An Overview of Results in the ITER Generic Site Safety Report (GSSR)

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Abstract: This paper summarises the results of the ITER safety assessments during the course of the Engineering Design Activities (EDA). The key aspects of ITER safety are effluents and emissions from normal operation, including planned maintenance activities; occupational safety for workers at the facility; radioactive materials and wastes generated during operation and from decommissioning; and potential incidents and accidents and the resulting transients. The implementation of a generic safety approach, the safety aspects of the design, and the assessments of effluents, occupational safety, waste, and accidents are documented in the Generic Site Safety Report (GSSR). The analyses and assessments completed in collaboration with the Home Team experts and documented in the GSSR offer a well-developed technical basis for regulatory applications in potential host countries.

1. Introduction

This paper reviews the accomplishments in ITER safety during the course of the EDA. This work needed to integrate detailed analyses by a geographically dispersed safety team consisting of Joint Central Team (JCT) and Home Team experts who initially had different approaches and methods based on conceptual fusion reactor studies and fission power plant practices. Since an ITER site was not yet selected, a safety approach was developed for a generic site in such a way that compatibility with the Parties' regulatory frameworks can be expected. The work on safety has contributed to a design providing the technical basis for regulatory approval with the expectation that only minor changes would be needed to meet the host country's regulations. After siting, safety design and implementation will be finalised in accordance with host country regulations and practices.

The implementation of a generic safety approach, the safety aspects of the design, and the assessments of effluents, occupational safety, waste, and accidents are documented in the Generic Site Safety Report. The GSSR comprises about 1100 pages of text and figures, summarising the contributions of designers and analysts from the JCT and Home Teams in eleven volumes ordered as follows:

Volume I	Safety Approach
Volume II	Safety Design
Volume III	Radiological and Energy Source Terms
Volume IV	Normal Operation
Volume V	Radioactive Materials, Decommissioning and Waste
Volume VI	Occupational Safety
Volume VII	Analysis of Reference Events
Volume VIII	Ultimate Safety Margins
Volume IX	External Hazards
Volume X	Sequence Analysis
Volume XI	Safety Models and Codes

2. Safety approach

ITER aims at demonstrating the safety and environmental potential of fusion, to provide a good precedent for the safety and regulatory approval of future fusion power plants. The safety approach is driven by a deployment of fusion's favourable safety characteristics to the maximum extent feasible [1]. A conservative, fault-tolerant safety envelope is provided to enable flexible experimental usage. Experimental components are conservatively designed, considering the expected loads from plasma transients so as to reduce the demands on systems which are required for safety. A safety function is not assigned to experimental components, but faults in these are considered as expected events in the safety assessments.

A staged process is planned to establish full facility operating conditions (Table I). The use of a step-by-step approach through progressive stages of operation allows further validation of safety-related data and analyses when the hazards are considerably lower.

TABLE I: ITER PHASES OF OPERATION

Phase	Activities
Machine Commissioning (prior to first plasma)	• Individual subsystem and integrated system tests
Hydrogen Phase	• H plasma operation (without fusion reactions, activation, or contamination)
Deuterium Phase (with limited tritium use)	• Active (tritium) commissioning • DD and DT plasma operation with limited tritium
Deuterium-Tritium Phase	• Full DT plasma operation

To confirm the acceptance of the generic safety approach, meetings of the Parties' Designated Safety Representatives (i.e. regulators) were convened. A consensus on the safety principles and criteria was reached, based on internationally recognised ICRP and IAEA recommendations, in particular on the concept of defence-in-depth and on the As-Low-As-Reasonably-Achievable (ALARA) principle. Furthermore, it was agreed that the scope of the implementation and documentation outlined for ITER appears to be a reasonable basis.

3. Assessment tools and data

At the start of the EDA, the methods for the safety assessments including the necessary tools and ITER-specific data needed to be developed. To this end, a safety-related R&D programme with the Home Teams was pursued which up to the end of 1998 was primarily oriented at understanding and investigating ITER-specific safety issues [2]. A significant effort was the development of analytical tools to undertake the safety analysis including development of new computer codes and modification of existing ones for fusion applications capable of analysing: transient behaviours of plasma-wall interactions, thermo-hydraulic behaviour of the heat transport system under anomalous conditions including discharge into vacuum and onto cryogenic surfaces, temperature and pressure dependent chemical reactions due to ingress of coolant into the vacuum vessel, and aerosol, dust and tritium mobilisation and transport. Recent safety-related R&D has the main objective of verification and validation of data, computer codes and assessment models [3].

4. Results of the safety assessments

The need to ensure an integrated and consistent assessment of an evolving design by JCT and Home Team analysts led to the introduction of a single safety analysis data list, a single list of detailed analysis specifications (setting the assumptions and conditions to be analysed), and templates for documentation to allow ready assimilation into the overall documentation. The following summarises only some of the results documented in the 11 volumes of GSSR.

Normal Operation - Effluents

The ITER design incorporates many features to ensure that the environmental impact during normal operation will be low, including confinement barriers to prevent releases, and air and water detritiation and filtration systems to treat releases. The hazards are known and the control technologies are well established at existing facilities. To estimate effluents, a systematic approach based on ITER's Work Breakdown Structure was developed so that each system could be examined as a possible source of effluents. Conservative estimates of expected end-of-life conditions were used to ensure that potential effluents were not underestimated.

Radioactive effluents identified are tritium (oxide and elemental) and activated dusts, corrosion products and gases (Table II). These can be released through detritiation systems (atmospheric, water and cryogenic distillation), ventilation systems, cooling tower plume and blowdown, and/or site waste water, all of which are monitored. Based on GSSR estimates, 100% of elemental tritium is released through cryogenic distillation to the plant exhaust, 82% of tritium oxide and 100% of activated dusts and gases are released through the ventilation to the plant exhaust, and 82% of activated corrosion products are released in site waste water. Maintenance related activities lead to most releases: 83% of activated corrosion products, 80% of tritium oxide, and 60% of activated dusts. Tritium fuel cycle systems lead to most tritium releases (100% of HT and 37% of HTO).

TABLE II: ESTIMATES OF EFFLUENTS AT EXPECTED END OF LIFE CONDITIONS

Species	Estimate	Project Guideline	% of Guideline
Tritium – as HTO in air	0.05 g tritium /a	0.1 g tritium /a	50
Tritium in water	0.0004 g tritium /a		
Tritium – as HT in air	0.18 g tritium /a	1 g tritium /a	18
Activated dust	0.25 g metal/a	1 g metal/a	25
Activated corrosion products	0.85 g metal/a	5 g metal/a	17
Species with no specified project guideline			
Species	**Estimate**	**Notes**	
Activated gases ^{41}Ar ^{14}C	 <1 TBq/a 10 MBq/a	Release limits not specifically established for these isotopes but not significant at these levels	
Direct radiation at 250 m	4 μSv/a	< 0.2% of background	

The results confirm that ITER can be operated to satisfy the restrictive guidelines that have been established by the project for the design leading to doses less than 1% of the natural background level. Annual effluents will increase with time from the start of operation but will only gradually approach the estimated levels. In addition, a process is in place to ensure any discharges are ALARA. For ITER, this process involves systematically reviewing systems, activities and pathways with a release potential, estimating releases, and examining ways to reduce the main contributors.

Normal Operation - Waste and decommissioning

The issue of radioactive materials, decommissioning and waste has been carefully considered. The design approach includes practices to reduce the quantities and hazards of radioactive materials, such as modular components, choice of materials, control of impurities, shielding, and re-useable components. To ensure that ITER can be safely dismantled at the end of its useful operating life, decommissioning plans have been developed.

For waste characterisation, activation calculations based on a one-dimensional (1-D) radial build-up of ITER were used and mapped onto the 3-D components. A conservative assumption for the total neutron fluence to ITER was selected to help compensate for the uncertainties inherent in a 1-D approximation to the complex ITER geometry, and results from Home Teams and JCT were cross-checked to ensure consistency. In the absence of an actual site for ITER, the waste amounts were estimated on the basis of 'clearance' [4] by which materials with nuclide-specific activation levels less than the specified clearance level can be released from regulatory control. Decay and decontamination will reduce the radioactivity with time after final shutdown; therefore, not all radioactive materials need to go into waste repositories; rather a significant fraction has the potential to be 'cleared'. Of the total estimated radioactive material at shutdown (about 30,000 t), only about 12,000 t remain above clearance levels after a decay period of 30 years and 6,000 t after 100 years.

Accidents
A limited set of 25 Reference Events was developed, each consisting of a postulated initiating event, all consequential failures and assumed aggravating failures (additional independent failures in mitigating systems). These have been shown to encompass all failure sequences identified by systematic event identification studies. In addition, accidents were analysed assuming a coincident loss of off-site power. The Reference Events were analysed using detailed quantitative modelling and integrated system simulation codes assuming limiting or bounding conditions to maximise consequences.

The Reference Events cover the major systems, the radioactive inventories distributed amongst these systems and the initiator types that have the potential to cause releases. The plasma behaviour was addressed in a conservative way to show the limited effects of loss of plasma control or exceptional plasma behaviour. Loss of power was investigated to determine if there are requirements for the supply of emergency power. Many events were grouped around the cooling water systems which are key issues whose safety had to be demonstrated. Air and water ingress into the vacuum vessel and cryostat under various off-normal plant conditions were investigated. Events during maintenance of the vacuum vessel were considered since maintenance will be a typical state of operation. Safety of the tritium plant with its significant inventory was addressed. Magnet system structural integrity and the potential consequences of arcs were examined. Consequences of failures of confinement and decay heat removal in the hot cell were investigated.

As an example, consider a loss of vacuum in the vacuum vessel during plasma operation. Although vacuum vessel penetrations are designed with care to provide two confinement barriers, the large number of these penetrations suggests that failure of a penetration line should be investigated to demonstrate the tolerance of the design to such failures. Failure of windows/valves in a vacuum vessel penetration line (0.02 m^2 cross-sectional area) was selected to encompass all kinds of postulated loss of vacuum events. Air ingress into the plasma chamber terminates the plasma with a disruption. Loss of off-site power is also assumed to coincide with the initiating event and last one hour.

The vacuum vessel and room pressures equalise about 25 minutes after event initiation. The air in the vacuum vessel heats up but stays below 200^{o}C following the event. Chemical reactions do not occur due to the limited temperatures. In-vessel tritium and dust are mobilised by the air ingress, and some of them are transported to the vacuum vessel pressure suppression system. No mobilised radioactivity is transported out of the vacuum vessel due to the operation of venting systems, which pump out the air in vacuum vessel through the normal vent detritiation system to prevent a back flow. Environmental releases (0.55 g HTO and 0.53 g W-dust) are below project release guideline for Accidents by a factor of eight.

In addition, ultimate safety margins of the facility were examined by analysis of hypothetical events, arbitrarily assuming more and more failures occur. Analysis shows that the design is tolerant to failures, that there is no single component whose failure leads to very large consequences, that there is no single event that can simultaneously damage the multiple confinement barriers, and hence that the design provides a high level of public protection even for these hypothetical events.

5. Conclusions

Looking back at the activities in safety over the EDA, a significant step forward for fusion safety has been accomplished. The discipline of an integrated, detailed design and the anticipation of a future regulatory review led to the development and validation of new approaches, tools and data to examine ITER safety. The need to integrate the Home Team and JCT analyses in a single assessment led to means ensuring a cohesive and internally consistent document. The resulting safety analyses have led to the most comprehensive and well-documented assessment of a fusion design to date.

The results indicate:

- Effluents during normal operation are estimated for a generic site to entail doses to the public which are less than 1% of natural background radiation levels;
- Occupational exposure of workers is estimated to be less than guidelines set for the next generation nuclear power plants;
- The majority of the radioactive materials from operation and decommissioning can be released from regulatory control: 60% after 30 years (80% after 100 years) would be below IAEA clearance levels.
- Doses from postulated accidents are estimated to lead to doses to the population at worst comparable to the average annual natural background for a generic site;
- No single component failure leads to very large consequences and no single event can simultaneously damage the multiple confinement barriers provided.

In summary, the assessments completed with the involvement of the Home Teams experts and documented in GSSR show that ITER can be constructed and operated safely and without significant environmental impacts and offer a well-developed technical basis for regulatory applications in potential host countries.

REFERENCES

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