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A C Bell, J Williams, J D Neilson and A Perevezentsev

Detritiation Processes Needed for JET Operation and their Wider Applicability

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A C Bell, J Williams, J D Neilson and A Perevezentsev

Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK

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ABSTRACT

Around 100 grams of tritium was supplied to the JET machine during the 1997 DTE1 campaign. A significant proportion of this was retained in the machine and only released slowly over the succeeding operational and maintenance campaigns Tritium is also present though permeation and surface adsorption of materials.

Means of detritiation of JET waste which could be applied within the facility are being developed. These must take into account the full waste cycle including the generation of secondary waste and the possibility of recovery for re-use of tritium.

Each of the typical JET tritiated waste streams is described and the detritiation processes being developed and under consideration are discussed.

1. INTRODUCTION

Around 100 grams of tritium (about an order of magnitude lower than the ITER inventory) was supplied to the JET machine during the 1997 DTE1 campaign[1]. About 35 grams was injected into the torus and a significant proportion of this was retained in the machine and only released slowly over the succeeding operational and maintenance campaigns In addition during DTE1, a continuous level of tritium was present in the torus hall atmosphere as a result of permeation through the vacuum vessel which reduced substantially after tritium operation ceased. Although there has been no tritium injection since 1997, it continues to be necessary to pump the evolved tritium with the Active Gas Handling System (AGHS) and to adopt procedures for control of tritium contamination[2]. Several species of tritium have been identified as contributing to contamination, including highly mobile dust and flake material of high specific activity which has a high tritium off-gassing rate. Tritium is also present through permeation and surface adsorption of materials. As a result, strategies have been developed for dealing with each of the tritiated waste streams which arise during operation and maintenance, and which will be a major factor during decommissioning and of particular relevance to ITER.

2. WASTE STREAMS

Although tritium is produced by fusion reactions, this had no effect on the waste management arrangements during the early DD operation of JET as the levels produced were below that at which controls were required. Following the first tritium experiment in 1991, a significant amount of material came into the radioactive waste category when 0.1g of tritium was supplied to the machine and waste management procedures and equipment needed to be developed to handle this[3]. However, following vessel decontamination[4], tritium was not a significant issue affecting the continued operation of the JET machine. The only significantly contaminated equipment that remained was associated with tritium supply and recovery during the experiment. The situation changed considerably as a result of the DTE1 series of experiments as many previously inactive waste streams became subject to controls and outgassing from the machine became an issue.

3. OPERATION

Although the amount of tritium circulated through the fuel cycle was of the order of 100 grams[5], tritium was recovered by AGHS with an extremely high efficiency and only 2.7TBq (<0.01% of the throughput) was discharged to atmosphere, well within (<2%) of the authorised discharge limit. Permeation through the bellows section of the vacuum vessel was the main source of direct atmospheric discharges, amounting to about 1TBq. Figure 2 shows the torus hall average weekly concentration and in particular the influence of the pure tritium injections to load the plasma facing surfaces with tritium in Oct 97. Figure 3 shows the concentration in the AGHS building stack over the operational period and also the first shutdown when significant amounts of tritiated water vapour were handled by the Exhaust Detritiation System (EDS) and there was some increase in the level in the process areas.

In addition, the helium baking loop of the vacuum vessel, operating at 320C, was connected to a detritiation system using removable molecular sieve beds which played a part in lowering the tritium concentration in the torus hall and absorbed an estimated 40TBq of tritium[6]. The Torus Hall air conditioning system removed atmospheric moisture and was the main source of small authorised discharges of 0.16TBq to the river Thames during the operational period. The experience with cleanup after the 1991 experiments suggested that a sharp fall in the tritium outgassing from the machine would occur after DT operation ceased and it should be possible to cease tritium recovery from the exhaust gases after a period of about six months[7]. However, with the different divertor configuration, there was increased retention of tritium which led to continuous outgassing[8]. Although a sharp reduction did occur, it has, four years later, not yet been possible to disconnect the AGHS. The outgassing rate from the torus at >50GBq/day is still considerably above the level at which routine release would be possible[2].

The main consequence of DT operation is not however in the direct discharges but in the long term effect of tritium contamination and absorption which has the impact on the arrangements for maintenance, modification and decommissioning. This has arisen despite the relatively low level of tritium in the JET buildings and short time of exposure and is partly due to the particular species of high specific activity (> 1TBq/g) carbon dust and flakes created by plasma-wall interactions. These materials outgas at 2.5GBq/hr per gram of material[9] and are a radiological issue in future DT machines with carbon plasma facing materials.

4. MAINTENANCE AND MODIFICATION

During maintenance, access facilities are used to gain entry to areas of potentially high tritium contamination with remote handling equipment or personnel in airline fed plastic suits[10]. To provide ventilation in these areas when the air has significant tritium content, typically up to 100MBq/m^3, it is necessary to use the Exhaust Detritation System[11] in the AGHS to reduce atmospheric discharges. A consequence of this is that tritiated water is produced that may be above environmental discharge limits and may require further processing to recover the tritium.

Both in the access facilities, and in the maintenance facility, which is used to maintain and modify components removed from the JET machine, contamination control involves the use of sacrificial plastic sheeting or strippable coatings. These techniques are in common use in the nuclear industry but produce secondary or "housekeeping" waste. Housekeeping waste also includes oversuits, gloves, and other generally low density materials. As well as becoming surface contaminated with the high activity carbon dust, the material becomes bulk contaminated through contact with the dust. A significant proportion of this waste is above the limit of 12kBq/g for tritium disposal in the Drigg facility in the UK. It is neither economically viable nor the best practicable environmental option to consign this material for future disposal in an engineered Intermediate Level Waste (ILW) facility (at a projected cost about 100 times higher). Means of detritiation of JET waste that could be applied within the facility are therefore being developed. This will allow the well established practices for contamination control to continue. These means must take into account the full waste cycle including the generation of secondary waste and the possibility of recovery for re-use of tritium from materials of high specific activity.

The quantities of tritiated LLW and ILW processed during the period after DTE1 are shown in Figure 5 above. This illustrates the increase in the ILW arising from the In-vessel work and associated activities in the 1998, 1999 and 2001 shutdowns.

Additional wastes are liquid organics such as pump oils, and liquid scintillation cocktails. Disposal routes for these exist at present but the increase in activity from future DT operations may inhibit their use.

5. DECOMMISSIONING

The last phase of JET operation may be an extended tritium phase with about an order of magnitude increase in neutron production compared with DTE1 and with a corresponding increase in tritium throughput. Following the experience of DTE1 it could be possible that 20g or so of tritium could be retained in the machine. The first phase of decommissioning involves a raised torus temperature to remove as much of the retained tritium as is practicable. Additional more aggressive methods of cleaning which were not possible during experimental operation may also be used. The exhaust gases would be handled by the AGHS in the same way as during operation. However even after this initial phase, which is likely to last for more than six months there will still be significant inventory of tritium in the in-vessel components such as carbon tiles and the associated dust and flakes. Removal of these will require similar contamination controls to those used during operation with the consequent production of housekeeping wastes. In addition, to comply with the requirements for the use of the Best Practicable Environmental Option (BPEO) for the treatment of radioactive waste, tritium will need to be recovered from them where possible. This particularly applies to carbon tiles and flakes which have high specific activity. A dedicated plant for detritiation of these and other waste streams will therefore be necessary, coupled to the AGHS for separation and recovery of tritium. Detritiation of other waste streams will be applied mainly to allow it to be disposed of at a lower category and may

be coupled with volume reduction. These processes are likely to increase the quantity of tritiated water generated and will justify the construction of a plant on site for tritium recovery from this.

Once dismantling starts there will be a significant increase in the volumes of waste produced including that from building fabric which has been exposed to tritium during operation. The planning assumptions at present are that there will be approximately 3000m^3 of radioactive waste from the dismantling of the plant and 350m^3 > 12kBq/g. There is therefore considerable incentive to carry out more detailed assessment and identify processes for detritiation to reduce the volume of higher activity material. This is also of relevance to ITER decommissioning.

Measurements taken of other materials in the torus hall in the shutdown following DTE1 have shown activities up to several kBq/g (Table 1).

Table 1

Material	**Maximum Tritium Activity (Bq/g)**
Aluminium	6
Steel	< 0.4
Paint	270
Insulation	660
Plastic	12000

Even the relatively low exposure during DTE1 has led to Torus Hall concrete remaining radioactive some four years afterwards with values up to 33Bq/g at ceiling level. The levels in the core samples taken from the surface of the Torus Hall walls are generally below 10Bq/g. Further DT operation will be expected to increase these levels.

In addition there will be process plant components such as uranium and other getter beds which will need to be treated before disposal. As well as having been exposed to pure tritium for several years, they contain material which may react with air so any process must be capable of demonstrating that the getter material has been inerted.

6. REGULATORY ASPECTS

At the beginning of 2000 UKAEA received new Authorisations under the Radioactive Substances Act (1993) for radioactive waste disposal permitting discharges of a total of 100TBq/year to atmosphere and 0.5TBq/month to the river Thames. These have been justified both technically on the basis of the maximum operational requirement and on the basis of insignificant environmental impact (Critical group dose <10μSv/year). Although it is expected that these authorisations will continue during the decommissioning phase, there is likely to be pressure to reduce emissions to well below these limits. This arises partly from a changed regulatory culture which places additional duties on the regulators and from international agreements such as OSPAR which may affect the continued use of the river Thames for even extremely low levels of tritiated water disposal. As an example from the non-

radioactive area, legislation on Integrated Pollution Prevention and Control now requires the Best Available Technology (BAT) to be used for discharge abatement. What is acceptable now may not be justifiable in future so the development of processing options is necessary as a contingency.

Another important issue from the regulatory perspective is the means of demonstrating compliance with the relevant disposal limits. Analytical sampling of individual samples is extremely time consuming and expensive and also relies heavily on the sampling protocol. Means of rapid measurement of tritium activity, possibly involving the use of calorimetry, will need to be developed.

Although new European Union legislation has resulted in nuclide specific criteria for *exempting* activities from regulatory control[12], in many countries, partly as a result of public pressure, it seems likely that *clearance* levels will not fully reflect the relatively low risk from tritium.

7. WASTE STREAMS, CURRENT STATUS AND FUTURE DEVELOPMENT

Table 3 shows the key waste streams which may be present in the three states of JET facilities and the current disposal route immediately available. Some of these routes have limitations as set down. A summary of the main issues to be dealt with is given and the techniques available or under consideration are set down . Some of these are already defined as activities under the European Fusion Development Agreement (EFDA) or through the UKAEA decommissioning programme for eventual JET decommissioning. These, and others are being considered in collaboration with other laboratories are linked to the ITER R&D programme.

JET has a number of material samples which have become contaminated with tritium under the range of conditions of an operating tokamak. These will be used to evaluate the various techniques that have been identified.

CONCLUSIONS

1. Although there was only modest exposure to tritium during the 1997 experiments at JET, the long-term effects of tritium arising from this continues to be the dominant factor in waste management planning.
2. This mainly arises through the presence of high specific activity dust which as well as causing surface contamination, leads to permeation of tritium into materials. This dust is specific to those fusion machines with carbon plasma facing materials.
3. Detritiation of housekeeping wastes is vital to permit the continued use of well-proven techniques for contamination control.
4. Recovery of tritium from high activity waste must be carried out where practicable to both facilitate disposal and recover tritium for the fusion fuel cycle.
5. As the building fabric contains measurable tritium, tritium measurements and techniques for detritiation are major items in decommissioning of JET. The lessons learned from JET decommissioning will be valuable in establishing the parameters for decommissioning of future machines such as ITER.

6. Regulatory pressures and trends should be anticipated in the specification of waste handling for future DT machines.
7. A range of techniques can be identified for detritiation of the various waste streams to lower the waste category and possibly recover tritium. Evaluation of these using common standards where possible should be carried out to identify the candidate processes for optimising the tritiated waste management of both JET and future DT machines.

ACKNOWLEDGEMENT

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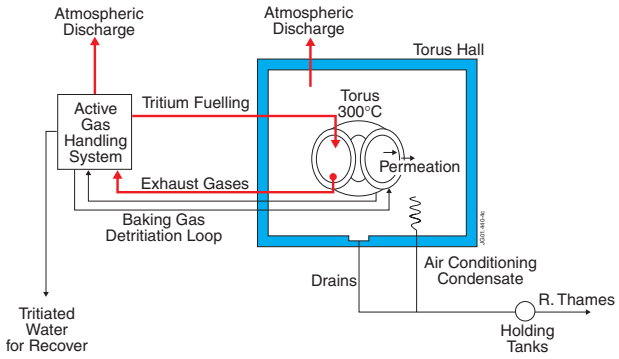

Figure 1: Main tritiated waste streams during plasma operation

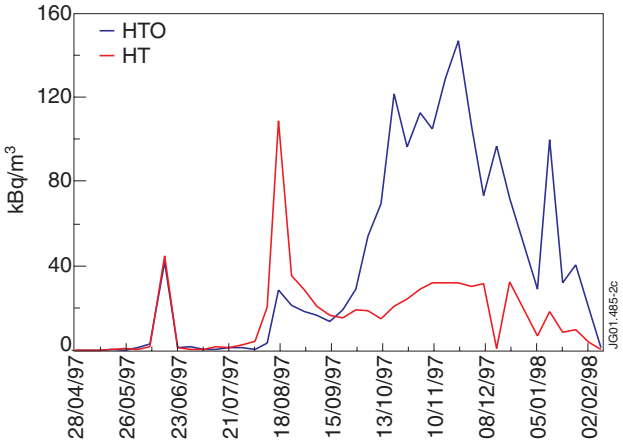

Figure 2: Torus hall tritium concentration (Bq/m³)

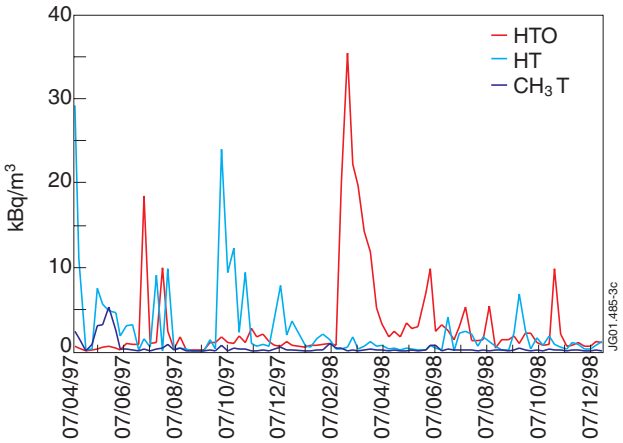

Figure 3: AGHS building stack tritium concentration (Bq/m³)

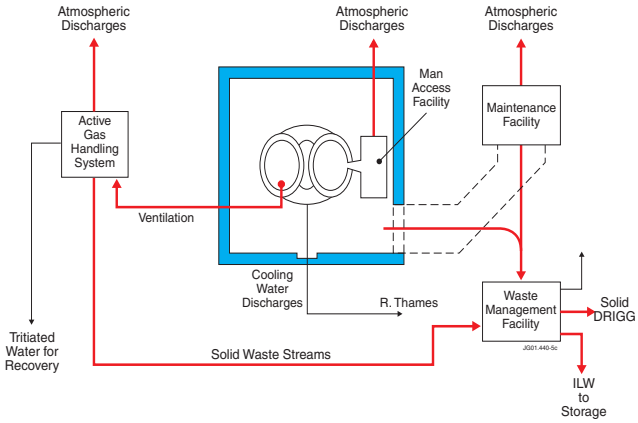

Figure 4: Main tritiated waste streams during JET maintenace

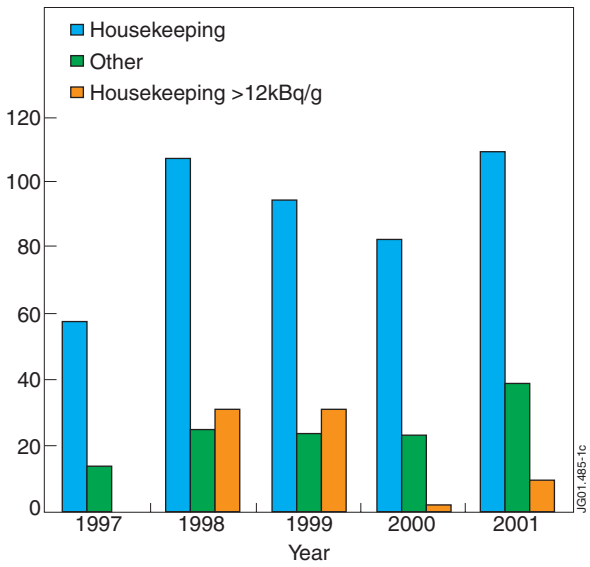

Figure 5: Waste volumes (200ℓ drums)

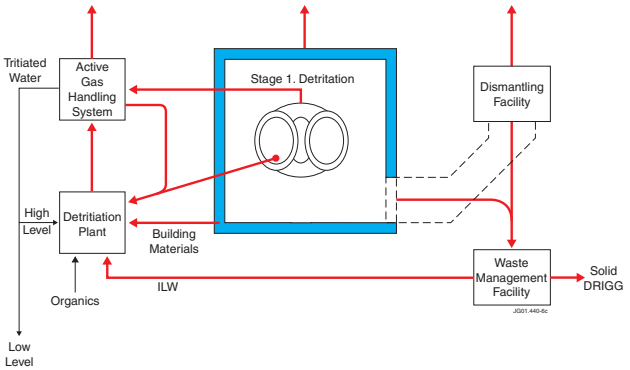

Figure 6: Main tritiated waste streams during decommissioning

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 hig 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 ofrecovery 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 detritiationplant 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	Structual steels and cladding. Painted materials. Concrete	Store pending waste minimisation	Detritiate to exempt level where practicable	Surface removal techniques. Controlled Weathering

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