JOINT EUROPEAN TORUS

JET–P(92)06

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Preprint of Paper to be submitted for publication in
Fusion Engineering and Design

Radiation monitoring, environmental and health physics aspects during the first JET tritium experiment.

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Abstract

The first JET tritium experiment was performed with no radiological incidents, minimal radiation exposure to JET personnel and controlled aerial discharges of tritium to the environment well within daily release limits derived from the discharge authorisation. Most of the radiological protection measures are fundamental design features of the machine and its buildings. These have been in place for many years as JET is intended for protracted tritium operations. They all performed well and confirmed not only their basic design but also minor areas where enhancements had been thought necessary. Special additional equipment was necessary to perform this limited experiment and they were all designed and operated to the same criteria of safety and radiological protection, taking into account the extent of the experimental programme. The range of radiological protection measures implemented and their performance are described in the paper.

1. Introduction

The JET machine, its subsystems and buildings have been designed and constructed for safe operations with tritium and the associated high neutron and gamma radiation yields. To be ready for earlier expected dates for tritium operations, an extensive set of radiation monitoring equipment for gamma and neutron radiation and tritium had been installed in and around the main Torus Hall facility and also the Active Gas Handling Building in which a tritium processing plant is installed. A comprehensive environmental monitoring programme had also been in operation for some time, certain aspects for several years. A Health Physics team has been built up with the required expertise and facilities to provide a full health physics service including radiological protection advice, radiation and contamination surveys, dosimetry etc. Hence a large part of the necessary preparations for tritium operations were in place or highly advanced before the first JET tritium experiment was proposed and these are described below. However the nature of this particular experiment required other measures to control and monitor unavoidable tritium releases and keep

contamination and radiation exposures to a minimum. The JET policy of double metal containment of components containing tritium could not be followed entirely for this short experiment so ventilated confinement systems were adopted for the critical components and justified in the safety assessment. This involved a ventilated glovebox containing the uranium beds in the Torus Hall and ventilated isolators around the components of the Gas Collection System [1], all with once through air flow, which were connected to a common exhaust stack . This combined exhaust and also the major individual branches feeding into the system were monitored for tritium content. The confinement, monitoring and ventilation system are described below as well as the Health Physics measures that were implemented.

2. Radiation and tritium monitoring - the JET RPI system

2.1 Gamma and neutron monitoring

During tritium operations the prime radiation hazards are gamma and neutrons from the D-T reactions and tritium-in-air. A comprehensive Radiological Protection Instrumentation (RPI) system has been progressively installed as the JET programme developed. Fixed gamma and neutron monitors for the working areas were installed in time for the first JET plasma operations in 1983. These are on-line to the JET computer system, CODAS, and have operated continuously ever since. The original scheme is still operational with a few minor alterations in monitor positions and some extra monitors as required by the JET diagnostic systems. These monitors send pulses proportional to the dose rate along fibre optics to a CAMAC system connected to CODAS, which then computes and displays the dose rates on a console in the JET Control Room, raises alarms and logs the data. The system has proved satisfactory and reliable and is planned to continue in operation until the end of the JET project.

In addition, a large set of passive dosimeters (thermoluminescent dosimeters for gamma and neptunium dosimeters for neutrons) were deployed around the building, particularly at penetrations through the biological shield and known scatter paths.

2.2 Tritium-in-air monitoring

The instruments for tritium monitoring were scheduled to be installed nearer to the period of planned tritium operations. The order for the main set of equipment was placed in mid-1989 and

was commissioned well before tritium was brought on to the JET site. On-line systems are based on two variations of an ionisation chamber with common electronics. Off-line sampling devices were developed specifically for JET and are based on silica gel as the collecting agent for tritium oxide (HTO).

2.3 On-line working area monitors

For on-line working area monitors open-walled ionisation chamber devices were chosen for their simplicity and lack of air pumping system, and hence a high degree of reliability can be expected. The chambers have dust filters and ion traps to minimise spurious outputs due to contaminants or local atmospheric conditions. The electronics process the chamber output, averaged over 60 seconds, and sends information to CODAS when polled. Each area monitor has local audible and visible alarms and also a hardwired alarm output to the JET Incident Desk, where all such alarms are sent. A local printer records the output from the monitors, this is primarily to assist in the rapid control of any tritium release incident by providing an immediate local history of tritium levels.

2.4 On-line stack monitors

Pumped flow-through ionisation chambers are used in all the on-line stack monitoring systems and sample lines connect the chambers to the ducts a few metres upstream from the discharge points. The systems measure the tritium concentration of the air discharged to atmosphere and also the volume flow rate through the discharge duct. The integrated discharge is computed at the monitor on a 24 hour basis and these three measurements are sent to CODAS for display, alarm handling and logging.

In the full tritium phase significant air activation products will be produced by the neutron fluxes inside the Torus Hall. These are beta and gamma emitters and will eventually be discharged to atmosphere. These air activation products are measured separately but they would also swamp the signal due to any tritium in an ionisation chamber, so for the Torus Hall discharge stack a proportional counter is used for low level tritium measurements. The electronics for all these devices have common components to those of the area monitors and the interface to CODAS is identical. All the tritium on-line monitors are multiplexed using a common programme and results are logged on the same database as the gamma and neutron monitors.

2.5 Configuration for the first JET tritium experiment

The full set of tritium monitors for the JET Active Phase was installed and commissioned for the first JET tritium experiment except for the proportional counters, these are to be fitted to the Torus Hall depression plant which is not yet installed. The Torus Hall air conditioning system, described in section 4.1, was adjusted to provide a degree of depression inside the Torus Hall, the exhaust being released to atmosphere via its own monitored stack. Hence any tritium releases into the Torus Hall would be measured. The limited neutron yield from the tritium experiments meant that air activation in the Torus Hall would not be significant but would produce some response from the air conditioning stack monitor.

2.6 Off-line sampling systems

A HT/HTO discriminating sampling system for off-line measurements was developed for JET based on silica gel as an absorption medium for HTO (fig. 1). Three versions were produced for environmental, working area and stack monitoring, differing primarily in the sampling flow rate through the devices. Sampled air is drawn through a series of columns, the first contains silica gel and absorbs all water vapour, including HTO. A catalyst system follows where any hydrogen is oxidised and is then collected on a final silica gel column. Any tritium in this last column was therefore originally HT and hence the average HT and HTO concentrations over the sampling period can be calculated. The tritium oxide absorbed by the silica gel is extracted and analysed by liquid scintillation counting.

2.7 Additional monitoring for the first JET tritium experiment

Additional monitoring was required for the experiment to determine the tritium levels in the various temporary ducts in use during the experiments and for health physics survey purposes. A consequence of the experiments is that the JET vacuum vessel and all internal components are tritium contaminated. As extensive internal modifications to the vessel are planned during 1992, notably the installation of the pumped divertor, and a considerable amount of tritiated waste will arise from this work, tritium-in-air monitoring requirements are greatly increased and brought forward from those anticipated for the full JET Active Phase, planned for 1996. Seventeen portable tritium-in-air monitors were purchased from Overhoff Technology Corporation (USA), modified to

JET's requirements, for a variety of tasks during and after the experiments, notably duct monitoring, working area monitoring and tritium surveys.

The glove box in the Torus Hall and the two isolators around the Gas Collection System components in the West Wing had once through ventilation and were all connected to a common stack (fig. 2). The three individual ducts coming from these containments were monitored for tritium concentration using the portable monitors. The outputs were recorded locally and the alarms connected to the JET Incident Desk. This arrangement allowed identification of the source of any tritium release, typically the permeation of tritium through the walls of the uranium bed in the Torus Hall was clearly identified during the day of the experiment. Some controlled tritium releases to atmosphere were anticipated during the subsequent clean-up phase and these were also clearly identified. The local monitors proved invaluable in controlling these releases from the collection system and in identifying hold-up of tritium in pipework. The combined output through the common stack had an on-line monitor and an HT/HTO sampler measuring the discharge to atmosphere.

In addition a pair of gas-flow proportional counters were purchased for the counting of 'wipe' samples used in the measurement of tritium surface contamination. A liquid scintillation counter had been purchased much earlier and was used in the analysis of the HT/HTO samplers and was available for tritium assay in liquids and on 'wipes' as required.

2.8 Experience with the tritium monitoring systems

The tritium experiments gave JET its first experience in monitoring for tritium, particularly for the stack discharges to the environment, and many operational features were determined which are important for full tritium operations. When the results from the HT/HTO discriminating sampler on the special stack became available it was apparent that there were discrepancies between the on-line and off-line measurements. The HT/HTO sampler results showed lower overall tritium releases than the on-line system had indicated. The catalysts on these samplers are cold and will not crack hydrocarbons and hence will not collect the tritium contained in them. It was assumed that some of the discharged gases could be typically tritiated methane and this might explain the difference.

To examine this feature during the clean-up phase a hot platinum catalyst running at 450°C was installed in series after the output from the HT/HTO sampler and then fed into a further sampler.

Any methane leaving the first sampler should have been converted to water and collected on the first column of the second sampler. However the results showed than only a small fraction of tritium made it to the second sampler, suggesting that methanes might not have been the problem.

Further tests were done by placing two portable monitors in series with both the on-line stack monitor and the HT/HTO sampler and recording the measured tritium concentration entering both systems. When the tritium evolution rate from the Torus was acceptably low the gases coming out were sent directly to the stack. The tritium appeared as a pulse in the stack gases after each Torus pulse and hence it was quite easy to discriminate the effect of various pulses. These tests showed that the much slower sampling rate through the HT/HTO sampler not only produced a delay in the tritium appearing at the sampler but also the tritium concentration was considerably less. The first effect is understandable but the second requires further investigation. It has been suggested that long plastic tubes absorb tritium and this could explain the apparent difference in concentration measured in the two sampling lines. Absorption is a function of time and further experiments have confirmed that a fast sampling rate reduces this effect. In future all HT/HTO samplers, which have a very small flow rate through the instrument, will be modified to take its flow locally from a fast primary sampling loop.

3. Stack releases

The Gas Collection System was designed to recover, as far as practicable, the tritium which was injected into the JET machine. Some tritium was, however, not recoverable and resulted in minor aerial discharges. Such releases had been anticipated and were less than 0.5% of the authorised monthly discharge limit. In accordance with the authorisation all discharges of tritium were justified against the principle of using 'Best Practicable Means'. This requires that the options for limiting discharges, taking into account economic and social factors, should be evaluated.

Tritium discharges arose from three sources. The first was from permeation through the walls of the Amersham uranium bed used to supply tritium to the experiment. This operated at about 450°C and at this temperature permeation is significant. Although the measured rate was considerably less than the calculated steady state value, this was the dominant release during the experiment.

The second source came from the gases recovered from the Torus and Neutral Injector cryopump. These gases were passed through uranium beds to absorb all the hydrogen species and crack any hydrogen compounds before absorption. However some tritiated compounds could not be absorbed by the uranium beds and these were assayed for activity before discharge to the stack. They could not be stored indefinitely because the build up of gases would eventually exceed the explosive pressure limits determined for the collection vessel and all collection and processing would stop.

The third major source was when the tritium concentration in the gases recovered from the Torus during the Torus clean-up operations became low enough for them to be discharged directly to atmosphere whilst still remaining well below the daily release limit derived from the Authorisation. Recovery of these gases onto uranium beds was not considered justifiable as it would have resulted in excessive consumption of limited uranium capacity and additional risk of radiation exposure of operators.

The Torus Hall air conditioning stack monitor did indicate slight increases in activity around the times of the two tritium pulses. These were deduced to be due to activated air products and are consistent with estimates derived from calculated data for full D-T operations at JET [2].

4. Ventilation arrangements for the first JET tritium experiment

The Torus Hall was used as an enclosure as designed for full tritium operations and two ventilation systems were implemented for the experiment. The Torus Hall air conditioning system was configured to provide a once through flow and also slight depression in the Torus Hall. A separate ventilation system was provided for the confinement arrangements around the critical tritium containing components of the experiment. Both these systems were to ensure that any tritium released was vented to atmosphere by known and monitored routes and with minimal contamination of working areas.

4.1 Torus Hall air conditioning system

The Torus Hall air conditioning system is designed to provide contamination control by changing the routing of air flow, operating in conjunction with a once through air flow system to maintain a negative pressure differential with respect to atmosphere [3]. The once through system had not been installed at the time of the experiment, therefore the existing Torus Hall system had to be used to

create the flow and pressure differential within the Torus Hall. This was carried out by using the existing discharge stack (fig. 2) to provide a flow rate of 7000 m^3/hr at a pressure differential of 175 Pa. This equates to an air change of 5.5 per day or 9% of the total system flow. When the Torus Hall was open for access the flow rate increased to 35000 m^3/hr giving 28 air changes per day or 45% of the total system flow. In addition to ventilating the Torus Hall the depression provided by the system would ensure that, in the event of special extract system failure, the air flow through the enclosures external to the Torus Hall would be into the Torus Hall and not into the surrounding wings, an important safety consideration.

4.2 Special extract system for the experiment

The special extract system for the experiment was designed as a once through system (fig. 2) and used to maintain a 100 Pa negative pressure differential across the process plant enclosures. The air flow was provided by a run and standby fan system discharging to atmosphere via a stack which was monitored for flow and tritium concentration. The flow rates through the enclosures were 20 air changes per hour, designed to minimise the build up of concentration in the event of a release.

Four of the connections were in continuous operation, these being Neutral Beam Gas Introduction glove box [4], Gas Collection System and Tritium Recovery Trolley [5] isolators and an X-ray spectrometer diagnostic vacuum pump exhaust. The exhaust from the Gas Collection System was connected to the duct from the Tritium Recovery Trolley before the monitoring point and a further connection to the Neutral Injector drum filling [4] system was intended only to be used in an emergency and was hence valved off during normal operation. A final connection was installed to the main vacuum pump exhaust by discharging it into the special extract system and hence to the monitored discharge stack. This connection was used during the clean-up experiments when tritium levels coming from the vessel were low enough to be discharged directly.

As a result of the many combinations of possible flow in the system the individual connections were controlled by constant volume dampers on the non-emergency plant. This provided the freedom for the plant operators to change any part of the system without affecting the other items. Pressure differential across the enclosure was controlled by counter-balanced pressure relief dampers set for 100 Pa. This provided a confinement velocity of 13 m/s across any opening. The fan system was controlled through a control panel which had a duplicated electrical supply. The two

supplies were fed from two separate points so that on the loss of the duty power supply the standby would be available. Three fault conditions - fan stopped, fan tripped and low airflow - were indicated on the panel, any of which would cause the standby fan to be selected.

4.3 Confinement system for critical components

The tritium delivery and collection systems for the experiment were enclosed in ventilated secondary containment. The tritium delivery system connected to the Neutral Injector box was installed in a glove box as the components were relatively small and could all be assembled inside the box and handled as a complete unit.

Several major components of the Gas Collection System already existed from previous experiments and are large, over 2.5 m high, with many pipes and electric cables connected to it. Two sealed isolators made from clear PVC sheet with many glove ports, posting ports and cable and pipe entries were fabricated on site to enclose totally the two major groups of components of the Gas Collection System. These tent structures were supported from lightweight steel tubular frames constructed around the Gas Collection System components. The isolators performed very well, proving easy to work with and readily modified. A further isolator based on the same design concept was added later when additions to the Gas Collection System became necessary.

4.4 Flow monitoring

The discharge stacks for the special extract system and the Torus Hall air conditioning system were both monitored for flow and sampled for tritium concentration. Flow measurement was by a pitot static "Wilson" flow grid connected to a pressure differential measuring device, the electrical output from this device was connected to the RPI stack monitor system to compute the integrated discharge of tritium, as described in section 2.4.

5. Radiological protection features of JET

JET was designed and built for D-T operations and most of the radiological protection features required for such operations have been in-place since 1983. The major safety features include massive shielding, controlled ventilation of active areas, neutron production control, environmental monitoring and radiological protection instrumentation. The Health Physics Group has also been established to a suitable size for the anticipated tasks. The staffing level was increased in 1989 to 12

to cope with the introduction of beryllium at JET. This was viewed as being adequate for the first JET tritium experiment though some use of contractors was anticipated for the following shut-down.

5.1 Shielding

The Torus Hall enclosure is the primary shielding and is designed against a forecast yield of 10^{20} 14MeV neutrons per pulse (5 x 10^{23}/year) with a transmission criterion of 1 mSv/year. The resultant shield walls are 2.8 m of high density concrete, including 0.3 m of borated concrete block on the inside.

5.2 Ventilation

In the full D-T phase the Torus Hall will operate under depression of a few mbar and with less than one air change per day. This is to minimise the emission of activated air products, most of which have a short half-life, and provide a controlled and monitored path to atmosphere of all radioactive gases arising from JET operations. For the experiment the existing air conditioning plant was adjusted, as described in 4.1 above, to provide a degree of depression. The Torus Hall enclosure is, as far as is practicable, hermetically sealed, the discharge rate to atmosphere being primarily determined by the leak rate through the penetrations in the walls.

5.3 Neutron production controls

Restrictions have been in place since 1988 to control the neutron yield from D-D operations in order to constrain the induced activity inside the vacuum vessel below a level at which hands-on maintenance and modifications inside the Torus during shut-downs and other interventions can be carried out within the JET dose constraint policy. The neutron production during the experiment and the time lapse before the planned entry are consistent with this criterion.

5.4 Environmental monitoring

An environmental monitoring programme has been in operation around the JET site for several years now, primarily to determine the background levels of radiation and radioactivity in order to establish the effect of JET operations. Air, rain, groundwater and vegetation samples are taken and analysed quarterly for gamma and beta activity. Passive neutron and gamma dosimeters are also deployed around the site boundary.

More recently, instruments have been deployed around the Culham site specifically for tritium-in-air measurements. At 4 locations HT/HTO discriminating monitors, as described in 2.6, were

installed in mid-1990 and are analysed every 4 weeks. In addition up to 20 passive samplers for HTO can be deployed around the site boundary, of which 4 were in operation during the experiments. Food crops are also grown at specific plots around the site and are analysed for tritium uptake, both HTO and organically bound tritium. Some results from the period of the tritium experiment are presented later in this paper.

5.5 Radiological Protection Instrumentation

The installed RPI system has been described in 2 above. A set of standard portable monitors was also available for surveys.

6 Health Physics preparations for the first JET tritium experiment

Most of the preparations required by the experiment arose from the presence of tritium on the site rather than the D-T operations of the Torus. These included biological monitoring, increased passive dosimetry, access restrictions and contamination control.

6.1 Biological monitoring

The assessment of personal radiation exposure at JET is carried out using thermoluminescent dosimeters (TLD) supplemented as necessary by neutron dosimeters (of the nuclear emulsion type). Arrangements were made for the experiment with a Health and Safety Executive approved laboratory (AEA Technology, Harwell) for the analysis of tritium in urine. Urinalysis is the recognised dosimetric method for assessing committed effective dose equivalent following exposure to tritium as HTO. It can also be used as an indicator of exposure to HT.

6.2 Passive dosimetry

The routine distribution of TLD and Neptunium dosimeters was expanded significantly for the period before and after the experiment, with particular emphasis on monitoring radiation transmitted through penetrations in the biological shield.

6.3 Access restrictions

Restrictions were imposed on access to the roof of the JET building which had two objectives. The first was to prevent access to the immediate vicinity of the special ventilation stack from which tritium discharges were expected, the second arose from the reduced shielding on the Torus Hall ceiling relative to the walls.

6.4 Radiologically designated areas and contamination control.

Under UK legislation it was necessary to designate the area immediately around the uranium beds as supervised areas (>2.5 μSv/h). The uranium in a 'bed' generates a low but measurable gamma-radiation dose rate in the immediate vicinity of the bed 3 - 10 μSv/h. It was decided that once a bed was loaded with tritium the area would be re-designated as a controlled area (>7.5 μSv/h, or >3/10 DAC, or >4 Bq/cm^2 for β) These controlled areas were also subject to clothing change and other contamination control measures.

Non-essential diagnostic system with their own vacuum systems, which had previously allowed their filtered exhaust to discharge into the Torus or Diagnostic Halls, were isolated in order to prevent the discharge of tritium into those areas.

7 Radiological experience during the first JET tritium experiment

The experiment had two stages, the 1% and 100% experiments. The 1% experiment did not yield much radiological protection information, the machine activation was not significantly higher than previous high yield D-D operations. As with previous D-D operations, the 1% experiment did not produce any measurable increase (above background) in radiation levels outside of the biological shield.

7.1 Uranium beds

Whilst the 1% experiment did not produce a measurable increase in work-place radiation levels, it did provide an opportunity to gain experience with the installation and disconnection of a tritium loaded 'bed' with a modest inventory (~2 TBq) before the installation of the 74 TBq 'bed' for the 100% experiment. With the standard double containment transport package and the use of a glove box 'posting' facility, it was possible to install and disconnect the uranium beds for the experiments without measurable personal exposure to tritium and no workplace contamination (outside of the glove box). The internal surfaces for the glove box were found to be contaminated to a general level of ~30 Bq/cm^2 with a maximum of 497 Bq/cm^2.

7.2 100% tritium experiment

The two demonstration pulses on 9 November each yielded about 8 x 10^{17} 14 MeV neutrons and these had a number of radiological implications. Radiation measurements carried out within the Torus Hall shielding indicated levels on the inside of the shield of:

Gamma (TLD) 3.9 - 8.0 mSv/pulse and Neutron (Np) 18 - 125 mSv/pulse.

The radiation levels (neutron and gamma) incident upon the west wall of the shield, i.e. opposite Octants 4 and 5, were noticeably higher than the average.

The effects outside the Torus Hall were encouraging. The shield criterion of 1 mSv/y equates to a transmitted dose of 200 nSv per pulse of 10^{20} neutrons. For an 8 x 10^{17} pulse this would be reduced to 1.6 nSv which is approximately 2% of natural background for gamma radiation over 1 hour. The shield was challenged by gamma radiation levels of up to 8 mSv/pulse and neutrons equivalent to 125 mSv/pulse. The results of passive dosimetry outside of the biological shield are generally indistinguishable from natural background. The exceptions include specific locations above the shielded ceiling of the Torus Hall in the Roof Laboratory and Shielding Beam Housing. In these areas spot measurements showed enhanced neutron levels above penetrations through the Torus Hall ceiling of up to 280 μSv in the Roof Laboratory and up to 400 μSv in the Beam Housing, both for the period between 23 October and 18 November 1991. These levels indicate the need for access control during subsequent tritium operations on JET. Other exceptions include spot neutron levels in the North Wing of 180 μSv, the Diagnostics Hall of 400 μSv and 280 μSv and the West Wing of 70 μSv. These measurements are all associated with particular penetrations in the main or secondary shields or known scatter paths recognised as requiring secondary shielding prior to a prolonged D-T campaign. All the mentioned areas are immediately outside of the Torus Hall walls

7.3 Neutron activation

There were three main radiological protection implications resulting from the observed neutron activation: air activation, external and internal activation of the machine. For the first time noticeable air activation products, ^{41}Ar, ^{16}N, ^{13}N, and ^{37}S, were observed. The gas bake-out system at JET is currently operating with air as a major constituent of the heat transfer medium. During the pulses on 9 November a 'slug' of activated air was observed to generate a transient gamma-radiation field in the vicinity of the gas bake-out duct where it exits the biological shield. The level generated reached

300 μSv/h, but this decayed rapidly (minutes). A combination of ^{16}N and ^{41}Ar is suspected to have been the cause. The integrated dose in the area amounted to only 2 μSv/pulse, but the radiation levels were sufficiently high to induce responses in the local tritium-in-air monitors despite their gamma-ray compensation.

Externally to the machine, within a few hours of the cessation of D-D operations on JET, measurable levels of the short-lived radionuclide ^{56}Mn have been routinely observed, generating dose rates of up to 150 μSv/h in contact with the machine following a daily yield of 2×10^{17} neutrons (2.5 MeV). The decay has been observed to follow the 2.58 hour half-life expected. Following the two 100% tritium pulses a residual gamma radiation field in excess of 240 μSv/h was observed by a compensated Geiger-Muller detector head mounted on the inside Torus Hall wall. The induced activity decayed rapidly ($t^1/2$ effective ~5 minutes) for approximately 15 minutes, by which time a longer half-life decay was evident ($t^1/2$ effective ~120 minutes) (fig. 3).

Preliminary activation analysis of the JET vessel was made by measurements of the gamma levels inside the Torus Hall during the first two days after the experiment to give a first order estimate of the isotopes produced by neutron activation. Among the identified isotopes 30 minutes after the second tritium pulse were ^{56}Mn, ^{57}Ni, ^{24}Na and ^{64}Cu, the ^{56}Mn with a half life of 2.58 hrs being dominant. Many short lived isotopes were present in the first few minutes after the pulse where the radiation levels were over an order of magnitude higher than at 30 minutes.

Contact dose rates on top of the JET machine were measured at 2 hours and 20 hours after the second tritium pulse of about 1000 μSv/hr and about 10 μSv/hr respectively. The predicted dose rates from activation due to the known neutron production were about 30% higher at 2 hours and slightly higher at 20 hours.

The Torus Hall radiation levels had decayed sufficiently two hours after the second pulse to permit a comprehensive gamma-radiation survey in the Torus Hall using a portable ionisation chamber survey instrument (fig. 4). The contact dose rate immediately on top of the machine in the vicinity of Octants 6 and 7 were 25% higher than the other Octants. It is not yet possible to explain this phenomenon - but it may be associated with the orientation of the neutral injection trajectory for the tritium PINIs.

The more important result of the neutron activation is the enhanced inventory of ^{58}Co in the Inconel of the vacuum vessel. Although it has not yet been confirmed, it is expected that the in-vessel radiation environment will be approximately 50% higher at the start of the divertor shut-down than at the equivalent point for other major shut-downs since 1989. A starting dose rate of ~90 μSv/h ($t^1/2$ - 71 days) will require rotation of staff at a higher frequency than experienced before at JET for the 5 mSv/year limit to be adhered to.

7.4 Tritium in the working environment

The working environment, the ventilation stacks and secondary containments were monitored for airborne and surface contamination. The working environment remained free of tritium contamination throughout the experiment with the exception that the 'posting' out of uranium beds involved handling of contaminated items outside the glove box but controls prevented the spread of any contamination into the working environment.

Following the experiment, tritium concentrations rose in the Torus Hall atmosphere and it was also observed that tritium was being collected in the condensate from the Torus Hall air conditioning plant. The specific activity in the condensate was consistent with the specific activity of the water vapour in the Torus Hall atmosphere, ie 4-9 KBq/l. The results are summarised in table 1. The rise in HTO levels in the week after the experiment, 11 to 18 November, are believed to be due to permeation through the JET vacuum vessel walls and also from the uranium bed delivering tritium that was not confined by the glove box. The appreciable rise in HT levels during the period 18 to 25 November is believed to be due to the re-start of vacuum systems on diagnostics previously isolated from the torus and subsequent opening of torus isolation valves.

7.5 Urinalysis

Urine sampling was carried out before and after the experiment for about 30 people involved directly in work on uranium beds or associated plant. The results of these samples are all at or close to the limit of detection (100 Bq/litre). No measurable exposure to tritium resulted from the experiment amongst the JET workforce. All other personal dosimetry results for November are indistinguishable from normal D-D operations.

7.6 Tritium in vacuum pump oil

Tritium in vacuum pump oils has been experienced at JET since 1987 at levels as high as 0.43 MBq/l, resulting from the tritium produced in D-D reactions. Following the experiment oil samples were analysed and levels as high as 60 MBq/l were measured. Basic precautions for handling such oils are in place.

7.7 Environmental measurements

JET has had a routine environmental monitoring programme in place for many years, though much of the data from these programmes post experiment is not yet available. Those elements of the programme that are available (e.g. discriminating samplers - airborne HT and HTO) are generally consistent with the discharges JET has made as quantified by on-line monitors and discriminating stack samplers.

The 4 main air sampling stations are at a range of about 250m and positioned approximately North West, North East, South East and South West relative to JET. The results are shown in table 2 for the period around the experiment.

8. Conclusions

The first JET tritium experiment was conducted without radiological incident and with very low personal exposures to tritium and ionising radiations. The radiological protection measures implemented in the main design of the machine and its buildings performed as anticipated and the installed Radiological Protection Instrumentation system performed satisfactorily. The extra measures necessary for the experiment, notably the confinement system for critical components, ventilation systems and additional tritium monitoring instruments were commissioned well before the experiment and proved very satisfactory for their tasks. The experience gained in the operation of the RPI system with tritium was invaluable and showed some shortcomings which can readily be resolved.

It has been recognised that secondary shielding in certain areas will be necessary prior to a protracted tritium phase. The first JET tritium experiment has confirmed this and that major access restrictions will need to be enforced. The need to have a low activation gas in the Torus bake-out system was also confirmed as essential. Access restrictions may be required for the Roof Laboratory

and almost certainly for the Torus Hall roof itself. The latter will need to be assessed against gamma and neutron radiation as well as tritium discharges from the short ventilation stacks designed for JET.

Acknowledgements

The authors wish to thank their many colleagues whose assistance has been invaluable in the work described above, in particular C May for the design and construction of the excellent isolators used in the Gas Collection System. J-F Jaeger analysed the gamma data to gain first estimates of the isotopic content of the machine after the experiments. The Health Physics Group at JET also provided the essential support for much of the work. R Otlet and Miss A J Walker of Radiocarbon Dating are thanked for their efficient analyses of the discriminating samplers during the period and prompt responses to the various additional work requested by JET for the experiment.

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Table 1

HTO and HT levels in the Torus Hall over the experimental period

Period	HTO Bq/m^3	HT Bq/m^3
28/10 - 4/11	2	23
4/11 - 11/11	17	3
11/11 - 18/11	79	2
18/11 - 25/11	44	764
25/11 - 2/12	40	183

Table 2

Environmental levels of HTO and HT measured at sampling stations around the JET site over the experimental period

		Sampling station			
		NW	NE	SE	SW
Sampling Period	Species	Bq/m^3 +/- 20%			
24/9/91 - 22/10/91	HTO	80		40	
	HT	70		60	
7/10/91 - 4/11/91	HTO		30		30
	HT		70		100
22/10/91 - 19/11/91	HTO	100		190	
	HT	90		230	
4/11/91 - 3/12/91	HTO		430		30
	HT		260		70
19/11/91 - 16/12/91	HTO	80		40	
	HT	230		80	
3/12/91 - 30/12/91	HTO		120		60
	HT		50		100

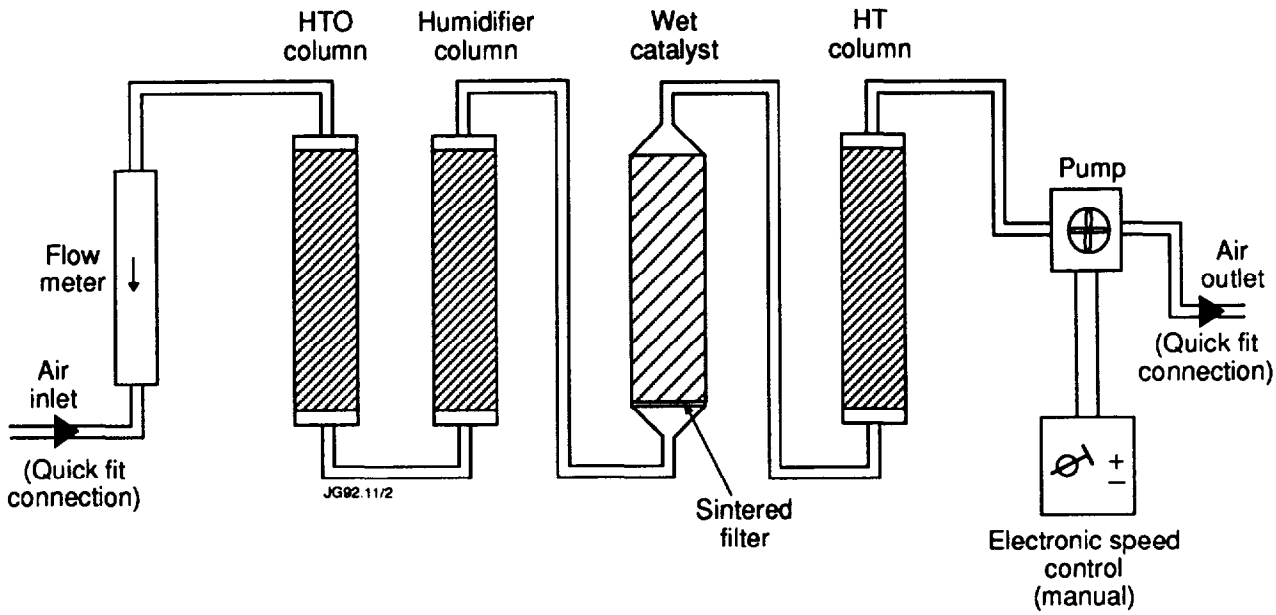

Fig.1. Schematic of JET HT/HTO discriminating sampler.

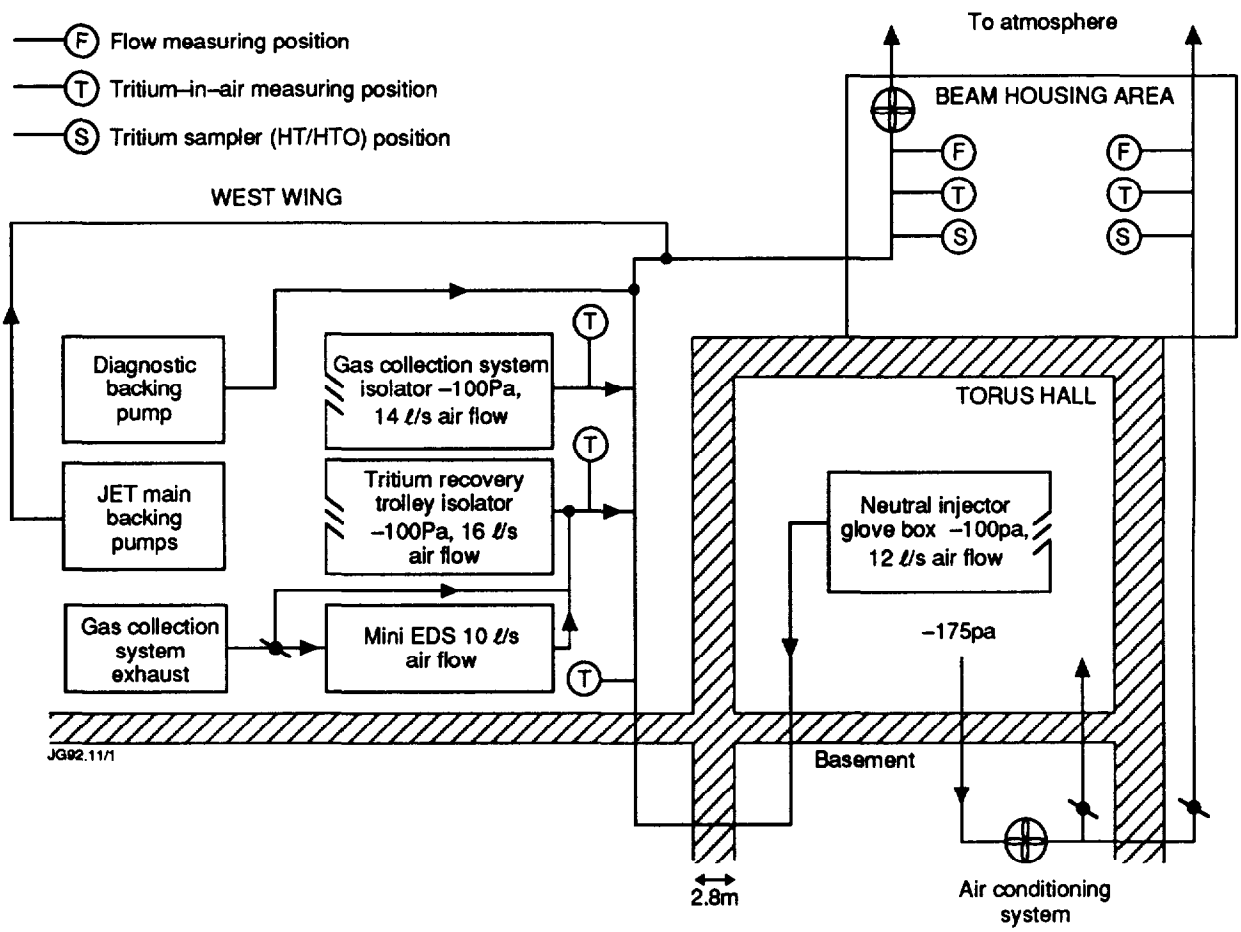

Fig.2. Special ventilation and monitoring scheme for the first JET tritium experiment.

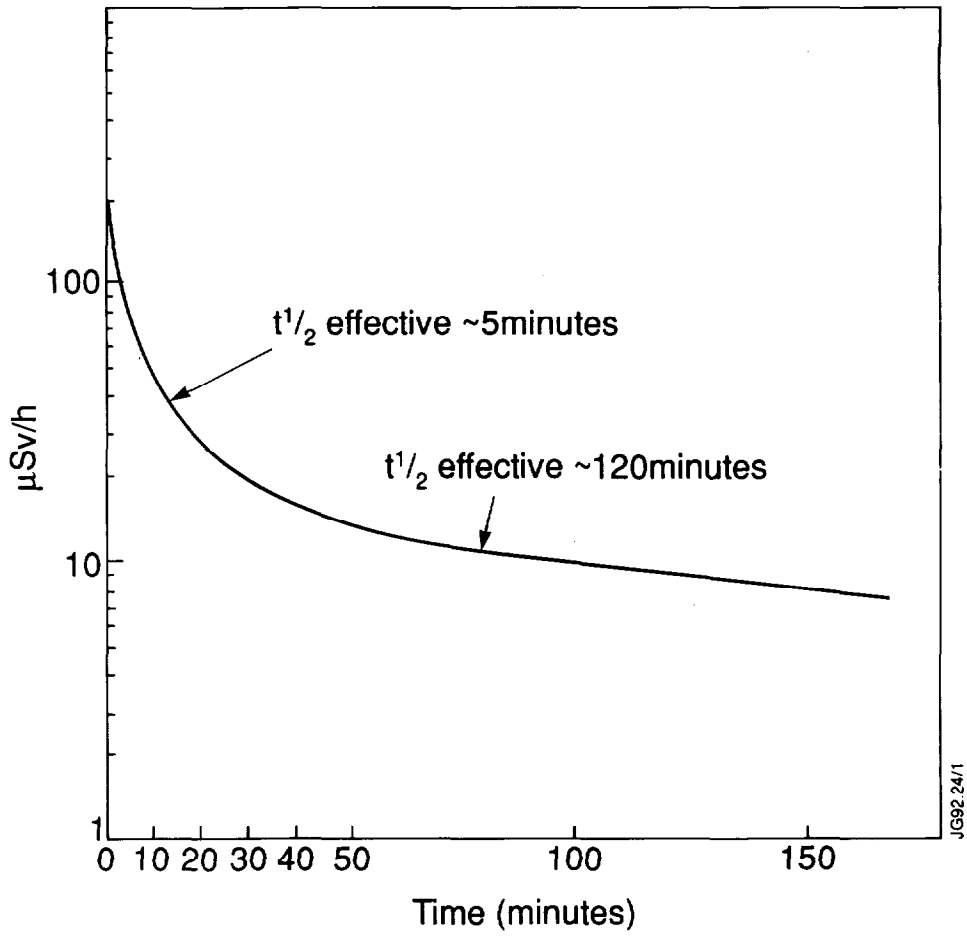

Fig.3. Gamma dose rate at west wall of the Torus Hall following the 100% tritium pulse.

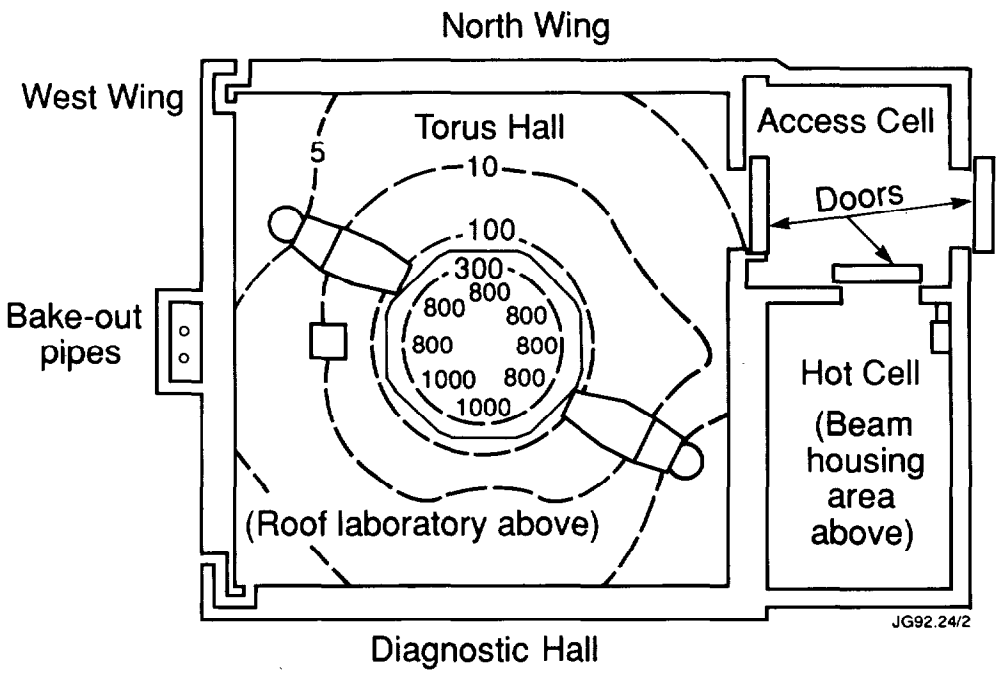

Fig.4. Isodose rate contours 2 hours after the 100% tritium pulse.

ANNEX

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