hydrogen isotopes to be separated by one of two isotope separation systems and impurities by an oxidation/reduction process. The displacement gas chromatography system was used for enrichment of tritium to 99.5% purity from mixtures with tritium content greater than 1.5%. Although the cryogenic distillation system is capable of enriching to high purity, this would have required a significant inventory in the last column of > 35 grams of tritium so it has only been used for stripping of tritium from deuterium and hydrogen streams with a DF of >10000.

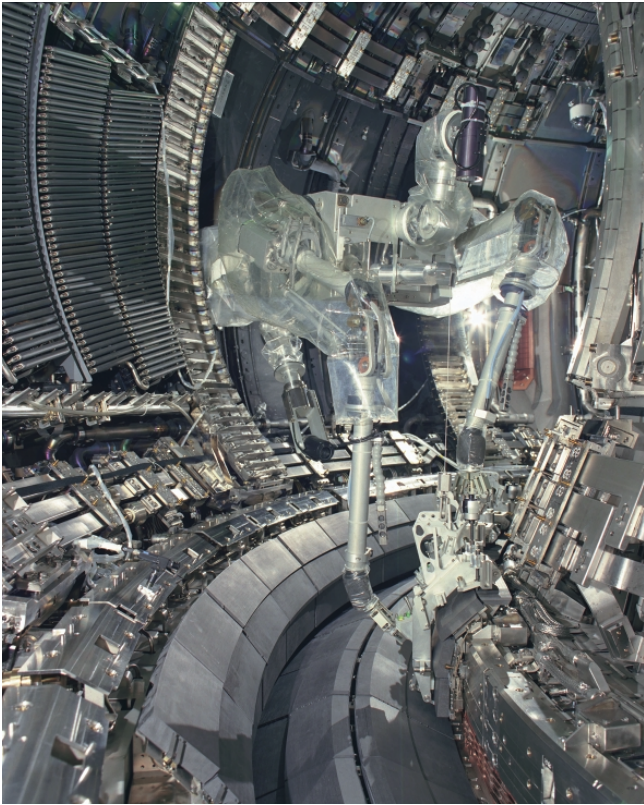


Figure 4: Remote Handling Manipulator

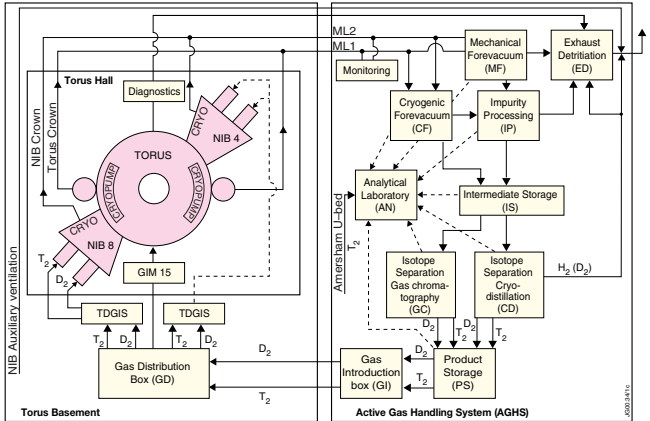


Figure 6: Active Gas Handling System (AGHS)

The AGHS uses uranium beds for transfer and storage of hydrogen isotopes, this choice having been determined amongst other things by the need to avoid disproportionation effects. These beds have successfully handled several tens of m³ of hydrogen isotopes and continue to exhibit the original pumping/storage characteristics.

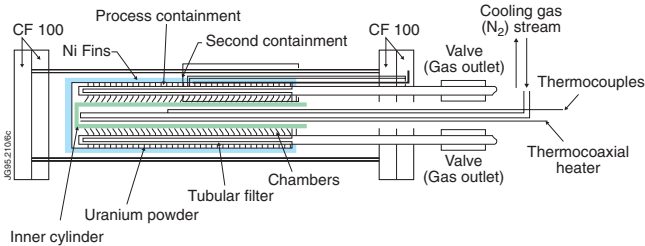


Figure 7: JET Uranium Bed

A key system was the Exhaust Detritiation System (EDS), which, as well as providing depression for the containment boxes of the AGHS, provided detritiation of air streams during maintenance (and also emergency detritiation in the event of an up-to air accident in the torus).

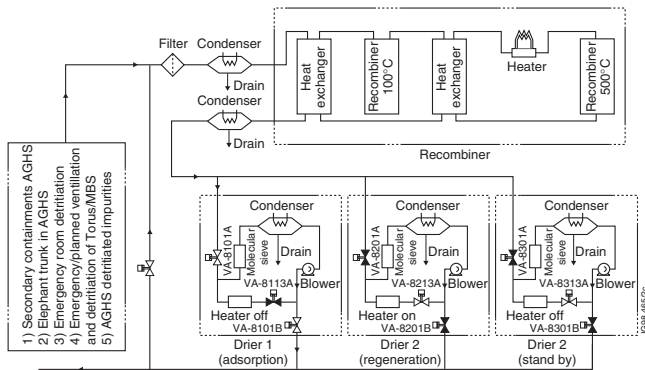


Figure 8: Exhaust Detritiation System

The AGHS supplied about 100g during DTE1 split about 35g to the vessel by direct gas injection and 65g to the Neutral Beam injection system, of which 0.6g were injected.

During DTE1, fusion power of 16 MW was produced for about 1 second. However longer pulses were also obtained which required loading of the wall with tritium. These and other transport experiments in tritium plasmas meant that at one point up 11.5g of the site tritium inventory of 20g was retained in the machine.

A significant consequence of DT operation was increased activation of the JET inconel vacuum vessel. Prior to this, the maximum radiation level in the JET vessel was a few hundred microSv/hr, decaying with a 70 day half life from mainly Co58. This permitted man-access to the vessel, in pressurised suits to protect against the Be hazard. Following DTE1, the dose rate was initially 6 mSv/hr and man-access

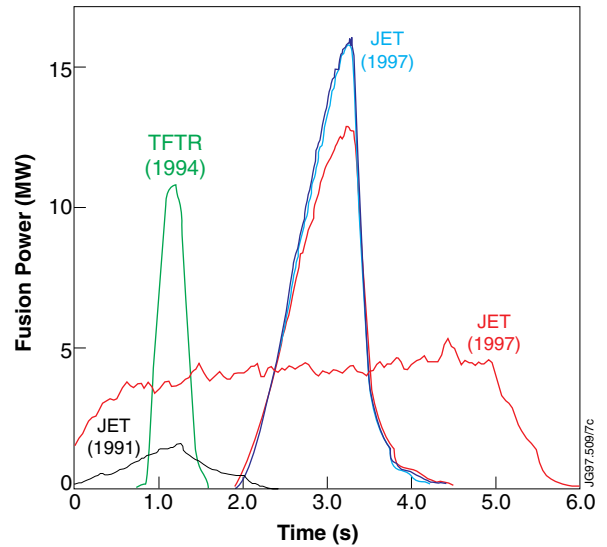


Figure 9: Fusion Power during JET tritium experiments

was precluded. The in-vessel work in the shutdown following DTE1 was therefore planned to be carried out completely using remote handling techniques. The main task of changing the divertor tiles required an additional boom to be used to enable tiles to be detached and transferred out of the vessel.

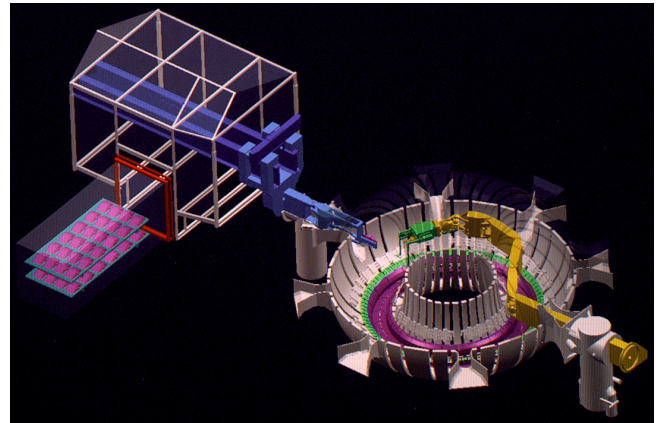


Figure 10: Double boom arrangement for tile exchange

TRITIUM RETENTION

Predictions based on the PTE would have suggested much lower levels of retention. However the configuration of the machine had been altered significantly since the PTE by the addition of the pumped divertor in the lower part of the vessel. Co-deposition of carbon deuterium material in the divertor had been observed in earlier DD operation with the new configuration and a similar effect was expected with DT operation.

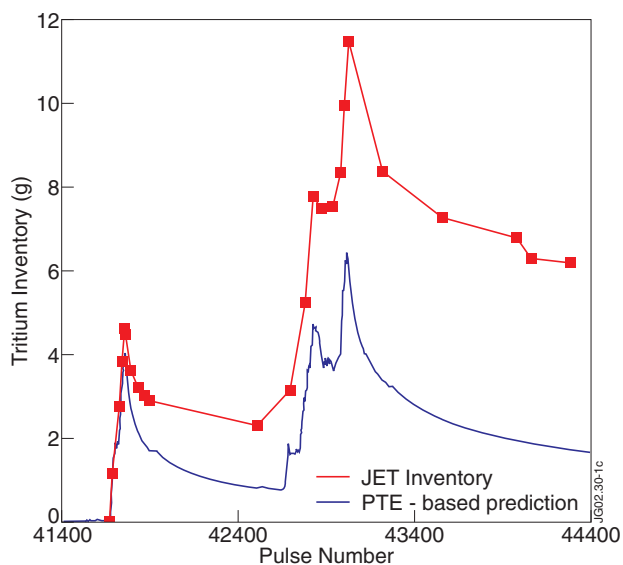


Figure 11: Tritium Retention

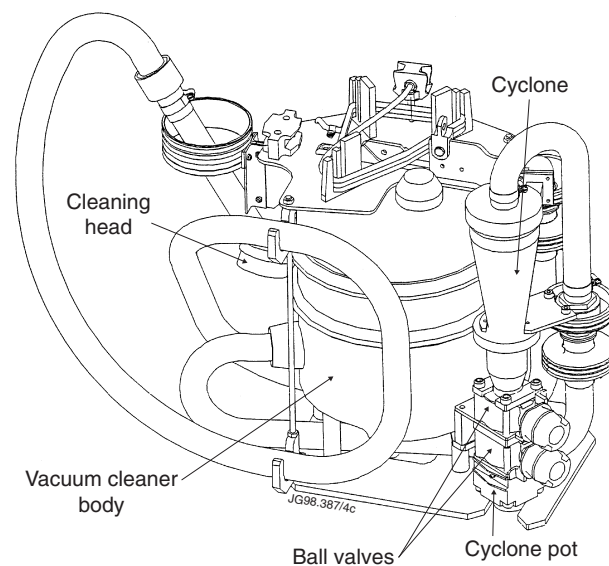


Figure 13: Cyclone Pot Cleaner

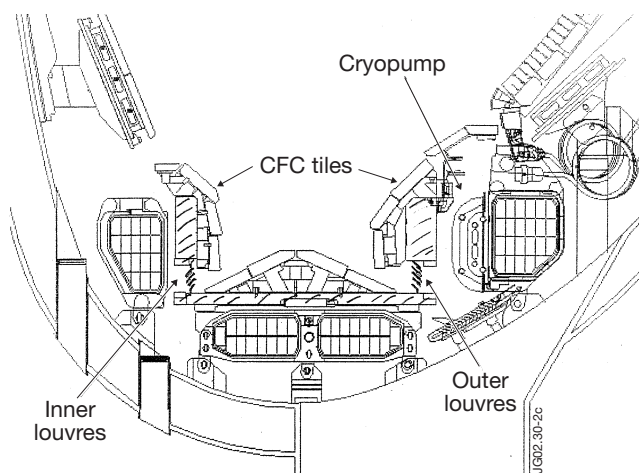


Figure 12: Cross-section of Divertor

Preparations were therefore made to vacuum clean the divertor in the shutdown following DTE1 to enable the codeposited material to be collected for analysis. This was done using remote handling techniques. The collected material was transferred in cyclone pots to a glove box in the AGHS to enable the inventory to be measured and samples taken. From the earlier analysis of DD material, the tritium/carbon ratio was expected to be high and stringent precautions to prevent contamination spread and to handle the high tritium offgassing rates were employed. Calorimetry was employed to determine the inventory of 1.47g of material. The tritium concentration was $\sim 1.5\text{TBq/g}$ and offgassing rate of $\sim 3\text{GBq/h}$ per gram of material.

The material was in the form of extremely friable flakes which readily disintegrate into dust in the 10 micron range. A characteristic of this dust which became apparent during its sampling and the handling of divertor components contaminated by it was the ease with which tritium transferred from it to other materials such as PVC leading to bulk as well as surface contamination. This is now a significant waste issue in the JET facilities.

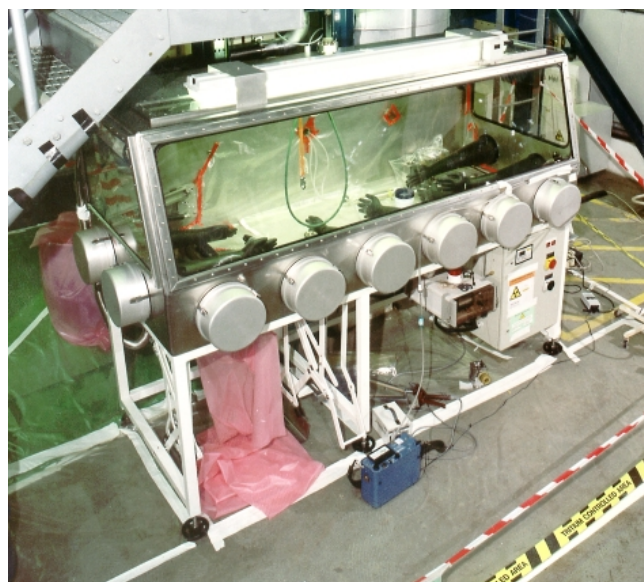


Figure 14: AGHS Sampling Glovebox

At the start of the shutdown, the in-vessel inventory had reduced to 6g. With the removal of the dust samples and divertor components, together with the effect of the air purge, it had reduced to 4g by the end of the shutdown. Figure 16 shows the continued reduction of the succeeding period of plasma operation. It can be seen that a plateau of around 1.7g is reached

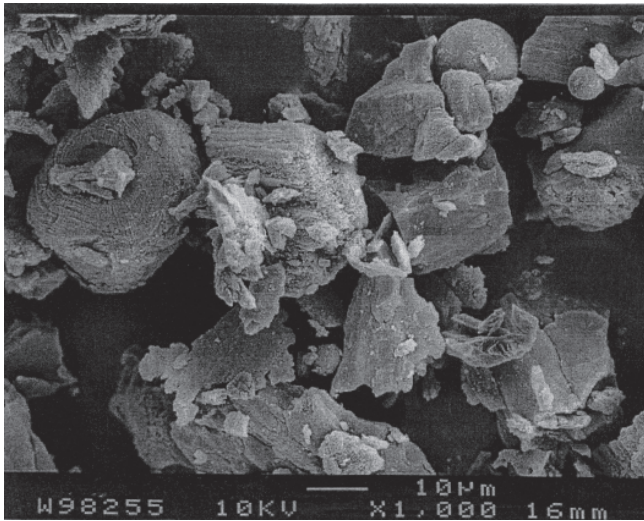


Figure 15: SEM of tritiated dust

by mid 2000. This was postulated to be associated with dust and flakes which had been deposited on divertor components and then spalled off into the void below the divertor. An exercise was undertaken during the 2001 shutdown to gain remote access to the area and recover a proportion of the material. A significant quantity of dust was observed and samples are being analysed.

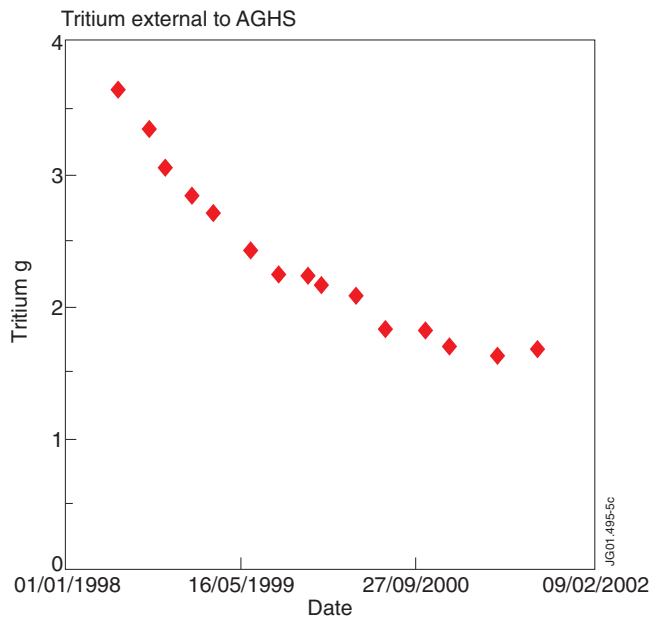


Figure 16: Tritium inventory during plasma operation

Recovery of tritium from the machine took two forms. During plasma operations, exhaust gas was processed and tritium was separated for reuse. Table 1 shows the gas separated from the regeneration of the cryogenic divertor pump, which traps most of the hydrogen isotopes during plasma operation. During shutdowns, tritium from ventilation of the vessel (and other areas) is collected by the EDS in the form of tritiated water. Table 2 shows the amounts collected.

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

JG01.495-3c

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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TRITIUM CONTENT OF OTHER MATERIALS

As well as components within the vacuum vessel and AGHS, other machine components such as the neutral beam central column were exposed to tritium during DTE1. Handling of these large components has required special arrangements for control of contamination to enable transfer from the machine.



Figure 17: Neutral Beam central column

In addition, with the vacuum vessel operating at around 300°C during DTE 1, permeation of tritium through thin the bellows section of the vacuum vessel into the helium filled interspace and thence into the torus hall atmosphere lead to measurable tritium in the torus hall and tritium uptake by a range of materials.

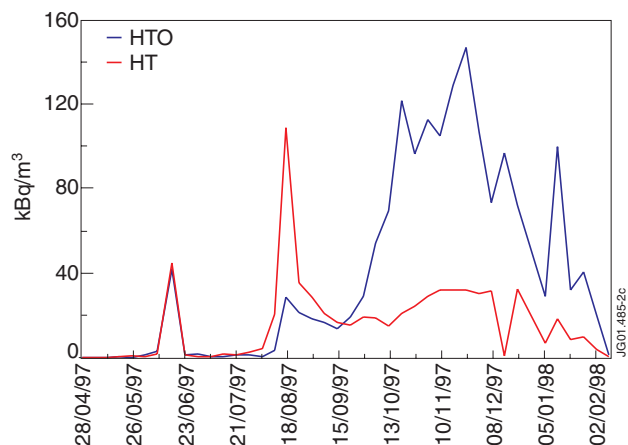


Figure 18: Torus Hall tritium concentration

As discussed earlier, material which is in contact with tritiated dust also becomes bulk contaminated. This affects the range of tenting materials and personal protective equipment which when disposed of may be described generically as housekeeping waste .

Analysis of the bulk activity of materials below the limit of detection of calorimetry generally has to be done by destructive methods which are time consuming and expensive. It has therefore not yet been possible to analyse the tritium content of all materials but the values given below give an indication of the range in the torus, torus hall and AGHS.

Concrete	30 Bq/g
Paint	up to 300 Bq/g
Rubber	100 — 2000 Bq/g
Plastics	10 Bq/g — 20kBq/g
Housekeeping Wastes	up to 60 kBq/g
Metals	0.1 Bq/g — 1MBq/g
Graphite/CFC tiles	up to 140 MBq/g
Co-deposited flakes	up to 1.5 TBq/g

Table III

Class	Form	Current Disposal Status	Detritiation and Related R&D necessary	Techniques available or under consideration (Measurement techniques in italics)
Exempt waste	Solid	Free release	Techniques and protocols to demonstrate clearance to the satisfaction of the regulators	Improved QA and sampling
Housekeeping LLW	Plastic sheeting and protective clothing, paper, filters.	BNFL Drigg	Volume reduction and control of outgassing.	Surface cleaning Compaction (Outgassing)
Housekeeping ILW	Plastic sheeting and protective clothing, paper, filters	Package immobilise then long term storage at UKAEA Harwell until UK national ILW site available	Reduction to LLW where practicable and methods of demonstrating this. Control of outgassing Understanding mechanism of contamination	Surface cleaning ¹³ Moist gas heat treatment Incineration Ozone treatment ¹⁴ (Calorimeter, Outgassing)
Plant materials - Surface Contaminated	Mainly metals exposed at low temperatures but may include others such as ceramics	LLW to BNFL Drigg. Storage of ILW to be held on site pending resolution of treatment options	Reduction to LLW where practicable and methods of demonstrating this.	High temperature air purge ^{13,15} Surface reactions to promote release of molecular hydrogen Flame heating ^{13,16} (BIXS) (PIN diode) ¹⁷
Plant materials - Bulk Contaminated	Metals exposed at high temperatures and in vessel components	Storage on site pending resolution of treatment options	Techniques for measurement including depth profile. Bulk detritiation	Vacuum Melting/Sparging ¹⁸ Purge gas heat treatment ^{13,15} Flame heating ¹⁵
High specific activity non-metals	Tiles and associated material from in-vessel. Activated charcoal	Storage on site pending construction of recovery plant	Recovery of tritium and control of outgassing. Preferable reduction to LLW	Flame heating, high temperature oxidation and recovery, UV laser ¹⁹ YAG laser ²⁰
Getter Beds	Uranium, ST707, molecular sieve	In use	Recovery of tritium and control of out gassing and chemical reactivity to permit dismantling and disposal.	Isotopic swamping and controlled oxidation ¹³
Organic Liquids	Vacuum oils, Liquid Scint. cocktails	Incineration at off-site facility	Methods of dealing with higher activity	On-site oxidation and recovery ²¹ Isotopic swamping
High level Tritiated Water	Low volume high chemical purity from process operations and EDS	Recovery at off-site facility	Water detritiation plant with recovery	Catalytic exchange/Electrolysis ^{22,23}
Low level Tritiated Water	High volume including other species such as Be	Discharge to River Thames after filtration	Minimise dilution. Increase atmospheric emissions. Water detritiation	Catalytic exchange/Electrolysis ^{22,23}
Process gas	AGHS	Discharge or treat with EDS	Monitor environmental impact and effects of HTO, HT and CH3T. Review dilution mechanisms and ability to recover	(Discriminating samplers)
Ventilation air	From contamination controlled areas	Discharge or treat with EDS in accordance with BPEO	Monitor environmental impact and effects of HTO, HT and CH3T. Review flowrates and ability to discharge directly	Local air detritiation systems
Building materials	Structural steels and cladding. Painted materials. Concrete	Store pending waste minimisation	Detritiate to exempt level where practicable	Surface removal techniques. Controlled Weathering

Although these were sampled at different times and are therefore not self-consistent, it can be seen that there is a wide variation of materials with contamination levels which require them to be dealt with as radioactive waste of the appropriate category. This is an issue for current JET operations and enhancements as well as for future decommissioning.

DETRITIATION ISSUES

There is considerable incentive both from an operational and decommissioning cost point of view to detritiate these materials. As well as reducing the ultimate disposal cost, detritiation reduces off-gassing and cross-contamination, thus reducing the potential personnel exposure and the cost and time required to provide protective measures.

It is also consistent with ALARA to recycle tritium where practicable. This is particularly the case with the high activity materials and tritiated water in which gram quantities of tritium were retained during DTE1.

A coordinated programme for studies on the detritiation of different materials, focussed on the use of JET and its materials, is being established under EFDA. The key elements of this are shown in Table III.

CONCLUSIONS

1. Tritium operation of the JET machine required additional facilities to be constructed which have operated successfully since the DTE1 experiments.
2. A wide range of tritiated materials is produced in the JET facilities and improved analytical techniques, particularly for metals, would assist in assessing their tritium content.
3. A range of detritiation processes has been identified as necessary for continued exploitation of the JET machine.
4. These requirements will also be relevant for future machines

ACKNOWLEDGEMENTS

Since the beginning of 2000, JET has been operated by UKAEA under the European Fusion Development Agreement (EFDA)

This paper draws on work by many other contributors to the success of the JET programme. As well as current EFDA-JET staff, the author wishes to acknowledge the work of members of Fusion Technology and First Wall Divisions under the former JET Joint Undertaking.

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The main references for this work are to be found in:

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