INITIAL EXPERIENCE OF TRITIUM EXPOSURE CONTROL AT JET

B. Patel, D. C. Campling, P. A. Schofield, P. Macheta and K. Sandland

JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA, UK

Abstract: The Joint European Torus (JET) project aims to demonstrate the scientific feasibility of controlled nuclear fusion using magnetically confined plasmas. Recent experiments have involved significant use of tritium and deuterium as fuels for plasma discharges. The project imposes tight limits on radiation exposure to its staff. This paper describes some of the safety procedures and controls in place for work with tritium, and discusses initial operational experience of handling tritium. A description is given of work to rectify a water leak in a JET neutral beam heating component, which involved man-access to a confined volume to perform repairs, at tritium levels of ~100 DAC (80MBq/m^3, HTO). Control measures involving use of purge and extract ventilation, and of personal protection using air-fed pressurised suits are described. Results are given of the internal doses to project staff and of atmospheric discharges of tritium during the repair outage.

1. Introduction

The JET project is part of a collaborative EURATOM research programme, investigating the long-term feasibility of controlled nuclear fusion as source of energy. On JET, the gaseous fuels, isotopes of hydrogen, are heated to temperatures in excess of 100M°C within a vacuum vessel. The JET device, Fig 1, uses a toroidal magnetic field to confine and isolate the hot plasma. The fusion power output is dependent on achieving sufficient values of temperature, density and confinement time. The plasma is heated initially by passing a large electric current through the gas mixture, with additional heating supplied by RF and neutral beam injection (NBI). In May 1997, plasma operations commenced with significant amounts of tritium in the deuterium fuel mix.

Although tritium is regarded as a low radiotoxicity nuclide ($E_{\beta(max)}=18.6$ keV, $t_{1/2}=12.3$y, ALI=1×10^9 Bq (ICRP-61)), there may be significant risks to workers and the public whenever large quantities are handled and it is in its more hazardous oxide form.

The foremost method of controlling tritium exposure at JET has been the use of UHV technology to provide high integrity containment for all active gas handling processes. However, there exists greater potential for worker exposure to tritium during beaches of containment for maintenance or repair work. One such task became necessary when a water leak developed on one of the NBI systems which had been exposed to tritium. The only feasible method of repair involved manual intervention to an area with high levels of tritium, and this required a controlled approach to limit worker doses and minimise aerial discharges of tritium.

2. Regulations, limits

In the UK the Ionising Radiations Regulations 1985, specify the standards for dose-limitation, control of work, dosimetry, monitoring, medical surveillance. The dose limits in the 1985 regulations relate to the 1977 recommendations of the ICRP[1]. The project's own policy on radiation exposure to workers under JET control is to restrict dose to its classified persons to 5mSv/year, and 1mSv/year to all others. This limit is regarded as stringent even now, compared to forthcoming changes to statutory limits, and has been a prime factor in attaining compliance with the principles of ALARA.

JET had to obtain regulatory approval to hold tritium and accumulate and discharge tritiated waste, in accordance with the UK Radioactive Substances Act, 1993. Prior to the use of tritium, JET also completed a safety assessment and accident analysis to demonstrate to external auditors that it could safely handle PBq quantities of tritium. JET currently holds 20g (7.4×10^{15}Bq) of tritium, although it has authorisation for up to 90 g. Approvals have also been granted for aerial and liquid discharges to the local environment. JET aims to limit discharges, so as to restrict off-site doses to below 50μSv/year.

3. Tritium handling and control

A dedicated active gas handling plant serves to store the tritium gas and supply it to torus gas injectors. The process systems are shown in Fig 2. These systems receive torus exhaust gases, process and purify them and isotopically separate them using cryogenic techniques. The exhaust de-tritiation system (EDS) is designed to remove excess tritium from the processed gas stream prior to discharge through the building stack. Catalytic re-combiners and molecular sieve beds oxidise and trap the tritium, achieving de-tritiation factors of 1000 [2].

Fig1. Schematic View of JET Machine

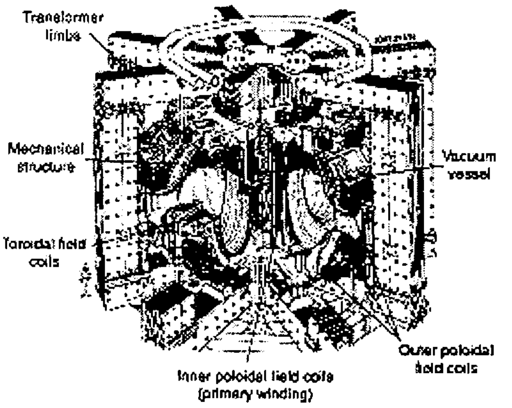
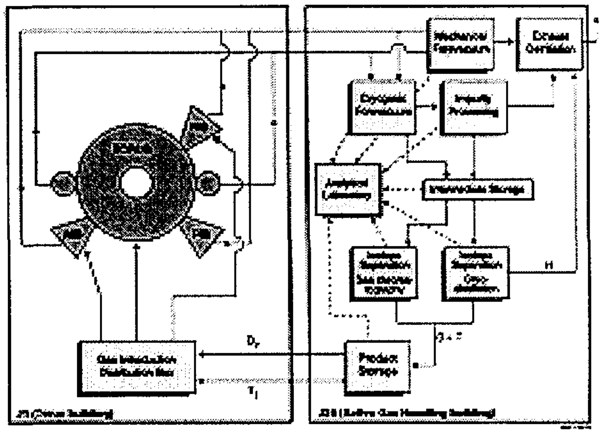


Fig2. Active Gas Handling System



4. Operational experience

Doses to plant operators have been barely measurable in over a year of processing several tens of grams of tritium. Several small breaches of primary containment were made during this period. The procedure has been to pump out the containment volume, and purge with moist air to allow tritium exchange. This is repeated several times until the process ion-chambers show the concentration is low enough to permit opening. Even then, local exhaust ventilation provided by a flexible, large diameter hose, is used to reduce tritium concentrations in the breathing zone of the worker. Airborne concentrations of several tens of DACs of HTO have been observed for short intervals. Only simple protective clothing has been prescribed in these situations, i.e., coveralls, rubber gloves and overshoes, mainly to avoid spread of surface contamination. Greater tritium concentrations have been found in waste water streams. Regeneration of the EDS dryers has yielded tritiated water with activities of 100GBq/litre, whilst some vacuum pump oils show 100MBq/l. Work with tritiated oils or water has required further protection involving use of PVC aprons and boots.

5. NBI intervention

Neutral beam heating is achieved by accelerating beams of charged ions (deuterium and tritium) to high energies, neutralising them and directing into plasma. This also serves to refuel the plasma. The injector comprises of several beam sources and a large 8m high vacuum chamber containing neutralisers, deflection magnets, beam dumps, cryopump and calorimeter (Fig3). Two NBI boxes are connected to the torus and form part of the tritium containment. Typically during operations, 0.2g of tritium is fed to the injectors for each pulse. Only 1%-4% of the injected tritium enters the torus, the rest being trapped on liquid helium cooled cryopanels. Following operations, several grams of tritium is contained on the cryopanels. They are regenerated periodically, and gases recovered for reprocessing.

Recently, a water leak on a coolant hose to a shutter mechanism compromised further injection of tritium to the torus. The only feasible method for repair was to make man access to the affected vacuum box to locate the leak, cut out the faulty pipework, and weld in a replacement. As such the work represented a major breach of containment.

The radiological condition of the box was such that even after several regenerations of the cryopump, ~100 TBq of tritium remained in the box, both implanted and as surface contamination. For the purposes of controlling tritium uptakes during the intervention, a dose constraint figure was established at 2mSv/person. This was set to be compatible with the previous experience of the average dose accrued by JET workers undertaking specialist tasks in radiation areas. On this basis, the maximum tolerable exposure would be 1 DAC (HTO) for the 80 hours estimated to complete repairs.

Given the potential for large tritium uptakes, there was a clear need to extract as much of the tritium as possible beforehand and then ventilate the box. However, direct pumping and discharge to stack would not be possible, since a target of 40GBq/day aerial discharge was agreed with regulators.

Initially dry nitrogen was introduced into the box, and later moist air. The air was allowed to soak the tritiated atmosphere prior to recovery via EDS. The in-box concentration fell from 32GBq/m^3 to 6GBq/m^3 after 9 pump/purge cycles. The in-box off-gassing rate was estimated to be >>100 GBq/day. Further analysis of the tritium content showed that >99% was in the oxide form. The intention was to ventilate the box through the EDS during the period of personnel access. Given a capacity of 300m^3/hr of the EDS, this permitted only 5-6 air changes per hour. This implied concentrations >100 DAC in the box initially. Given the dose-constraint on exposure to 1 DAC averaged over 80 hours, and the limit on discharges to the atmosphere, the only workable option was to use personal protection in the form of air-fed pressurised suits. Protection factors for pressurised suits in excess of 1000, in laboratory tests, have been reported [3]. Even assuming a protection factor of 100, and a mean concentration of 100 DAC, the dose constraint could be met. However there were considerable logistical difficulties in establishing suited access to the NBI box. The main difficulty was the confined work area, 1.3-2.9m x 3.6m , and the problem of entry and egress from the 8m height. Further, some of the work required access to various heights in the box, and demanded additional safety precautions to counter conventional safety hazards.

Prior to establishing access, the 7m high central support column, which was a major source of tritium itself, had to be removed. Without the benefit of containment, exposures were controlled by using building ventilation in purge mode. The problem of storage of the column during the repair was solved by transferring it to the second, less tritiated NBI box.

The prescribed protection for in-box entries was full pressurised suits. The JET air-fed pressurised suit is a one-piece PVC or polyurethane unit with integral hood and gloves. The suit material has a thickness of 0.3mm. It is supplied with compressed breathing air, at flow rates >320l/min, controlled by a mobile air regulator. Given the high levels of surface contamination likely to be encountered, additional protection in the form of an oversuit (0.15mm) was worn. For work at height, a pressurised suit incorporating a fall arrest system and safety harness was utilised.

Access to the NBI box was achieved by means of a purpose made change area cabin, assembled from modular fibre-glass panels and metal floor mounted over the top of the box. The cabin served as a change area/access control point for suited work. Audio and visual communications allowed safety supervision. The interior surfaces of the cabin were spray coated with a thin peelable coating (0.1mm) of PVA formulated solution (Gramos 6121), to assist with subsequent de-contamination. Entry and exit to the box was arranged using a purpose made man-access lift suspended over the box, lowered and raised by a winch.

With a ventilation rate of ~5 air changes/hour, the initial entry indicated tritium levels >80MBq/m^3 airborne, and 7000 Bq/cm^2 surface. Initial analysis of urine bioassay samples showed uptakes of 2μSv/hour. This indicated a suit protection factor nearer 1000. However, later operations were likely to raise concentrations further. In the event, one of the first tasks following inspection of the repair area was to use high capacity air heaters to dry out the coolant pipes. The box temperature was raised to 50-

200°C for ~36 hours. This had the effect of further increasing gross airborne levels, but later measurements after cooldown showed that the in box levels had fallen to a few DAC (Fig 4).

Fig 3. Schematic View of NBI Box

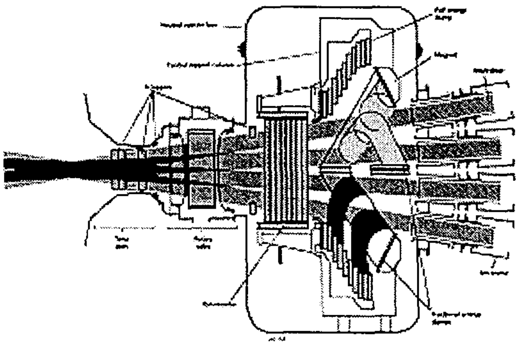
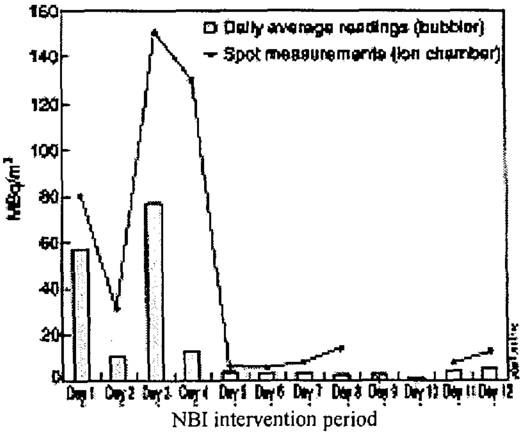


Fig 4. In box tritium concentrations for first 12 days of NBI intervention



In total, 217 man-hours of suited work was carried out. Levels in the box reached 180 DAC, and in the change areas 5 DAC. Surface levels of 56kBq/cm^2 were found on the columns. For the entire

7 week operation (involving transfer of columns, establishing access, leak detection, cutting, welding, and leak checking), a total of 65 persons were involved in the containment breach. The highest individual dose was 70μSv, the collective dose was 500μSv. Residual contamination levels in the cabin were 80-300 Bq/cm^2, the PVA coating on the cabin reducing levels further by factors of 2 to 40. The total tritium discharged in the 7 week period was 300GBq (HT) and 360GBq (HTO), giving negligible impact off-site.

6. Conclusion

Initial experience of tritium handling at JET shows that the methodology of using containment and ventilation systems, with tight radiological control has been important for minimising worker dose to tritium. Procedures for containment breaches involving pump/purge cycles and local and general ventilation have been found to be effective. Large containment breaches have required careful prescription of dose-constraints and personal protection. However, future operations are likely to require greater controls, particularly with the handling and disposal of tritiated solid wastes, water and oils. This initial experience of tritium handling will be useful for planning future maintenance operations at JET, involving much larger quantities of tritium.

7. References

[1] ICRP Publication 26, Annals of ICRP ,1 No 3 (1977)

[2] J. L. Hemmerich et al. 'Installation and Inactive Commissioning of the JET Active Gas Handling System (AGHS)', Proc. 15th Symposium on Fusion Engineering, USA (1993)

[3] IAEA Technical Reports Series No. 324, Safe Handling of Tritium, IAEA (1991)