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

J. Vallory[a], H. Boyer[b], F. Moreno[c]
[a]Association EURATOM-CEA, CEA/Cadarache, F-13108 Saint Paul-lez-Durance, France - CCFE/Engineering department Culham Science Centre, Abingdon, OX14 3DB, UK
[b]CCFE/ Active operations department, Culham Science Centre, Abingdon, OX14 3DB, UK
[c]CEA Nuclear Energy Directorate, CEA/Grenoble, F-38000 Grenoble

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 D-D and D-T experiments, safety reports are produced to obtain approval for the experimental campaigns. 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 in the main chamber, 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,
- Specialist assessment of the impact of the beryllium wall on the releasable tritium inventory and on the potential for hydrogen evolution under various fault conditions.

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 which are used as input to assess the impact of beryllium wall on the potential for hydrogen explosion.

Keywords
Safety Case, Fitness for purpose, Human factor, Loss of coolant analysis

1 Introduction and background

The Joint European Torus (JET) is currently the largest operating tokamak in the world. The JET Programme is a collective activity used by more than 40 laboratories of EURATOM Associations managed by EFDA (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 operated for a number of years in D-D mode using deuterium as a fuel, which is inactive and produces a relatively low level of induced activation and associated radiation from fusion reactions. The JET Facility was designed to operate in D-T mode where the fusion reaction is fuelled by deuterium and tritium. D-T operation produces higher energy neutrons which have the potential to activate the structural components of the machine, and tritium itself is a radioactive isotope.

In 1991 a Preliminary Tritium Experiment (PTE) was undertaken using a small amount of tritium and then further campaigns, the so-called Deuterium-Tritium Experiments (DTE), were planned with an increased amount of tritium. The first DTE (DTE1), carried out in 1997, was considered to be the active commissioning phase as, on completion of this phase, the Torus would have the potentiality to operate routinely with tritium fuelling. The Active Gas Handling System [1] was designed to supply, recover, process and recirculate the hydrogen isotopes, including tritium, which are used by the Torus.

To justify the safety of DTE1, safety reports were produced in various stages to obtain approval for the experiments [2], the most significant being the JET Pre-Construction Safety Report (PCSR). Once the DTE1 phase had been completed, the Torus and the AGHS safety cases were combined and updated in the form of a Pre-Operational Safety Report (POSR) which was issued in 2001. Since then, the Torus has continued to run experimental programmes including the Trace Tritium Experiment (TTE) in 2003. The Safety Case has recently undergone a periodic safety review and a new Safety Case for D-D operations has been issued. Preparations are also being made to undertake a tritium campaign in 2015.

In this framework, the detailed hazard analyses have been reviewed to ensure that they reflect the current machine for D-D operations. This has provided a new sub-set of KSRE (Key Safety Related Equipment) and KSMR (Key Safety Management Requirement) specific to D-D operations. A final set of KSRE/KSMR will be derived for the next D-T campaign. The radiological accident categories considered for the Torus safety case are Loss of Vacuum Accident (LOVA), In-Vessel Loss of Coolant Accident (IV-LOCA), Ex-Vessel Loss of Coolant Accident (EV-LOCA), Loss of Flow Accident (LOFA), Plasma Heating and Fueling System Event (PHFSE), Magnet Events (ME), Shielding Event (SE), Loss of Plasma Control (LOPC) and Loss of Electrical Power (LOEP). In addition to this, the assessment of the existing industrial hazards with emphasis on the more detailed assessment of beryllium, hydrogen explosion, cryogen and electrical hazards has been enhanced. The frequency data applied in the Hazard Assessments has been updated to reflect current plant and processes, operational experience and improved reliability data where available. The same has been applied to Non-operations to clarify the sub-set of KSRE and KSMR for Shutdown(s) prior to the next tritium campaign.

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.

The methodology by which these candidate systems are identified as (Key) Safety Related Equipment (SRE) or (Key) Safety Management Requirements (SMR) is summarised in figure 1.

All fault sequences were reviewed for candidate safety systems for potential inclusion. The engineered systems primarily include the shielding against neutron and gamma radiation, containments, including ventilation systems, Personnel Safety Access Control System (PSACS), Radiation Protection Instrumentation (area gamma, tritium-in-air monitors and alarms), etc...

In addition to the detailed review of hazards, the following areas have been identified for assessment prior to the production of the JET Torus Facility Safety Case to justify D-T operations:

- A Human Factor Assessment of KSMR;
- An Engineering Fitness for Purpose assessment of KSRE

commencing with the key controls identified in the Torus D-D safety case,

- Specialist assessment of the impact of the beryllium wall on the releasable tritium inventory under various fault conditions and an assessment of the potential tritiated dust source terms;
- Specialist assessment of the impact of the beryllium wall on the potential for hydrogen explosion under various fault conditions. Because the JET Vacuum Vessel (VV) contains complex demineralised 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 [3]. A LOCA analysis using the CEA developed thermal hydraulics code CATHARE has been conducted to update the analysis in the PCSR using “state of the art” software. The results obtained will be used as input to assess the impact of beryllium wall on the potential for hydrogen explosion.

2 Human factor analysis of Key Safety Management Requirements

2.1 Background

As described in paragraph 1, a system (engineered or a management rule) that minimizes, controls or eliminates the major hazards arising from safety analysis is defined as a KSRE (for equipment) or KSMR (for management rule). For each type of operations (DD or DT) a set of KSRE/KSMR is being derived from the hazard analysis.

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 Safety Management Requirement and to demonstrate that operator performance in the defined task(s) is acceptable and that plant equipment, task design, organisation and environment are sufficient to assure that human error levels are ALARP and that the potential for operator error is minimised.

The typical issues considered during the assessment included the general ergonomics of the task environment, plant operations assessment, management arrangements, staffing and competency, training, emergencies, alarm handling/prioritisation, substantiation of the 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 human factor assessment report has been internally and independently peer reviewed and commented.

2.3 General recommendations

From an operational point of view, the JET machine is operated in the framework of Operating Instructions (OI), Local Rules (LR), and Machine Operation Documents (MOGDOC) describing the systems and their operating and emergency procedures. The OIs define limits within which the machine may be safely operated and ensure the integrity of the machine. The J2 Control Room Local Rules are used by J2 Control Room staff to operate (or check the operation of) plant from the control room, or other plant which interfaces with it. They specify working arrangements and duties in particular areas and provide the link between the plant safety case and working level arrangements. The MOGDOC system is an information retrieval system concerned with JET plant and machinery, working practices, rosters, general JET knowledge, operating and emergency procedures. Most of the safety management requirements assessed refer to at least one of these rules/instructions/ procedures. The principal generic recommendation is that the KSMRs should be highlighted in the JET Operation Instructions / Local Rules / MOGDOC 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. For example, the KSMR “evacuation in the event of an RPI alarm” should be stated in Torus Hall building evacuation procedure.

Other recommendations including forward action for tritium campaign to improve the awareness of the tritium inventory in the plant by undertaking a specific training programme 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. This material will chemically react at high temperatures with steam to produce hydrogen in case of in vessel LOCA as does CFC (Carbon Fibre Composite) and tungsten. However, the specificity of the beryllium oxidation reaction is that it is strongly exothermic, whereas the carbon one is endothermic. Therefore since the risk of hydrogen generation is increased under an accident scenario, 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 in OI 7.5 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 [4, 5, 6]. 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. Thereby avoiding the control on that limit being done on a system relying on software.

3 Fitness for purpose review of Key Safety Related Element

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. The process of Engineering Substantiation or Fitness for Purpose review is applied to SSCs within existing facilities and commonly involves plant walkdowns, review of operational history, confirmation of maintenance practices and a review of the SSC design against applicable, current, engineering standards.

The precise scope of the substantiation exercise varies depending upon the safety significance of the role delivered. Where appropriate, recommendations are made for the rectification of any shortfalls against the specified performance requirements and passed forward for formal ALARP consideration.

A Fitness for Purpose (FfP) study of the Key Safety Related Equipment (KSRE) was carried out in preparation of the 2003 trace tritium experiments (TTE) [7]. This report has been revisited and updated as part of the periodic safety review of the safety case with a particular focus on the modifications implemented and ageing mechanisms acting on the SSCs.

Table 2 defines the list of the KSRE and SRE identified for the DD campaign.

For each listed (K)SRE, 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 Fitness for Purpose review listed in References [8, 9, 10, 11, and 12]. The margins available with respect to original design are evaluated, along with dependencies on other systems or operator interaction.

Secondly, KSRE current situation is described. The modifications since installation or last fitness for purpose analysis are reviewed. The margins available are re-evaluated taking into account the modifications since installation. The ageing mechanisms are identified and taken into account.

Reference 8 defines the notion of physical ageing of SSCs resulting in gradual deterioration on their physical characteristics through process such as the ones described in Table 3.

It also defines the notion of non-physical ageing (called obsolescence) that is the SSC becoming out of date in comparison with current knowledge, standards and technology. The management of this type of ageing is described in Table 4.

The appropriate consideration of operating experience feedback analysis should be given with respect to ageing. The components to be considered for ageing are mechanical components, electrical, instrumentation and control components and civil structures.

The feedback from the JET Machine and other machines is also reviewed for this analysis. Operational feedback from other fusion devices has been gathered into reports mainly for safety and environmental assessments during the course of ITER Engineering Design Activity [13, 14, and 15].

Inspection regimes / results have also been studied. The Machine inspection regime is defined in Reference [16]. This document defines for each KSRE the maintenance arrangements, interval and the tracking arrangements along with the responsible group. During the FfP analysis, the defined maintenance interval can be re-defined following the methodology in Reference [12] where the equipment life stage (initial, maturity, ageing, and terminal) can be estimated for the vulnerable components based on engineering judgement. The tolerance to fault sequences is also evaluated.

The third stage deals with the future requirements in terms of operating conditions and effect on the safety function, inspection regimes, life limiting features and described recommendations or proposed modifications.

3.3 General recommendations

The FfP reviews highlighted the importance of material, parts and components identification and control as an essential requirement for an effective programme dedicated to the monitoring, prediction, detection and mitigation of plant systems degradation important to safety. The review found that no single common asset register is controlled for the machine. However, the information describing these components is available from discussions with the individual responsible officers of the systems on the machine. Similarly, the functional and physical configuration (design requirements and drawings) of JET are contained within disparate sources and not managed in a controlled design requirements document(s). It is therefore proposed that the configurations of KSRE systems could be captured in a post Enhancement Programme 2 shutdown baseline for JET and thereafter that configuration control is applied. With regards to maintenance, a great reliance is made on commissioning activities to performance test components. The extent of preventative maintenance should be improved. It is recommended that a systematic analysis is undertaken on all of the KSRE to determine a targeted inspection programme prior to the start of a D-T campaign.

3.4 Specific recommendations

KSRE - Removable Shielding Elements and Biological Bulk Shielding:

The shielding of all systems have been examined and appear to be in good condition and are considered fit for purpose for D-D operation. This is confirmed by the radiation records which show no evidence of any weakness. Some modifications will need to be carried out if full D-T operation is to take place. The shielding calculations for all the modifications carried out since 2003 (year of TTE experiment) should be reviewed to ensure that the shielding calculations have taken loss of shielding and sky shine into account.

SRE - 15mbar vessel pressure and in vessel water isolation system and 200mbar vessel pressure signal - Drain and Refill System (DRS) (see table 2)

Up to now, the drain and refill has not been used very much and the components have not displayed many failures, if any at all. Each component has been operated between 4 to 22 times during each commissioning procedure after plant shutdowns (7-8). However, the current maintenance procedure consists simply of commissioning the plant using existing procedures. These procedures outline a sequence of operation of the valves and switches on the system but they do not include physical inspections of any of the components on the DRS. It is recommended that as a minimum the components, identified as being in Stage 3 “ageing” (see Reference 12) of their equipment lifetime or being critical to the operation of the DRS, be disconnected and inspected thoroughly for signs of wear or damage. This includes pneumatic actuators and axial flow valves.

4 Some results of Specific engineering analysis

4.1 Background

As detailed in previous chapters, one of the Fitness for Purpose review requirements is to assess the equipments' fitness with an updated knowledge of practice for codes and standards. On the JET machine, the drain and refill system has been nominated as KSRE/SRE and designed to drain and inhibit the refilling of the in vessel cooling pipes of the machine after a LOCA due to an in-vessel pipe break. The original calculations for the conditions in the vessel after a LOCA have been done by hand in 1996 and therefore involve some simplifications in the transient heat transfer mechanisms taken into account [17]. As part of the FfP review for the D&R system, it was proposed to analyze the accident of water ingress to the plasma vessel with thermal-hydraulic state-of-the-art CATHARE code and evaluate the pressure inside the VV as a function of time.

CATHARE is a thermal hydraulic systems analysis code for all transients and postulated accidents in Light Water Reactor systems, including both large and small-break loss-of-coolant accidents as well as the full range of operational transients. The main hydraulic components or elements are pipes (1D), volumes (0D), a 3D vessel and boundary conditions, connected to each other by junctions. Other sub-modules feature pumps, control valves, sinks and sources, breaks and many other ones. All CATHARE modules are based on a six-equation two-fluid model (mass, energy and momentum equations for each phase), with additional optional equations for non-condensable gases and radio-chemical components. The discretisation of all terms of the equations is fully implicit in 1D and 0D modules and semi-implicit in 3D elements including inter-phase exchange, pressure and convection terms, and the resulting nonlinear equations are solved using an iterative Newton solver. The code allows efficient use of several processors in parallel [18].

The first fusion related LOCA calculations using CATHARE [19] involved a benchmark to assess the capabilities of the best estimate thermal hydraulic codes to simulate the main physical phenomena occurring during an in-vessel break transient. The pressurisation of a volume at low initial pressure, the critical flow, counter pressure effect and relief into an expansion volume (ITER specific) had been calculated.

The ITER engineering design activity to assess safety issues associated with LOCAs and loss-of-vacuum accidents (LOVAs) for the non-site specific safety report involved calculations using a modified version of the MELCOR code [20].

4.2 Simulation of the In-vessel LOCA with CATHARE

The systems involved in the LOCA sequence are defined in figure 2. When an in-vessel water pipe breaks in the VV, the plasma disrupts and the cooling circuit (CC) liquid spreads in the vessel. The mechanisms involved in phase transformation of the liquid water are illustrated on figure 3. A fraction of the water immediately flashes to vapour. Some droplets are created in suspension within the hot gas and exchange with it. Some water hits the VV walls, streams down the Torus and boils on it due to the heating of the vessel walls. The remaining water then fills the bottom of the VV and boils on it. All these phase transformations must be represented because they create vapour which increases the pressure in the VV. In a single “VOLUME” element in CATHARE modelling, flashing at a SOURCE outlet is well represented with the pressure range extension implemented. The water streaming down a wall and exchanging heat with it can’t be represented with a two-mesh wall of a “VOLUME” element. Specific CATHARE element (VVRAIN AXIAL on figure 4) had to be added to the model to simulate that heat exchange. The droplet falling flow rate has been maximised in order to simulate the liquid to wall exchange on the previously defined AXIAL element. The complex geometry of the VV’s lower part can’t be represented with a single VOLUME and the complex geometries and filling sequences are represented by 4 VOLUMES on figure 4.

The LOCA sequence is managed as follows on the machine (figure 2). When 2 out of 4 pressure switches on the VV measure Pvv > 15mbar, some valves close and cut inlet/outlet flows of the cooling circuit (see valves on diagram figure 2). When the outlet CC pressure is less than 2.3bar(g) indicating a leak on the circuit, the water in the CC of the leaking octant is drained in the depressurized tank. When pressure in VV > 200mbar, the pumping circuit valves are opened. If the pressure in the VV is not reduced by the safety equipment then ultimately when Pvv > Patm + 45 mbar, the bursting disc will burst.

Similarly to the modelling approach considered for W7X LOCA [21], it was important to model the cooling circuit to assess the correct boundary conditions for the in vessel LOCA. The CATHARE model of the CC along with the drain circuit is given on figure 5. The analysis of that circuit with CATHARE involves “standard” CATHARE components and modelling.

4.3 Main results and further developments

Figures 6 and 7 illustrates the pressure calculated in the VV under an initial condition of mass flow rate and temperature at breach similar to the ones taken in the PCSR analysis [17] (temperature 30°C - small break Q=2.1kg/s up to Pvv=15mbar and Q=1kg/s until 100kg of water discharged in the vessel).

Figure 6 illustrates the pressure rise in the VV until the 15mbar pressure signal is reached. The time to reach 15mbar calculated with CATHARE is 6.9 s and this compares well with the 7.6s calculated in the safety case. Figure 7 illustrates the pressure evolution in the VV (dark blue upper line) and at the end of the pumping line (brown lower line). The pressure rise slope changes at 200 mbar when the pumping line valves are opened. The pressure peak is evaluated at 600 mbar and condensation in the pumping lines leads to pressure decrease after drain system managed to cut the flow and drain it into the depressurized tank.

Some parametric analysis both on physical (inlet/outlet temperature, failure of DRS to operate…) and modelling parameters are now being run. The final objectives of these analyses being to

- assess the limits of the modelling and define validation requirements (the model designed to simulate the streaming water to wall heat exchange could be validated on existing ICE experiments [22])
- obtain peak pressures in the vessel under different faulty scenarios of the safety systems.

5 Conclusions and future prospects

The human factor analysis of the KSMR and the fitness for purpose review of the KSRE is an ongoing work which is currently in progress to include the management requirements and equipments defined for the next D-T campaign. This paper presented an overview of the methodology and main conclusions/recommendations from these analyses. The importance of tritium awareness through review of procedures and training and the emphasis of preventative maintenance has been highlighted for the next D-T campaign. The first results of the LOCA analysis for in vessel cooling circuit breach with the "state of the art" CATHARE code show that there are no issues regarding the integrity of the Vacuum Vessel when the key safety related equipment such as the drain and refill system operates successfully. Parametric analysis on the physical and modelling parameters has to be conducted to draw final recommendations. The time evolution of the pressure in the vacuum vessel will be used as an input to the calculations of the beryllium-steam reactions to evaluate the impact of the beryllium wall on hydrogen deflagration.

Acknowledgements

The work was performed in the framework of the safety case review and the authors would like to thank the active gas handling and safety case engineering group, the engineering and design along with the chief engineer units for fruitful discussions. The CATHARE calculations were performed in the framework of a CEA-CCFE collaboration agreement and the authors would like to thank the CEA-DEN/DER/SSTH for their support.

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Corresponding author

Joelle Vallory

Association EURATOM-CEA, DSM/IRFM - CEA/Cadarache - F-13108 - Saint Paul-lez Durance - France

CCFE Culham Centre for Fusion Energy – Abingdon – Oxon – OX143DB - United Kingdom

E-mail: joelle.vallory@ccfe.ac.uk

Tel. 0044 1235 465142

Figures captions

Figure 1: Designation of safety systems

Figure 2 Description of circuits and components for the LOCA scenario

Figure 3 Illustration of the mechanisms involved in phase transformation of the liquid water after breach on the cooling circuit pipe

Figure 4 CATHARE model of the Vacuum vessel (left) – Elements of the VV modelled (right

Figure 5 CATHARE model of the cooling and draining circuit (left) – Components of the circuit modelled (right)

Figure 6 Pressure in the VV versus time (up to 15 mbar – Qinjected at break=2.1kg/s - *temperature = 30*°C)

Figure 7 Pressure in the VV and end of matrix line (see figure 2) versus time (Qinjected at break=2.1kg/s - *temperature = 30*°C)

Tables captions

Table 1: List of KSMR

Table 2: List of KSRE

Table 3: Physical ageing mechanisms of systems

Table 4: Non physical ageing mechanisms of systems

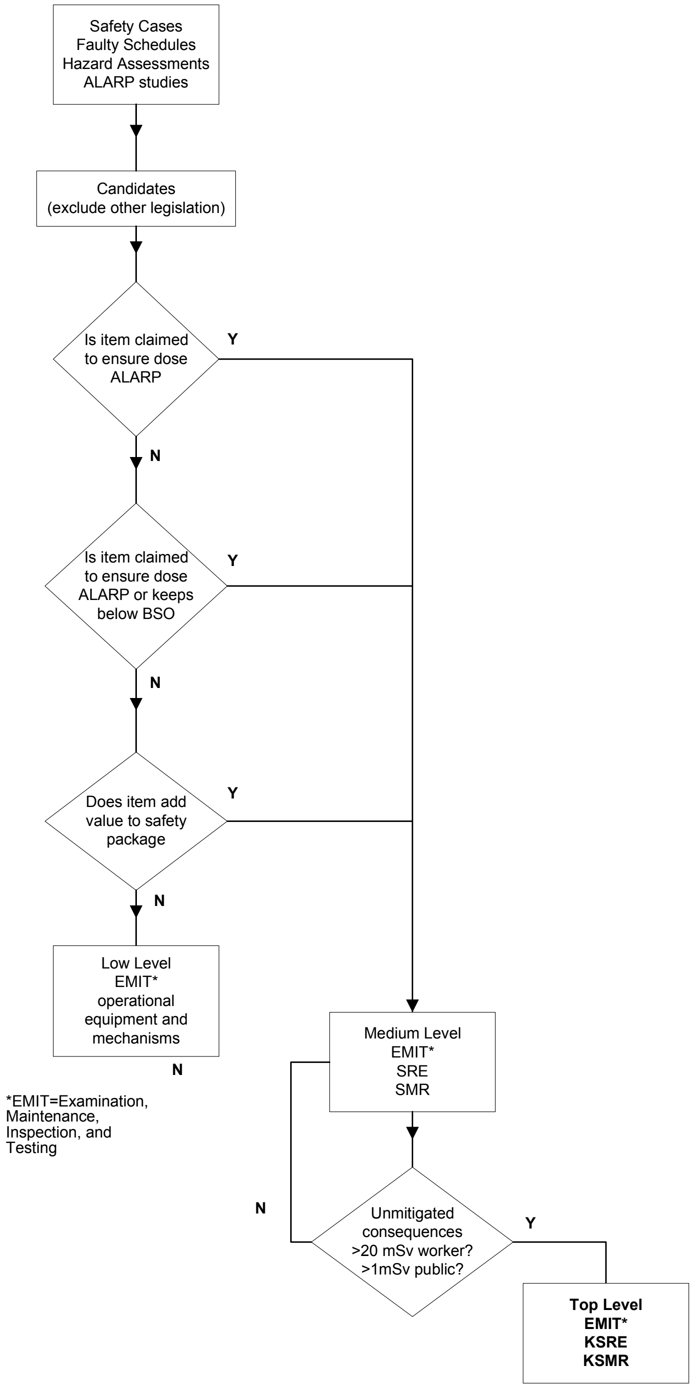


Figure 1 Designation of safety systems

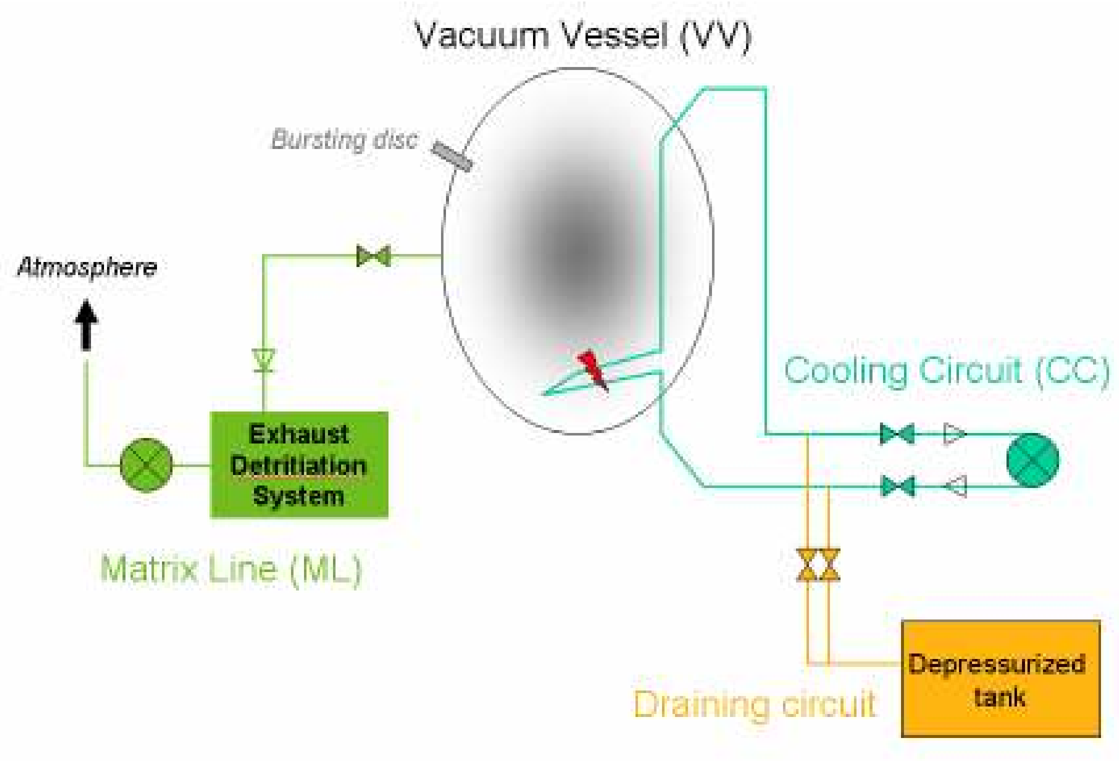
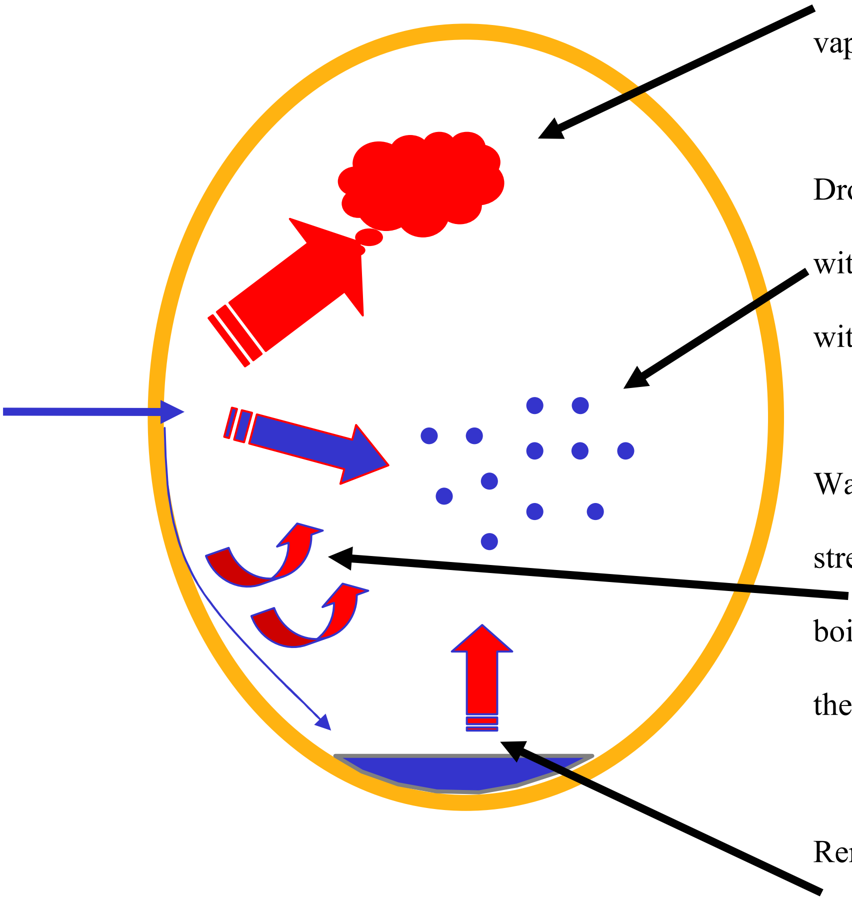


Figure 2 Description of circuits and components for the LOCA scenario



Water immediately flashing to vapour with a certain gas flow rate

Droplets created in suspension within the hot gas and exchanging with it

Water hitting the VV walls, streaming down the tore and film boiling on it due to the heating of the vessel walls

Remaining water then fills the bottom of the VV and boiling on it

Figure 3 Illustration of the mechanisms involved in phase transformation of the liquid water after breach on the cooling circuit pipe

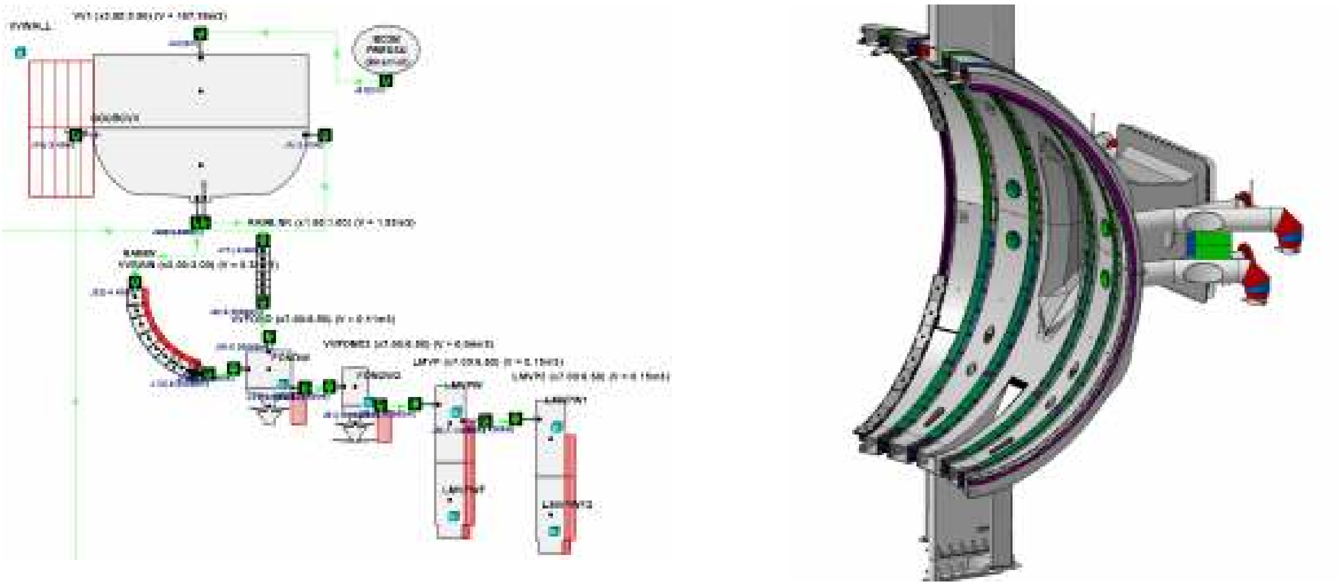


Figure 4 CATHARE model of the Vacuum vessel (left) – Elements of the VV modelled (right)

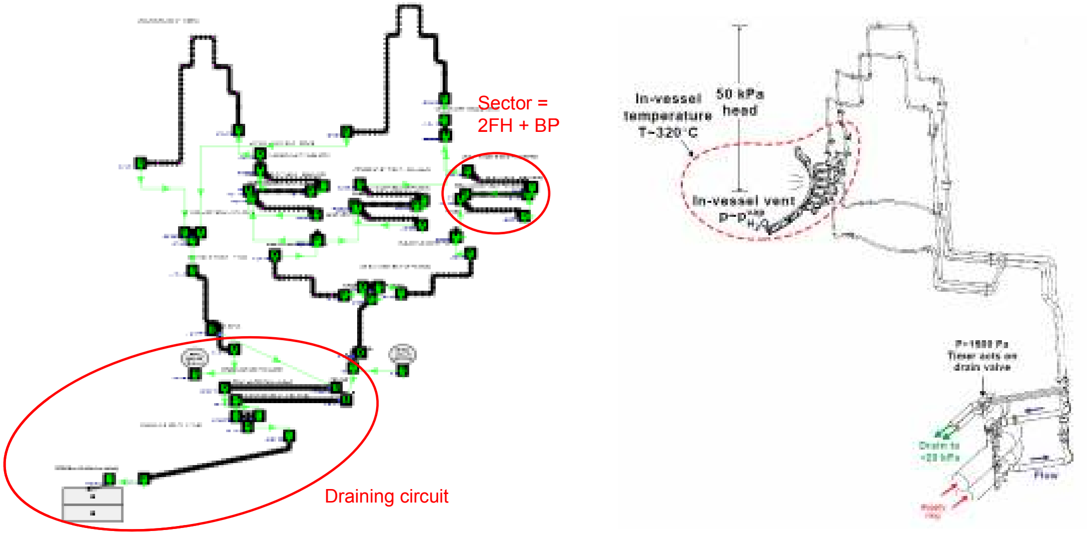


Figure 5 CATHARE model of the cooling and draining circuit (left) – Components of the circuit modelled (right)

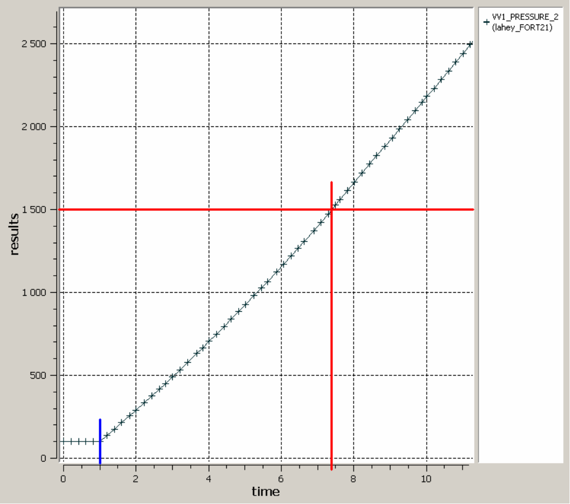


Figure 6 Pressure in the VV versus time (up to 15 mbar – Qinjected at break=2.1kg/s - *temperature* = *30*°C)

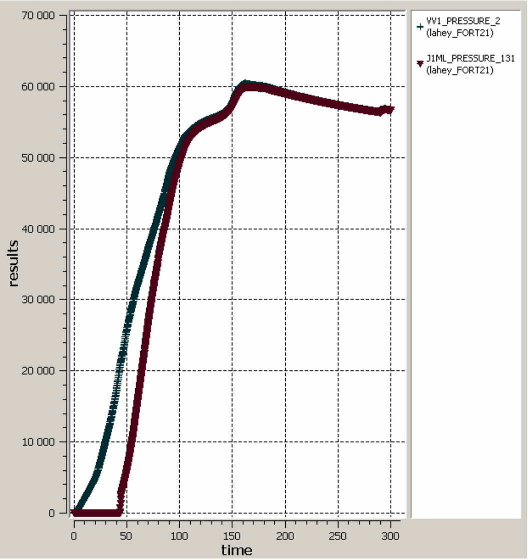


Figure 7 Pressure in the VV and end of matrix line (see figure 2) versus time (Qinjected at break=2.1kg/s - *temperature* = *30*°C)

Table 1. List of KSMR

Safety Requirement	Safety Function
Operational Limits	
KSMR: Limit on Hydrogen Isotope Inventory on Cryopumps	To prevent a hydrogen deflagration in the event of a LOVA.
Response in the Event of an Emergency	
KSMR: Evacuation Procedures in the Event of an Radiation Protection Instrument Alarm	To minimise operator exposure to an elevated dose-rate due to incorrect shielding configuration.
Pre-Operational (Pulsing) Checks	
KSMR: Pre-Operational Shielding Checks	To ensure that all shielding doors, beams and blocks are in the correct position prior to pulsing.
KSMR: Torus building Operational Areas Search	To ensure that no-one remains in the Torus Hall after it is locked prior to the restart of Pulsing operations.
Requirements prior to Breach of Containment	
KSMR: Interspaces must be pumped and purged and tested for tritium content in order to determine the appropriate RPE for safe access.	To minimise the internal dose to an Operator breaching a diagnostic interspace.
Access Requirements	
KSMR: For work requiring full pressurized suit (in vessel work for example during shutdown), 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 allow operators in the J2 control room to prevent another pulse from being fired until the shielding deficiency has been rectified.
PSACS (Personnel Safety Access Control System)	Ensure a pulse cannot be initiated until all shield doors and beams are closed and all removable shielding blocks are in place. To prevent access to the Torus Hall during pulsing.
Shielding Doors, Beams and Removable Shielding Elements	Reduce the dose rate outside of the Torus hall to below 0.25 µSv / hour during all operational modes and 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 / hour during all operational modes.
Torus Hall Emergency Stop Push Buttons	To allow an operator to prevent a pulse from being fired if they are trapped in the Torus hall.
Breathing Air Supplies	Supply breathing air supplies to pressurised suits when work is undertaken in vessel for example.
Uninterruptible power supply (UPS) for RPI	The un-interruptible power supplies are designed to support the area tritium monitors in some parts of J1 building and J25 building.
Tritium in air monitors (RPI - Radiological Protection Instrumentation)	In the event of a breach of containment, Area Tritium monitors, in some parts of J1 building and J25 building provide detection and alarm facilities to allow evacuation of an area. Evacuation of an area ensures that the dose received by an operator is minimised.
Drain and Refill System - 15mbar vessel pressure and in vessel water isolation	To limit the pressure rise and prevent the Torus primary containment bursting disc rupturing in case of In vessel LOCA, an automatic hardwired water isolation and drain-down system is installed. This is actuated when any 2 out of 4 vessel pressure exceed 15mbar. The Drain and Refill System is dependent on the 200mbar bypass valve interlock operating to satisfy the in-vessel water ingress limit to 75kg of water turned to steam will blow the torus bursting disc.
Torus primary containment non Active Gas Handling System tritium containment boundaries	The primary role of containments used at JET is that of controlling tritium release to the environment

Table 3 - Physical Ageing of Systems

Condition	Ageing Mechanism
Service Conditions	
Radiation	Change of material properties
Temperature	Change of material properties
Stress	Creep
Cycling of temperature, flow and/or loads (flow induced vibrations)	Motion / Fatigue / Wear
Flow	Erosion
Fluids chemistry	Corrosion / Galvanic cells
Operational Occurrences	
Power excursion	Thermal and mechanical ageing
Flooding	Deposition and chemical contamination
Fire	Heat, smoke and reactive gas
Environmental Conditions	
Humidity, salinity	Corrosion, Galvanic cells
Chemical agents	Chemical reactions
Wind, dust and sand	Erosion and deposition

Table 4 - Non-Physical Ageing of Systems

Condition	**Ageing Effect**	**Management**
Changes of technology	Obsolescence of existing SSC, unavailability of suppliers, shortage or lack of spare parts	Identification of useful service life - provision of spare parts for planned service life and timely replacement - long term agreement with suppliers - development of equivalent structures or components
Changes of safety requirements, advances in knowledge	Outdated knowledge of practice, standards and safety requirements Safety level below current standards and safety requirements	Systematic reassessment of plant against standards (e.g. periodic safety review) and appropriate upgrading, backfitting or modernization Continuous updating of knowledge
Obsolescence of documentation	Incomplete updating of documentation due to modifications and changes of utilization programmes Lack of information needed for safe operation	