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JET Tokamak, preparation of a Safety Case for tritium operations

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A new Safety Case is required to permit tritium operations on JET during the forthcoming DTE2 campaign. The outputs, benefits and lessons learned associated with the production of this Safety Case are presented. The changes that have occurred to the Safety Case methodology since the last JET tritium Safety Case are reviewed. Consideration is given to the effects of modifications, particularly ITER related changes, made to the JET and the impact these have on the hazard assessments as well as normal operations. Several specialised assessments, including recent MELCOR modelling, have been undertaken to support the production of this Safety Case and the impact of these assessments is outlined. Discussion of the preliminary actions being taken to progress implementation of this Safety Case is provided, highlighting new methods to improve the dissemination of the key Safety Case results to the plant operators. Finally, the work required to complete this Safety Case, before the next tritium campaign, is summarised.

Keywords: Tokamak, DTE2, Safety Case, Tritium Operation

1. Introduction

JET has unique capabilities in the fusion programme. It has previously operated with Tritium in 1991 (PTE - the Preliminary Tritium Experiment), DTE1 in 1997 (the largest use of Tritium in JET to date) and in the Trace Tritium Experiment in 2003. JET has not carried out any tritium experiments since this date. Preparations are now being made to undertake another tritium campaign known as DTE2.

JET is particularly suitable for investigating configurations and conditions relevant to ITER. Without further D-T experiments in JET, there could potentially be a generational gap between JET's previous D-T experiments in 2003 and the start of D-T operation in ITER.

It was recognized that since the issue of the last Torus D-T Safety Case (known as the Pre-operational Safety Report, POSR) in 2001 a large number of modifications have been made to the JET Vacuum Vessel including the replacement of the first wall. In addition changes to the methods and data used in hazard assessment have been introduced such that a new Safety Case is required.

As a result a D-D Safety Case was issued in 2011 to cover current operations and a provisional JET Torus D-T Safety Case has been prepared. The primary function of this case is to demonstrate that a future tritium campaign can be carried out safely at JET and to identify any Implementation Actions which will require completion to ensure the facility can continue to be operated safely during the DTE2 campaign.

2. Regulatory requirements

JET has always had a Safety Case regime. Although JET does not require a nuclear site license, production of a Safety Case provides a thorough means to demonstrate that all potential hazards at JET have been considered and all significant risks have been assessed as is required by the Management of Health and Safety at Work regulations, 1999. Since 2000 JET has adopted UKAEA methods and guidance for the production of Safety Case documents designed for nuclear facilities on nuclear licensed sites. This requires the issue of an Authority to Operate to each of the facilities by the Culham Site Safety Working Party. The membership of the Site Safety Working Party includes representatives from UKAEA departments responsible for Safety, Active Operations, Engineering, Health Physics, and Safety Case Engineering as well as two members independent of the organisation.

3. Safety Case content

The Safety Case is defined as the suite of documents that present the safety argument, determine the operating envelope, principal outcomes and outputs from the safety assessments and confirm whether the risks are tolerable and as low as reasonably practicable (ALARP). A Safety Case contains a description of the facility, a review of the performance of that facility, an analysis of fault conditions, identification of key safety systems, assessment of normal operations and a description of the safety management arrangements.

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3.1 Operational history review

The first stage in updating the Safety Case for DTE2 was to review the changes since the last Safety Case was produced.

A Periodic Review of Safety and Environment (PRoSE) is submitted, for the JET Torus, to the Site Safety Working Party on an annual basis. The purpose of a PRoSE is to demonstrate that an acceptable level of safety performance and safety management has been maintained, during the reporting period. Reviewing these reports provides information on the activities within the facility and highlights changes to equipment or process and safety management arrangements that have been made.

JET also operates a modification system where all changes to plant or process are categorized according to their radiological and non-radiological hazard potential. Since the last tritium Safety Case there have been around forty significant Safety Case modifications, some examples of which are outlined below.

The predominantly carbon based wall was replaced with a new beryllium and tungsten, ITER-like, wall. This change had an impact upon assumptions of tritium retention and release within the Vacuum Vessel as well as increasing the facility non-radiological hazard due to the potential exposure to toxic beryllium dust.

The Toroidal Field coils were previously cooled with Freon-113 but due to changes in environmental legislation, banning the use of Freon, this was changed to Galden-HT55 in 2001. This also has slightly reduced the inventory of longer lived neutron activation products.

Windows and mirrors were replaced/removed/added to several diagnostic systems and additional feedthroughs to the vacuum vessel were introduced. These are considered in the revised frequency assessment for loss of vacuum accidents, in the new Safety Case.

Diagnostics have been moved outside of the Torus Hall to protect them from damage due to the increased neutron fluence expected for DTE2. This has an impact on the tritium boundary and shielding requirements in their new locations.

Two Disruption Mitigation Valves have been fitted to JET with a third imminent. These are primarily provided for machine protection to reduce high thermal and magnetic energies that are released on a short timescale when sudden loss of plasma confinement, disruption events, occurs. However the disruption mitigation systems have an impact on the safety analysis as they add more flammable gas into the JET Vacuum Vessel which needs to be accounted for in gas inventory software to prevent a flammable mix forming if a subsequent LOVA were to occur.

3.2 Hazard Analysis

The Torus and Active Gas Handling Facilities Pre-Operational Safety Report identified the principal operations hazards as:

- Radiation (ionising and non-ionising);
- Electric/magnetic (high voltage, magnetic fields);
- Chemical (explosive/flammable, corrosive, toxic);
- Physical (extreme temperatures, mechanical);

Radiation doses arise from normal operation of the facility, both internal from routine exposure to tritium and external via neutron and gamma radiations. Accident scenarios could give rise to uncontrolled releases of tritium, tritiated water and activated tokamak dust, exposure to neutron/gamma radiation during pulsing operations, or exposure to neutron activated components and fluids. Non-radiological hazards include explosive and flammable mixtures of hydrogen isotopes, as well as toxic substances or asphyxiants such as beryllium, cryogens, Galden, and sulphur hexafluoride.

Key operational radiological accident categories have been carried forward and remain unchanged from early Safety Cases. These are:

- Loss of Vacuum Accidents (LOVA);
- Loss of Coolant Accidents (LOCA);
- Loss of Flow Accidents (LOFA);
- Plasma Heating and Fuelling Systems Events (PHFSE);
- Magnetic Events (ME);
- Shielding Events (SE);
- Loss of Plasma Control (LOPC);
- Loss of Electrical Power (LOEP);
- External Events;

Radiological hazards have been assessed under both operations and shutdown plant regimes when very different Machine conditions and operator access arrangements apply. This has required reviews with operators in order to ensure that the event sequences, processes and inventories reflect D-T and post D-T operations and shutdowns.

Hazards during shutdown periods were initially assessed in a stand-alone Safety Case but have now been incorporated in this Safety Case as operator tasks. It is recognized that many of these tasks are planned to be carried out remotely following the proposed tritium campaign. However, the Safety Case conservatively applies maximum permitted radiation and contamination levels for operator access. Faults including loss of containment, unplanned vessel breach, crane impact and dropped loads are considered. Non-radiological hazards have also been reviewed with a greater emphasis being placed on the beryllium hazard following installation of the beryllium first wall.

Deterministic hazard assessment has been carried out to identify any significant faults (i.e. those faults which could give rise to an unmitigated dose of more than 20mSv to the most exposed person on site or an unmitigated dose of more than 1mSv to a member of the public off-site). Safety controls have been identified to ensure that risks to workers and members of the public are kept below the Basic Safety Limits for risks from accidents as defined in the Safety Assessment Principles. Probabilistic risk assessment provides a measure by which the frequency and consequences of accidental releases of radioactive material and/or radiation from JET can be judged against the criteria laid down by the Health and Safety Executive for acceptability of risk in the UK.

The Provisional D-T Safety Case takes into account applicable D-T inventories and revised processes and procedures planned for both during and after a tritium campaign. This has led to modified accident sequences and predicted dose release estimates. It is noted that data is still being analysed on likely tritium retention behaviour following the installation of the beryllium first wall. As a result, current assessments have taken a conservative estimate of the retention until further data is available. The inside building dispersion coefficients applied in the D-T Safety Case for the calculation of operator doses have been revised to reflect JET specific ventilation scenarios and outside dispersion coefficients have been revised to be more representative of actual discharge conditions.

The assessments from the Provisional D-T Safety Case identified areas for further specialist assessment to improve the accident analysis prior to tritium operations. In particular these included the development and application of computer modelling of LOVA and LOCA accident sequences since the original analysis had been derived from hand calculations. The aim of this modelling was to reduce the conservatism of the conclusions by including time dependent features and parameters into the calculations (such as heat transfer profiles and mass flow rate changes); and by modelling the interconnected volumes in the system so that condensation within the matrix lines and on the cryopanels can be taken into account. Fig 1 shows a simulation of a LOVA leading to ingress of cool Torus Hall air into the hot JET vacuum vessel, 593k, and the temperature effects in-vessel.

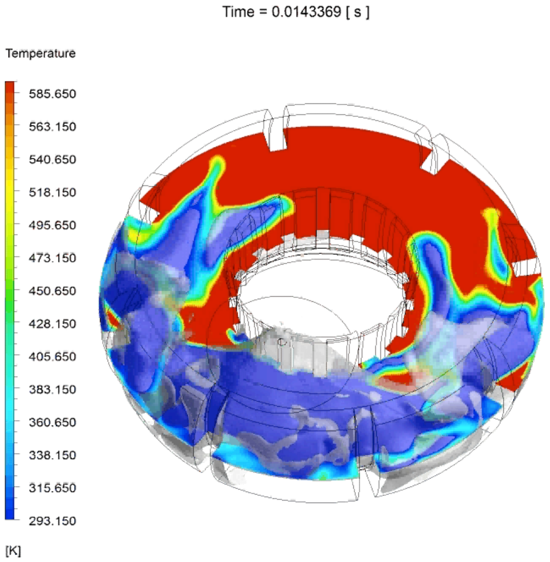

Fig 1 Example of a thermal image of air temperature in the vacuum vessel in the event of a LOVA (from ANSYS model)

The modelling has included the effects of each of the key safety systems on the accident progression and calculated the impact if any of these were to fail. The results provide confidence that with the safety systems operating as designed there is no significant release of radioactive material which may otherwise give rise to an elevated dose to the public or on-site workers.

The safety controls which protect operators and/or members of the public against the consequences of significant faults are assessed and nominated for designation as key safety related equipment (KSRE) or key safety management requirements (KSMR) where it can be demonstrated that they ensure that risks are reduced below the Basic Safety Limits for accident conditions. Twenty one KSRE have been identified including shielding, machine containment, access controls and pressure interlocks. These are listed in an Engineering Schedule together with their safety function and safety requirements. An extract from the Engineering Schedule is shown in Table 1 below.

KSRE	Safety Function	Safety Requirements
15mbar Vessel High Pressure hardwired interlock	To limit exposure to radiological contamination in the event of an In-Vessel LOCA by initiating isolation of In-Vessel Cooling Water/cryogen supplies	To limit the amount of water or cryogens released into the NIB and the JET vacuum vessel such that any coolant leakage is contained in the vessel.

Table 1: Engineering Schedule extract from Provisional D-T Safety Case

One of the conclusions of the hazard analysis is that JET still meets its design principle of no single failure of any system results in a dose to a member of the public or worker greater than the annual legal limit and that off-site countermeasures are not required for plant initiated events.

3.3 Fitness for Purpose

An essential part of a Safety Case is whether the key safety systems will fulfil their safety function when required. This is particularly an issue for an ageing facility. There is an ongoing programme of review of our key safety controls at JET.

For example one of the fitness for purpose reviews has considered all the tritium primary containment boundaries and examined where there are potential weaknesses. A number of actions have arisen from this review for example replacing a Torus beamline isolation valve for the x-ray spectroscopy diagnostic, which was a pendulum type with a linear gate valve. This reduces the time taken to close the valve and isolate the beamline from the Torus inventory in the event of a LOVA in the beamline.

Another fitness for purpose review considered the bulk and removable shielding. Since the bulk shielding was designed to attenuate a neutron production of 5×10^{23} neutrons/year and the DTE2 campaign is only planned to produce 1.7×10^{21} neutrons in total, there is a large margin of safety in the bulk shielding safety function. However, the secondary shielding elements, such as the penetrations and removable shielding, were not specifically designed to meet this target. Where the fitness for purpose assessment identifies that the shielding is not sufficient for DTE2 operations remedial action is recommended. One example of this is in the dog-legged north-west labyrinth in the Torus Hall. Fig 2 below shows the dose from neutrons and gammas, close to the 1E-03Sv limit, shown in red, extending beyond the labyrinth opening, during a DT pulse.

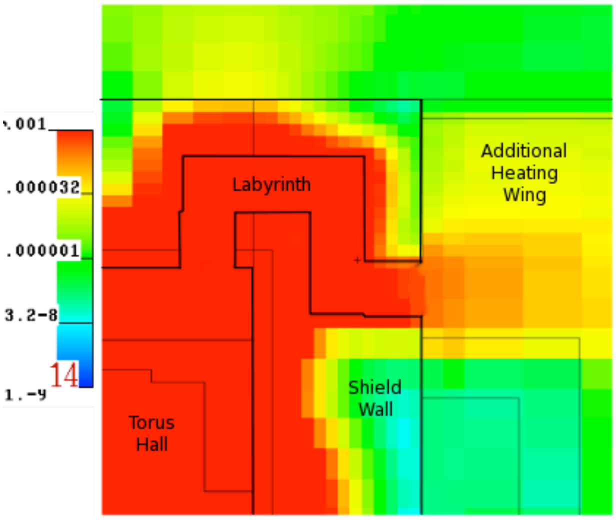

Fig 2 Dose map for the North-West labyrinth

To complement the fitness for purpose reviews human factors assessments of safety related tasks are also carried out. One of these assessments was carried out on the search and lock up system in the Torus Hall which checks that personnel have left the Torus Hall prior to lock up before Machine operations. The human factors review recommended improvements, and following a design review, it was decided to introduce a new barcode system in the Torus Hall to provide an auditable, predefined search route to provide confidence that the area has been adequately searched and is clear of personnel before locking up. Fig 3 shows the proposal for the search route around the Torus Vacuum Vessel.

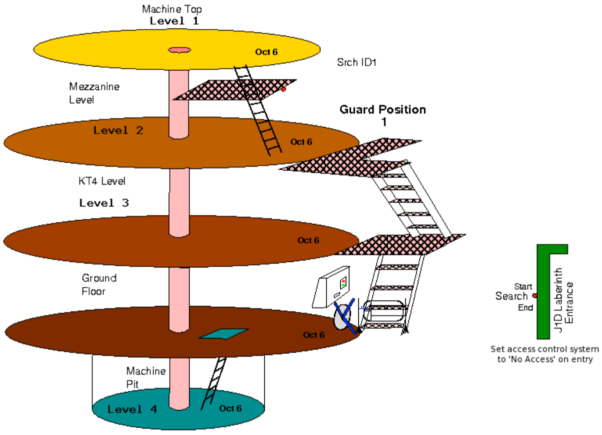

Fig 3 Torus Vacuum Vessel Search zones

3.4 Normal Operations

As well as examining fault conditions the Safety Case needs to demonstrate how radiological and chemical exposure is managed on a daily basis during normal operations.

The primary controls to limit radiological exposure are shielding and access control. The mechanical key system is currently being upgraded to extend access control during D-T operations. This involves considering adjacent areas, for example where there are penetrations coming out of the Torus Hall, to ensure that exposure to radiation is as low as is reasonably practicable (ALARP) and to ensure that both on-site and off-site normal operation doses are maintained within annual objectives.

There is provision of high integrity primary and secondary containment for tritium within the Torus Hall and peripheral plant. Control of discharges through the Exhaust Detritiation System assist in minimising the release of tritium to the environment

3.5 Safety Management

This section of the Safety Case describes the management arrangements for the facility.

Management of JET is complex as it involves staff from all parts of the organization as well as visiting scientists. Management of the safety of the facility is assigned to an Authority to Operate (ATO) Holder. Engineers in Charge (EICs) ensure safety during operations within the bounds of the JET Operating Instructions. Where decisions are required that may deviate from these instructions the ATO holder and / or Chief Engineer must give approval.

The Torus Authority to Operate area interfaces with a large number of other areas and these interfaces are managed through Local Rules. An example of a significant interface is the Active Gas Handling Facility;

which supplies, recovers, processes and recirculates the hydrogen isotopes, including tritium, which are used by the Torus.

The management arrangements for implementation of each of the key safety management requirements are defined to ensure that the safety function is delivered and understood.

Key staff and their training requirements are defined and the emergency response arrangements are documented. Emergence exercises performed to test the arrangements are described.

4. Safety Case Implementation

Writing a Safety Case on its own does not ensure safe operation, it is the communication and implementation of this Safety Case that provides this confidence.

The actions arising from the Safety Case are classified as Implementation or Improvement Actions. Progress against these actions is managed by the Authority to Operate Holder and monitored by the Site Safety Working Party via the PROSE. Those actions classified as Implementation are required to be carried out before the Safety Case is adopted. Those classified as Improvement must be considered but may be accepted or rejected provided a justification is made where an action is not carried out, which could be on cost-benefit grounds.

As mentioned above the operating instructions and local rules are being updated to reflect the new management requirements defined in the Provisional D-T Safety Case. Testing out these new procedures is part of the training and the forthcoming D-T rehearsal provides an opportunity for this. This is a rehearsal of operating procedures and access arrangements as if JET were in a tritium campaign but whilst still operating in deuterium. Of particular concern are the access requirements which will become more restrictive due to higher activation levels, neutron flux and tritium inventory. The rehearsal will highlight whether there are any issues in operating JET with limited access to ancillary areas.

Training of suitably qualified and experienced personnel (SQEP) is essential and a training matrix for all key staff has been prepared. Methods to better communicate the contents of the Safety Case are being developed. This includes having an on-line version of the Safety Case which supports; easy searching across multiple files, inclusion of full scale drawings, hyperlinks for ease of navigation, and provides a consistent and easy to read format. A simple, single page, safety case summary poster is also being trialled in one area of site to make the Safety Case more accessible to those working in the area

5. Further work before DTE2

To develop a final Safety Case for DTE2 as well as completing the Implementation actions raised in the provisional D-T Safety Case, it is intended to include results from the identified specialist assessments. This includes incorporating results from the completed MELCOR calculations for the LOVA in vessel and water and cryogen LOCA models for the neutral beam boxes. Further modifications to the JET Torus are underway and these need to be assessed and incorporated. Significant modifications planned include the new Diagnostic Vacuum crown, reinstatement of the nitrogen fire suppression system and the new gas introduction modules in the Torus Hall. In addition updated information on operating instructions, training and emergency preparedness will be included.

The final Safety Case needs to be externally peer reviewed and will then be submitted to the Site Safety Working Party for endorsement.

6. Conclusion

The Provisional D-T Safety Case demonstrates that risks to workers and public from operation of JET for DTE2 are ALARP and that no off site countermeasures are required.

Work on implementing the Safety Case is in progress and is an essential part of the safety management process to ensure that the safety case is not just a paper exercise.

The Safety Case has allowed JET to:

- Manage approval of operations
- Systematically analyse faults
- Identify Safety Controls and demonstrate that these will work as intended
- Provide a training tool for operators and managers to understand the safety aspects of the plant
- Provide a benchmark to assess changes

Acknowledgements

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