**Joint European Torus D-T Safety Case**

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The Joint European Torus (JET) is currently the largest magnetic fusion experiment in the world. As a fusion research facility, it is used to investigate the potential of fusion power as a safe, clean, and virtually limitless energy source for future generations. The JET facilities are collectively used by all European fusion laboratories under the EUROfusion consortium. Scientists from predominantly European countries, and more from around the globe, participate in JET experiments each year, within the integrated European research programme coordinated by EUROfusion. The Culham Centre for Fusion Energy (CCFE) is responsible for operating the facility for fusion researchers and for maintaining and upgrading it. This work is carried out under a contract between the European Commission and the United Kingdom Atomic Energy Authority (UKAEA) (CCFE's operator). This funds the scientists, engineers and other technical staff essential for operating and maintaining the device.

JET was established with a long-term objective to create safe and environmentally sound prototype fusion reactors. To meet this objective, JET operated for several years in Deuterium-Deuterium (D-D) mode using deuterium (an isotope of hydrogen) as a fuel, which is not radioactive and produces a relatively low level of induced activation and associated radiation from fusion reactions. The JET Facility was also designed to operate in Deuterium-Tritium (D-T) mode where the fusion reaction is fuelled by deuterium and tritium. D-T operation produces higher energy neutrons which have a greater potential to activate the structural components of the machine, and tritium itself is a radioactive isotope. JET has previously operated with tritium in 1991 (the Preliminary Tritium Experiment), DTE1 in 1997 and in the Trace Tritium Experiments in 2003 (TTE). JET has not carried out any D-T Experiments since the TTE.

As an operational experimental facility designed to investigate tokamak physics in sustained high current divertor plasmas with strong auxiliary heating, JET is particularly suitable for investigating configurations and conditions relevant to ITER and is unique in having tritium injection capability. D-T operation of JET is part of the European Research Roadmap to the Realisation of Fusion Energy [1]. Without further D-T experiments in JET, it could mean a gap of 30 years between JET's previous D-T experiments in 2003 and the start of D-T operation in ITER. As a result, a further JET D-T Experimental Campaign was developed (DTE2), with the scientific principle being accepted in 2013.

Characteristics of the campaign were as follows:

* 14 MeV Neutron Budget - 1.7 × 1021 neutrons.
* Pulse length - Limitation of 10 seconds for tritium beams
* Tritium fuelling - This will be predominantly through five new tritium introduction modules at the divertor. Additional fuelling will be through the relevant beams using tritium. Note there will be no tritium pellet fuelling; pellets will only be used to supply deuterium in the D-T stages.
* Tritium Inventory and Regeneration - 15 gram limitation in the torus at any one time. The frequency of pulses will mean that there will be simultaneous tritium feed and recovery in the Active Gas Handling System.
* Neutral Beams - The high-power operation is reliant upon maximum use of the neutral beams. Both Neutron Injection Beams (NIB) will be used with tritium in the T-T phase, with up to all 16 beamlines. D-T phases will require only one NIB to be operating with tritium, and the other with deuterium. It is anticipated that each tritium beam will deliver 2.2 MW to the plasma.
* Radio Frequency Systems - All Ion Cyclotron Resonance Heating (ICRH) systems are to be available. The Lower Hybrid Current Drive (LHCD) is not currently planned to be used in the DTE2 campaigns although it has still been included in this safety case.

Specialist assessments were needed to enable justification of continued Torus D-T operations following the introduction of the ITER-like beryllium wall. The preparation of a JET Torus DTE2 Safety Case required incorporation of an updated and standalone hazard assessment, taking into account the impact of the beryllium wall, and incorporating an assessment of hazards appropriate to both operations and shutdown regimes. In addition, the Key Safety Related Equipment (KSRE) and Key Safety Management Requirement (KSMR), identified in the 2003 TTE assessment, would need to be reviewed, updated, and extended to include the key controls identified in the new assessments. It was therefore agreed that a staged Periodic Safety Review (PSR) would be carried out.

The first stage of the PSR was conducted in 2011 to ensure that the JET Torus D-D Safety Case [2] reflected the current state of the facility, and to demonstrate that D-D operations can continue in compliance with modern standards of safety following the 2009 shutdown, due to the second enhanced performance programme.

A provisional JET Torus D-T Safety Case [3] was produced in 2014 to identify work required in preparation for D-T operations and to provide assurance that a robust safety case for D-T operations could be made. The primary function of this case was to demonstrate that the future tritium campaign could be carried out safely at JET. It enabled identification of most of the (K)SRE and (K)SMRs, so that their fitness for purpose and human factors assessments could be prepared in advance of producing the JET Torus DTE2 Safety Case, and any implementation actions requiring completion to ensure the facility can be operated safely during the DTE2 campaign.

Issue 1 of the JET Torus DTE2 Safety Case [4] updated the provisional JET Torus D-T Safety Case to reflect plans developed for the DTE2 campaigns and to review the interim period since 2014. This case includes computational modelling of key JET fault sequences including Loss of Vacuum Accident (LOVA), Loss of Cooling Accident (LOCA), and shielding events. Some implementation actions from the provisional JET Torus D-T Safety Case had been progressed to ensure the facility could return to full tritium compatibility and a number of new implementation actions were identified at this stage.

The JET Torus DTE2 Safety Case has since been updated to Issue 2 [5], reporting changes up to the end of 2019. This includes work to close the implementation actions, modifications to plant in preparation for tritium operations and further human factors reviews. This case provides an overall justification of the safety of the facility and demonstrates that risks from D-T operations and subsequent shutdowns are acceptable, can be adequately controlled and reduced to as low as reasonably practicable. With the identified key controls and implementation actions in place, it is anticipated that in the event of a single failure event, on-site doses will not exceed 20mSv and off-site doses will not exceed 1mSv. A number of dual and multiple failure events result in on-site doses in excess of 20mSv and off-site doses in excess of 1mSv. It is also anticipated that DBA frequency targets will be met for on-site doses and off-site doses will not exceed 10mSv for any event sequence. The analysis confirms that off-site countermeasures are not required for plant-initiated events.

Following DTE2, a period of non-tritium operations is planned. Before the non-tritium operations commence there will be machine clean-up operations aimed at reducing retained tritium levels within the vessel as much as possible, this will include deuterium and hydrogen fuelled pulses. While activation levels of machine components will remain elevated, there will be a step reduction in the neutron yield during subsequent non-tritium pulsing operations. Therefore, a less onerous subset of safety requirements, commensurate with the diminished radiological hazards associated with D-D operations, will be applied for ongoing operation under the DTE2 Safety Case. [6]

This paper presents the approach and methodology exercised for the JET safety case, and highlights the lessons learned from fission industry derived safety cases. This includes updated radiological hazard assessments, including the use of deterministic and probabilistic techniques, and how the risk criteria applied in the assessments are aligned to industry and fission regulator targets. The paper will also present the key hazards associated with the JET facility, including direct and indirect radiation both during and after pulsing, internal radiation hazards, hazardous/toxic substances and cryogenic fluids.

References

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