ITER-FEAT Safety Approach

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Abstract. Safety has been an integral part of the design process for ITER since the Conceptual Design Activities of the project. The safety approach adopted in the ITER-FEAT design and the complementary assessments underway, to be documented in the Generic Site Safety Report (GSSR), are expected to help demonstrate the attractiveness of fusion and thereby set a good precedent for future fusion power reactors. The assessments address ITER's radiological hazards taking into account fusion's favourable safety characteristics. The expectation that ITER will need regulatory approval has influenced the entire safety design and assessment approach. This paper summarises the ITER-FEAT safety approach and assessments underway.

1. Introduction

Examination of safety has been an integral part of the design process for ITER since the Conceptual Design Activities of the project[1, 2]. The safety approach adopted in the ITER-FEAT design and the complementary assessments underway, to be documented in the Generic Site Safety Report (GSSR), are expected to help demonstrate the attractiveness of fusion and thereby set a good precedent for future fusion power reactors.

The following discussion of the overall ITER-FEAT safety approach is organised around the contents of the GSSR: safety approach, safety design, normal operation including radioactive materials, decommissioning and waste, occupational safety, and safety analyses including radiological and energy source terms.

2. Safety Approach

A driving consideration for ITER safety is the need to obtain future regulatory approval. Since the site has not yet been selected, a self-consistent safety approach has had to be developed which generally covers the Parties' regulatory frameworks and is expected to lead to a design which could provide a basis for regulatory approval with only minor design changes needed to meet the host country's regulations. ITER's radiological hazards are addressed taking into account fusion's favourable safety characteristics. A goal of ITER is to demonstrate the safety potential of fusion. To accomplish this goal, the ITER design needs to address the full range of hazards and minimise exposure to these. However, it is necessary to account for the experimental nature of the ITER facility and the related design and material choices and the fact that not all of them are suited for future fusion power reactors.

The following safety objectives have been set for ITER:

- general safety: to protect individuals, society and the environment; to ensure in normal operation that exposure to hazards within the premises and due to any release of hazardous material from the premises is controlled and kept below prescribed limits; to prevent accidents with confidence, to ensure that the consequences of more frequent

events, if any, are minor; to ensure that the consequences of accidents are bounded and their likelihood is small.
- no evacuation: to demonstrate that the favourable safety characteristics of fusion and appropriate safety approaches limit the hazards from internal accidents such that there is, for some countries, technical justification for not needing evacuation of the public.
- waste reduction: to reduce radioactive waste hazards and volumes.

The ITER safety objectives not only provide direction for the design, but also produce a quantitative framework of limits against which independent review and assessment can be carried out to ensure the design will meet the safety objectives.

Deployment of Fusion's Safety Characteristics
The safety approach is driven by the deployment of fusion's favourable safety characteristics to the maximum extent feasible. Relevant characteristics are:
- plasma burn is terminated inherently when fuelling is stopped, is self-limiting with regard to power excursions, and is passively terminated by the ingress of impurities under abnormal high temperature plasma facing component conditions (e.g. by evaporation or gas release or by coolant leakage);
- the energy and power densities are low, the energy inventories are relatively low; and large heat transfer surfaces and masses exist and are available as heat sinks;
- the releasable inventories are limited: the bulk of the activity is bound in activated structural components;
- physical barriers exist inherent to the tokamak concept and must be leak-tight for operational reasons.

Passive Safety
Special attention is given to passive safety, based on natural laws, properties of materials, and internally stored energy. Where possible, passive features are preferred over active systems. Passive features, in particular, help assure ultimate safety margins.

Defence-in-Depth
The ITER safety approach incorporates 'defence-in-depth', the recognised basis for safety technology: all activities to ensure safety are subject to cascaded levels of safety provisions so that a failure at one level would be compensated by other provisions.

Consideration of the Experimental Nature
Consideration of the experimental nature of ITER leads to ensuring a robust safety envelope and to minimising the safety role of experimental components, taking into account current uncertainties in plasma physics. A conservative safety envelope enables flexible experimental usage. In addition, the experimental programs will be developed in such a way that design modifications will take account of experience from preceding operations and will stay within the safety envelope of the design. A safety role is not assigned to experimental components. Hence, faults in experimental components that can affect safety are part of the safety assessments and mitigating measures incorporated in the remaining design.

Review and Assessment
Safety assessments are an integral part of the design process, and results assist in the preparation of the safety documentation for regulatory approval. These analyses address normal operation, all types of events, and characteristics of radioactive materials. A combined deterministic and probabilistic approach is used to develop a set of 'reference accidents'

(limited to about 25) which encompasses the entire spectrum of events. Analysis of reference accidents also includes loss of power and aggravating failures in safety systems. Hypothetical sequences are used to investigate the ultimate safety margins. The intent is to demonstrate the robustness of the safety case with regard to the project's objectives and radiological criteria.

3. Safety Design

The GSSR provides a description of the facility from a safety point of view, identifying safety functions performed by each system and how these are implemented. Safety requirements arising out of the approach and assessments are identified. The project has mechanisms for the identification and control of requirements and interfaces, which includes safety, and confirmation that they have been met. In anticipation of seeking regulatory approval, information is also included in GSSR to provide confidence to an independent reviewer that the safety functions can be performed as required.

An extensive analysis of the 1998 ITER design [2] is being used to improve the implementation of safety in the current design. For example, it would be possible to meet project release guidelines, without the need for a high stack for enhanced dispersion, through careful attention to releases during normal operation (see Section 4), inventories (see Section 6), and confinement barriers. The design incorporates multiple confinement barriers or functions, such as detritiation systems, to ensure that any releases are reduced and are from controlled and monitored release points. The confinement requirements on buildings are relatively modest because of the moderate pressures generated in accidents. The application of "leak-before-break" concepts is being investigated to further simplify building design.

The degree of scrutiny required is a function of the margins available in the design and assessments, and the safety characteristics of ITER should allow for an acceptable level of assurance despite uncertainties inherent in the implementation of a new technology. For example, consider the vacuum vessel, which provides the first confinement barrier for tritium and activated dust in the tokamak:

- 0.2 MPa (absolute) was selected as the maximum internal pressure for design of vacuum vessel which simplifies design of connected systems and a pressure suppression system is used to ensure this pressure is not exceeded;
- an in-vessel coolant leak was selected which bounds possible in-vessel damage;
- diverse computer codes are used by JCT and Home Team experts to calculate peak pressure in the vacuum vessel for in-vessel coolant leaks;
- validation efforts [3] are underway for codes used in safety analysis, particularly using the ICE facility of JAERI [4];.
- the vacuum vessel pressure suppression system is designed such that the predicted pressure in the vacuum vessel is <0.18 MPa for the bounding case considering failure of one of the pathways from the vessel to the suppression tank;
- internal pressure loads are combined with electromagnetic loads in the assessments; the internal pressure during accidents is not a limiting aspect of the vacuum vessel design;
- consequences of coincident failure of multiple confinement barriers in a diagnostic or heating system penetration during an in-vessel coolant leak are assessed, even though these are designed to withstand accident conditions;
- safety assessments demonstrate that calculated releases to the environment are well below project release guidelines, typically about an order of magnitude.

The margins provided in the design and conservatism in the assessments provide confidence that the public is protected.

4. Normal Operation

Potential host countries require information about the impact on the surrounding environment caused by normal operation of the facility. This includes potential emissions from the site, and radioactive materials generated during operation and maintenance, as well as from decommissioning.

ITER aims to reduce emissions from the site to levels "as low as reasonably achievable". This is accomplished, for example, by reducing leaks during operation and provision of barriers and/or cleanup during maintenance. The assessment of the 1998 ITER design [2] found that 80% of the tritium releases estimated during normal operation would occur during maintenance, primarily from large components. For ITER-FEAT, the question of releases during normal operation is being addressed from two perspectives: improving the assessment methodology to ensure balanced allocation of resources to reduce releases, and contamination control measures during maintenance.

The reduction in the quantity and level of activity of waste is a project objective which has been addressed, for example, through control of impurities in materials and reusable components. As an example, activation calculations have been done to estimate the time after the end of irradiation for the material to reach the IAEA clearance levels. The calculations suggest that it is sufficiently stringent with regard to the impact of Nb and Co on clearance to limit their concentrations in the structural steels to 0.01 wt %. and 0.05 wt% respectively. At lower concentrations, clearance levels would be dominated by Ni-63 and Mo-93 which stem from the alloying elements Ni and Mo in the reference steel. Assessments underway for ITER confirm that materials that meet IAEA clearance criteria pose no more radiological hazard than materials generally considered non-radioactive, such as coal ash.

5. Occupational Safety

There is a need to ensure worker safety as part of the design process. A defined process is in place to examine the expected contribution from systems to the overall occupational exposure, and to focus attention on those with the highest contribution [2].

For example, for the 1998 ITER design, occupational radiation exposure for divertor maintenance has been estimated and the ALARA process applied. The initial estimate for collective occupational radiation exposure for a single cassette replacement was 73 pers-mSv. Shielding was introduced to reduce neutron streaming and the estimated exposure reduced to 19 pers-mSv, a reduction by a factor of 3.8. The next iteration examined those activities contributing the greatest dose in more detail (removing/installing the mobile shielded door, replacing the secondary closure plate, and installing/removing the contamination liner) and led to improvement in shielding reducing the occupational radiation exposure by a further 30%. Further application of the process would again address the design and activities to further reduce working times in radiation fields [5].

6. Safety Analyses

The accident analysis carried out for ITER has both external and project-oriented roles. For the Parties, the accident analysis helps provide assurance that the design is safe, and for potential host countries, it provides a technical basis to help prepare their regulatory submissions. Within the project, accident analyses are part of the iterative process to ensure safety. Assessments are based on plant design and plans for operation. However, since the design is in progress, assumptions are necessary. These are carefully selected to avoid, as far as possible, imposing restrictions on the facility solely from a safety perspective and to ease eventual regulatory approvals by providing margins to account for uncertainties. At the end of the process, the assessments, design and plans for operation must be consistent.

Radiological and energy source terms are at the heart of any nuclear safety assessment. If the releasable inventory can be kept below values such that dose limits in a host country are not exceeded even if the entire amount is released, it is expected that the licensing process could be simplified because the details of the accident sequence become much less important in demonstrating the adequacy of safety functions. Aggressive targets for releasable tritium inventories for in-vessel components and the fuel cycle were set (subject to confirmation of feasibility) based on a review of dose limits and typical site characteristics.

The accident analysis approach is a mixture of detailed deterministic analyses supplemented by sequence analyses to demonstrate that the full range of potential initiating events and mitigating system failures is addressed. Since a goal of ITER is to demonstrate the attractiveness of fusion from a safety perspective, part of these assessments goes well beyond regulatory analyses: the hypothetical events postulated address the robustness of ITER safety to show the adequacy of defence-in-depth and the absence of cliff edge effects.

7. Summary

The safety approach, its implementation in the design and assessment of safety against project criteria have been developed with the view of assisting regulatory approval from any host country. It is expected that the safety characteristics of fusion and margins provided in the ITER-FEAT design and assessments can lead to an acceptable level of assurance despite uncertainties inherent in the implementation of a new technology.

References

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