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Overview of the specialist assessments undertaken to support the JET safety case review

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ABSTRACT

The Joint European Torus (JET) operates using deuterium as a fuel but has also operated in D–T mode where the fusion reaction is fuelled by deuterium and tritium. To justify the safety of the experiments, safety reports are produced and approved. The safety case has recently undergone a periodic safety review and preparations are being made to undertake a tritium campaign in 2015. To provide information regarding the compatibility between reactor-grade plasma and the materials facing the plasma, an "ITER-like wall" was installed in JET comprising beryllium first wall tiles, solid tungsten and CFC tungsten coated tiles in the divertor region. In the prospect of the next D–T campaign with the new wall, the following areas of specialist assessment have been identified:

- Engineering fit for purpose assessment of key safety related equipment,
- Human factor assessment of key safety management requirement,

This paper will present a status report of these assessments and the methodology applied. Along with the results of a loss of coolant accident (LOCA) analysis using the CEA developed thermal hydraulics code CATHARE 2 V25-2.

1. Introduction and background

The Joint European Torus (JET) is currently the largest operating tokamak in the world and the JET programme is a collective activity used by European fusion laboratories and managed by the European Fusion Development Agreement. JET was established with a long-term objective to create safe, environmentally sound prototype fusion reactors. To meet this objective, JET was designed to operate in D–T mode where the fusion reaction is fuelled by deuterium and tritium.

The first D–T experiment (DTE1) was carried out in 1997. To justify the safety of DTE1, safety reports were produced to obtain approval for the experiments [1], the most significant being the JET pre-construction safety report (PCSR). The safety case has recently undergone a periodic safety review and a new version for 2011 D–D operations has been issued.

This has provided a new D–D specific sub-set of KSRE (key safety related equipment) and KSMR (key safety management requirement). Another review is ongoing for the next tritium campaign planned in 2015 which would provide a final set of KSRE/KSMR. Any protection system (engineered system or management rule) which is necessary to ensure that doses to workers or the public are below the basic safety limit (BSL) is defined as a safety mechanism that is KSRE or KSMR. The BSL for determination is simplistically defined as a dose of 20 mSv to a worker or 1 mSv to a member of the public. The KSMRs and KSREs are required to minimize, control or eliminate the major hazards on the plant. To justify D–T operations, the KSRE and KSMR need to be shown to be robust, to do this a human factor assessment of KSMR and an engineering fitness for purpose assessment of KSRE are required.

Because the JET vacuum vessel (VV) contains complex demineralized water coolant systems for plasma facing components and the divertor, the in-vessel LOCA (loss of coolant accident) has been identified as one of the worst accidental scenarios in each safety case reviews [2]. A LOCA analysis using the CEA developed thermal hydraulics code CATHARE 2 V25-2 has been conducted to update the analysis in the PCSR using "state of the art" software.

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Table 1
List of KSMR.

Safety requirement	Safety function
Limit on hydrogen isotope inventory on cryopumps	To prevent a hydrogen deflagration in LOVA
Evacuation procedures in the event of an radiation protection instrument (RPI) alarm	To minimize operator exposure due to incorrect shielding configuration
Pre-operational shielding checks	To ensure that all shielding elements are in the correct position prior to pulsing
Torus building operational areas search	To ensure no-one remains in the Torus hall prior to the restart of operations.
Interspaces must be pumped, purged and tested for tritium content	To minimize the internal dose to an operator breaching a diagnostic interspace
For work requiring full pressurized suit, the number of workers simultaneously drawing air from the breathing air supply system must be limited to 10	To ensure that the breathing air system is not overloaded so that the full efficiency of the system is maintained

Table 2
List of KSRE.

Safety system	Safety function claimed
Area Gamma Monitors	To alert operators to any shielding deficiency and prevent pulsing
PSACS (personnel safety access control system)	Ensure pulse cannot be initiated until all shield doors and beams are closed and all removable shielding blocks are in place.
Shielding doors, beams and removable shielding elements	Reduce operator doses outside a penetrations to as low as reasonably practicable.
Bulk radiological shield	Reduce the dose rate outside of the Torus hall to below 0.25 μSv/h during all operational modes.
Torus hall emergency stop push buttons	To allow an operator to prevent a pulse if trapped in the Torus hall

2. Human factor analysis of KSMR

2.1. Background

Table 1 defines the list of the KSMR identified for the DD campaign.

For each listed KMSR, a human factor analysis has been conducted.

2.2. Methodology

The aim is to examine the effectiveness of the management requirement and to demonstrate that operator performance in the defined task(s) is acceptable and that plant equipment, task design, organization and environment are sufficient to assure that human error levels are ALARP and that the potential for operator error is minimized.

The typical issues considered during the assessment included the general ergonomics of the task environment, assessment of plant operations, management arrangements, competency and training of staff, emergency alarm handling, suitability of procedures to effectively support tasks and maintenance tasks.

The assessment involved appropriate staffs who are familiar with the situations being assessed. In all cases, staff were encouraged not to have a too 'success oriented' approach. Each report has been internally and independently peer reviewed and commented.

2.3. General recommendations

The principal generic recommendation is that the KSMRs should be highlighted in the JET procedures in which they appear so that any modification to these documents would trigger a safety review. This recommendation became an improvement action in the D–D safety review.

Other recommendations included improvement of the tritium inventory awareness by undertaking a specific refresher training program and testing the response to RPI alarms prior to the start of a D–T campaign.

2.4. Specific recommendations on the KSMR related to hydrogen isotopes inventory limit on the cryopumps of the machine

Since the installation of the ITER- like wall, the machine is now equipped with PFC (plasma facing component) mainly made of beryllium. As opposed to the PCSR where the steam-graphite reaction has been ignored in LOCA analysis, the steam beryllium reaction is considered. The assessment of the control limiting the hydrogen inventory trapped on the cryopump panels in the machine during normal operation has been extensively reviewed.

The analysis concluded that the limits on hydrogen isotopes inventory should be reviewed to take into account the dependency of the LFL (lower flammability limit) of hydrogen with temperature and pressure. A conservative approach was taken in evaluating that limit since data on LFL at high temperature and low pressure (relevant fusion devices conditions) are lacking [3,4]. The human factor analysis also highlighted the fact that the control of hydrogen on cryopanels should be done by measuring the total amount of gas injected through the gas injection modules – without involving any software calculation for the partitioning of the pulse gas inventory.

3. Fitness for purpose (FfP) of KSRE

3.1. Background

Within any safety case, there is a requirement to demonstrate that any and all engineered structures, systems or components (SSCs) claimed as contributing to the achievement of safe operation are able to deliver those roles throughout the lifetime of that safety case.

Table 2 defines the list of the KSRE identified for the DD campaign excluding the ones related to non operational hazards.

For each listed KSRE, a fitness for purpose analysis has been conducted.

3.2. Methodology

The review was carried out in three stages.

Firstly, the KSRE is identified along with its safety functions. This stage also describes the performance requirements limits and conditions. The original standards used to design the KSRE are established. The methodology also provided the technical responsible officers with standards applicable for the KSRE FfP review listed in [5,6]. The margins available with respect to original design are evaluated, along with dependencies on other systems or operator interaction. This phase of the review also commonly involves plant walkdowns.

Secondly, KSRE current situation is described. The modifications since installation or last FfP are reviewed. The margins available are re-evaluated taking into account the modifications since installation. The ageing mechanisms are identified and taken into account. Ref. [5] defines the notion of physical ageing of SSCs resulting in gradual deterioration of physical characteristics and also non-physical ageing (called obsolescence) when they become out of date in comparison with current knowledge, standards and technology.