INTERNATIONAL COOPERATION IN THE SAFETY AND ENVIRONMENTAL ASSESSMENT FOR THE ITER ENGINEERING DESIGN ACTIVITIES

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ABSTRACT

The ITER Project includes design and assessment activities to ensure the safety and environmental attractiveness of ITER and demonstrate that it can be sited in any of the sponsoring Parties with a minimum of site-specific redesign. This paper highlights some of the efforts to develop an international consensus approach for ITER safety design and assessment, including: development of general safety and environmental design criteria; development of quantitative dose-release assessment criteria; development of a radiation protection program; waste characterization; and development of safety analysis guidelines.

The high level of interaction, cooperation and collaboration between the Joint Central Team and the Home Teams, and between the safety team and designers, and the spirit of consensus that has guided them have resulted in a safe design for ITER and a safety design and assessment that can meet the needs of the potential host countries.

INTRODUCTION

The European Atomic Energy Community and the governments of Japan, the Russian Federation and the United States of America (the Parties) have agreed to conduct jointly Engineering Design Activities (EDA) to produce a detailed, complete and fully integrated engineering design of the International Thermonuclear Experimental Reactor (ITER) (Shimomura 1998). Hazards associated with magnetic-confinement fusion are different from those of fission (Table 1, Shimomura 1996); hence, complementary design and assessment activities have been carried out to ensure the safety and environmental attractiveness of ITER. This has been an exercise in international safety cooperation in setting site-independent safety criteria and analysis guidelines that allow the project to proceed in advance of site selection while ensuring that the resulting design can be adapted to a site in any of the Parties with a minimum of redesign and that the assessments provide confidence to the Parties of the soundness of the design. Further, the detailed analyses to support these assessments have been carried out by an international team (Home Teams, HTs, of the Parties) distributed around the globe and coordinated by the ITER Joint Central Team (JCT). Results of the integrated, plant-level safety assessments have been documented to provide site-independent input for environmental impact assessment and for safety characterization. The main purpose is to provide potential host countries with a sufficient breadth and depth of information such that they can prepare the required regulatory submissions for site selection.

Table 1: Favorable Safety Characteristics of Magnetic Fusion

• reaction is self-limiting and bounded by physics; fusion reactions physically impossible under condition with any leakage into vacuum vessel
• moderate fusion power and radioactive decay heat densities; structural melting of vacuum vessel is physically impossible
• necessary performance of confinement barriers is about one order of magnitude reduction versus several orders of magnitude for fission
• neutron activation products are in structural material; quality and half-lives are determined by the choice of materials

This paper highlights some of the efforts by the JCT and the HTs to develop an international consensus approach for ITER safety design and assessment, including development of general safety and environmental design criteria; development of quantitative dose-release assessment criteria; development of a radiation protection program; waste characterization; and development of safety analysis guidelines.

GENERAL SAFETY AND ENVIRONMENTAL DESIGN CRITERIA

It was recognized that an upper tier set of criteria to guide safety design and assessment in a consistent manner would be needed for the EDA (1992-1998). Assessments carried out during the Conceptual Design Activities (CDA, 1988-1990) that preceded the EDA had identified the major hazards and outlined some key features of the ITER safety approach including the use of risk based targets, a multi-layered approach, and passive safety (Raeder 1991).

In order to ensure ITER would be site-able by any of the Parties, it was also recognized that a design was needed that would be *robust* to variations in safety approach and criteria. In other words, only a limited number of design changes would be needed to accommodate a Party's regulatory requirements. To this end, workshops and technical meetings were held to obtain inputs from all HTs on both the scope of the criteria and their contents. This was followed by several rounds of writing, review and revision leading to the General Safety and Environmental Design Criteria (GSEDC) (ITER 1996)

The purpose of GSEDC is to present general top-level safety-design objectives, principles and criteria for ITER that are considered necessary to ensure the safe performance for intended use over the lifetime of the facility, to minimize hazards and risk, and thereby protect site personnel, the public and the environment. The contents of GSEDC are presented in Table 2.

Table 2: Contents of General Safety and Environmental Design Criteria

INTRODUCTION	
ITER SAFETY OBJECTIVES AND PRINCIPLES	
General safety objectives	Special considerations for experimental use
General safety principles	External hazards
General safety requirements	Safety criteria
Radiation protection program	No-evacuation goal
SPECIFIC FUNCTIONAL SAFETY REQUIREMENTS	
Confinement of radioactive & toxic materials	Control the effects of coolant internal energy
Ensure heat removal	Control of chemical energy sources
Provision of off-normal fusion power shutdown	Control of the effects of magnetic energy
Monitoring of safety functions	Control operating hazards and releases of radio nuclides & toxic materials
ITER SAFETY REQUIREMENTS	
Classification of functions and components	Material selection
Safety importance classification	Physical security
Safety design limits	Fire protection
Quality assurance	Radiation protection
Codes and standards	Safe handling of toxic materials
General reliability design principles	Effluent management
Seismic and environmental considerations	Waste management
Considerations for chemical hazards	Control other industrial hazards
Maintenance and repair	Decommissioning
ITER SAFETY ASSESSMENT	
SAFETY MANAGEMENT	
ITER JOINT APPROACH TO REGULATORY APPROVAL	
APPENDIX 1 - ITER SAFETY CHARACTERIZATION	
APPENDIX 2 - POTENTIAL GENERIC ACCIDENT SCENARIOS	
APPENDIX 3 - DERIVATION AND EXPLANATION OF ITER PUBLIC DOSE LIMITS	
APPENDIX 4 - ITER RADIATION PROTECTION PROGRAM	

As well as internationally accepted standards and guidance such as Basic Safety Principles for Nuclear Power Plants (IAEA 1988) and others in the IAEA Safety Series, GSEDC draws on work carried out by the HTs for their national programs, e.g. US fusion safety standard (DOE 1996) and work prepared by the HTs specifically for the JCT. GSEDC was reviewed and generally accepted by the Parties as part of the Interim Design Report (ITER 1996). The criteria and approaches in GSEDC are translated into more design related requirements in the ITER General Design Requirements Document (GDRD) that guides the implementation into the system and component designs.

A recent review of GSEDC in advance of the ITER Final Design Report found that very few changes were needed, primarily the addition of a basic Radiation Protection Program and updates in terminology. This illustrates the basic soundness of the criteria and the extent that they have been implemented into the design.

DOSE / RELEASE CRITERIA

Several topics needed to be addressed with regard to establishing a set of high level safety acceptance criteria that could lead to a design compatible with any of the Parties' national practices. These included the use of risk-based criteria, the types and values of dose limits, and the assumptions used to calculate doses.

In many technologies in most countries, it is common to divide non-operational events into various categories when establishing limits on consequences. This recognizes that some events are more likely to occur than others, and optimal protection involves different assessment methodologies depending on event likelihood. Unfortunately, the terminologies and approaches used among countries and industries vary significantly. It is therefore impossible to use terminologies and approaches that simultaneously match those of all Parties, and ITER has had to establish its own terminologies and approaches.

Although the event categories used by ITER reflect the likelihood of events, countries vary in the degree to which the categories' frequency ranges are explicitly defined. For ITER, event categories have explicitly defined frequency ranges as well as qualitative definitions and objectives. There is no claim for rigorous frequency analysis, since the quality of such analyses will vary depending on the system involved. Rather, categorization is established by engineering judgment including frequency as a technically explicit guide. The net effect is a mixture of deterministic and probabilistic methodologies, which provides considerable flexibility in adapting to future regulatory approaches. If the future host country discounts frequency arguments, the explicit frequency definitions can be dropped without changing the framework or design. If the host country requires probabilistic analyses, the framework is already in place to do so.

During the CDA dose criteria were established which set the risk at approximately 0.1% of the background cancer risk, and corresponding guidance was established on how to calculate releases for each category. This guidance was believed to be more conservative than national regulations (Raeder 1991). At the start of the EDA the Home Teams were asked to review national criteria that would be applied to ITER . In developing GSEDC, a general principle was established that:

> *ITER design, construction, operation, and decommissioning shall meet technology-independent radiological dose and radioactivity release limits for the public and site personnel based on recommendations by the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (for example, ICRP-40 and ICRP-60; IAEA, International Basic Safety Standards).*

The category objectives and corresponding dose limits are conservatively set, taking into account international recommendations such as the new International Basic Safety Standards(IAEA 1996) and national regulations in ITER countries. These reflect the principle that accidents with higher consequences should have lower frequencies and that these consequences should be bounded.

The ITER project set *release limits* (g of tritium, Bq of activity, etc.) for radioactive and chemically hazardous substances to further develop many safety design requirements relating to effluent control, personnel safety, and radiological confinement. These release limits are derived from *dose limits* with assumptions on release duration, release height, weather, distance, etc. Derivation of release limits take into account the type of dose which is related to the category objectives as noted in Table 3 and the conditions of release. Types of dose considered include chronic doses with ingestion for more frequent events, early dose without ingestion for infrequent events where public countermeasures may be considered, etc. The baseline conditions are as follows:

- elevated release of 100 m and ground level release (considering building wake effects),
- release duration of one hour,

- average and pessimistic weather conditions including rain,
- site boundary distance of 1 km, and
- specified, nominal food chain assumptions.

Table 3: Doses/Release Limits to the Public for ITER Design

	I	II	III	IV	V
EVENT SEQUENCE CATEGORY	**OPERATIONAL EVENTS**	**LIKELY SEQUENCES**	**UNLIKELY SEQUENCES**	**EXTREMELY UNLIKELY SEQUENCES**	**HYPOTHETICAL SEQUENCES**
Category Description	Events & plant conditions planned and required for normal operation, including some faults & events that result from ITER's experimental nature.	Event sequences not planned but likely to occur one or more times during the life of the plant but not including Category I events.	Event sequences not likely to occur during the life of the plant.	Event sequences not likely to occur during the life of the plant with a very large margin; limiting events for "design basis"	Event sequences with extremely low frequency postulated with the goal of limiting the associated risk; outside the "design basis."
Typical Annual Expected Frequency	list of operational events to be defined explicitly	$f > \sim 10^{-2}$/a	10^{-2}/a > f > 10^{-4}/a	10^{-4}/a > f > 10^{-6}/a	$f < \sim 10^{-6}$/a
ITER Objectives	ALARA	Avoid releases	Avoid potential need for any public counter-measures	Avoid potential for public evacuation	Limit need for public evacuation
Dose Criteria *(pessimistic weather for Categories II-IV)*	0.1 mSv/a chronic dose (all pathways) integrated over all Category I events; also ALARA	0.1 mSv/a chronic dose (all pathways) integrated over all Category II events; and also 0.1 mSv/ event chronic dose (without ingestion)	5 mSv/event chronic dose (without ingestion)	5-50 mSv /event *(depends upon type of dose)*	~50 mSv early dose to avoid evacuation
Release Limit for HTO (tritiated water)	1 g T/a	1 g T/event (1 g T/a integrated over all Category II events)	50 g T/event	100 g T/event	1600-12,000 g T/event *dependent on assumed weather*
Release Limit for Divertor-First Wall Activation Products	10 g metal/a	0.5 g metal /event (10 g-metal/a integrated over all Category II events)	25 g metal /event	2000 g metal /event	130,000- 1,800,000 g metal/event *dependent on assumed weather*

Note that additional limits have been defined for ground level releases and other less limiting materials.

Table 3 shows the dose/release table. Note that additional release limits have been derived for ground-level release points and for other materials that are less restrictive (such as activated corrosion products in coolants), and these limits are applied depending upon the accident scenario. Their derivation considered different dispersion parameters and definitions of dose that may be applied by potential host countries, and limits were conservatively set such that the design should not have to be significantly modified after site selection. For Category I, the project release limits set challenging targets as a step to ensuring releases are as low as reasonably achievable (ALARA). Estimates of releases for reference accidents (Categories II - IV) in the Non Site Specific Safety Report (NSSR) show that release limits are met by wide margins, typically they are < 10% of the conservatively derived release limit. For Category V, hypothetical events, the large release limits are a reflection of the higher does limit to meet the “no evacuation” objective and the relatively low dose per gram hazard posed by ITER’s tritium and activation products. Further, assessment of ITER’s ultimate safety margin against the no-evacuation objective shows that off-site emergency planning for evacuation would not be technically justified using the ITER dose/release limits for Category V in Table 3.

RADIATION PROTECTION

The operation of ITER will be subject to the regulatory limits of the host country. In designing ITER, the recommendations of ICRP-60 are used as a basis for occupational safety, since most national regulations tend to follow the ICRP recommendations. Although ICRP has recommended an average of 20 mSv/a measured over 5 years, with an upper limit of 50 mSv in any single year, some countries have proposed a stricter definition of 20 mSv/a and many nuclear facilities have adopted practices that limit occupational exposures below 20 mSv/a. Hence, ITER has set internal criteria that individual occupational exposures shall be limited to 20 mSv whole body per year.

An important element in assuring worker safety at a nuclear facility is the Radiation Protection Program (RPP). The ITER RPP has been developed and is being implemented to further assure that ITER will be safe to operate and maintain from a radiological safety perspective. The objectives of the ITER RPP is to:

- Prevent acute over-exposures,
- Prevent occupational doses over legal limits,
- Maintain personnel doses As Low As Reasonably Achievable (ALARA),
- Minimize spread of contamination,
- Maintain public exposures ALARA, and
- Minimize releases of radioactivity to the environment.

The ITER RPP has been developed based on ICRP and IAEA guidelines and internationally accepted good practices. It addresses, for example, dose limits, ALARA benchmarks and processes, access zoning, monitoring, contamination control, and radiation protection organizational needs.

Further to the regulatory limits, defining and applying administrative limits is essential in prevention of occupational doses over regulatory limits. Also, well designed administrative limits assist in a better distribution of the collective dose such that individual exposures are maintained ALARA. The ALARA policy states that:

> "Every effort shall be made to ensure that risks created by the existence of radioactive hazards in ITER are maintained as low as reasonably achievable. Radiation exposures, risk of unplanned exposures, and production of radioactive waste shall be minimized during the design, operation, modification, and decommissioning phases of ITER by implementing known ALARA principles."

This is the standard in the nuclear industry and is recommended by the ICRP when discussing the framework of radiation protection (ICRP 1991). As reported in NSSR, there is a process underway to review the analysis and design to ensure that ALARA considerations are implemented in the design. For the ITER EDA, internal screening benchmarks of 2 mSv to an individual in one shift and 30 person-mSv for a task are used, based on examination of current international practices, to identify which systems and tasks to focus on initially. As noted above, administrative limits will be implemented in operation to ensure individual exposures are well below regulatory limits.

WASTE CHARACTERIZATION

An important objective of ITER is to demonstrate the environmental attractiveness of fusion over its entire life cycle including construction, operation and decommissioning. Thus, the ITER Project is also considering the following issues:

- minimizing the quantity of relatively highly activated waste that will need long-term storage;
- designing for safe handling of waste during maintenance and decommissioning;
- exploring "on-site" waste treatment to prepare the ITER waste for further waste treatment by a separate waste management organization; and
- providing the Host Country with detailed data concerning ITER waste.

For EDA design purposes, it is assumed that initial treatment and short-term storage of wastes will be provided on the ITER site. Longer-term storage and ultimate disposal is assumed to be accomplished by an organization within the host country in accordance with its particular national regulations, standards and practices. Also, as stated in the ITER site requirements and assumptions (ITER 1996), it is anticipated that the ITER site will be turned over to an organization within the host country for decommissioning one year after termination of ITER operation. At this time the organization will assume responsibility for decommissioning and final disposal of the ITER facility including the installed equipment that is classified as radioactive and/or contaminated waste. The decommissioning phase will be conducted under the regulations and practices of the host country; therefore, the details of the decommissioning plan are at the discretion of the host country organization.

For the EDA, the JCT is providing the Parties with a detailed characterization of the possible ITER wastes such as volumes, masses, specific activity, contact dose, decay heat and dominant isotopes. Attempts have been made to describe the operational and especially decommissioning wastes in a more general manner to aid in understanding the nature of the ITER wastes, which differ in many aspects from that from other nuclear facilities.

A clear distinction should be made between a *classification system* to simplify language and to help in planning and *regulatory limits* used to ensure safety. The actual quantity or concentration limits for classification of radioactive waste will be established by the regulatory body of the potential host country. A radioactive waste classification system is useful for generic safety considerations or non-site specific discussions, but it is not a substitute for specific safety assessment by a potential host country to its regulatory limits. There is a growing international consensus towards a quantitative classification scheme considering for example dose rates, activity level as opposed to a qualitative scheme that classifies waste according to its origin or physical state.

Following the ITER approach of trying to use internationally agreed standards, for NSSR waste characterization IAEA developed guidelines are being used, such as:

- International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, IAEA Safety Series No. 115, 1996;
- Principles for the Exemption of Radiation Sources and Practices from Regulatory Control, IAEA Safety Series No 89, 1994
- Classification of Radioactive Waste, IAEA Safety Series No. 111-G.1.1, 1994
- Clearance Levels for Radionuclides in Solid Materials, IAEA-TECDOC-855, 1996.

One advantage of the quantitative waste classification scheme is illustrating the large fraction of decommissioning wastes that may be low enough to be of no regulatory concern. NSSR provides the potential host countries with decommissioning waste characterization and includes for information an application of the IAEA-IBSS exemption guidelines:

- above clearance level decommissioning waste after 50-70 years: 16500 t (~33%)
- below clearance levels decommissioning waste after 50-70 years: 35000 t (~66%).

However, even within these IAEA developed guidelines there is still no international agreement on quantitative clearance levels and hence, ITER is proceeding by providing as much information as is needed by potential host countries to evaluate ITER operational and decommissioning wastes against their own national criteria.

SAFETY ANALYSIS GUIDELINES AND SPECIFICATIONS

As noted above, while the approach for safety analyses varies from Party to Party, it is necessary in the EDA to provide analyses which give confidence to each Party that the safety design is sound. Resource limitations lead to the need for a single, self-consistent set of analyses. To assist in the selection events to be analyzed and definition of the analysis, Safety Analysis Guidelines were developed. Again, IAEA safety guides and other internationally accepted standards were used, and inputs were sought from each HT and many iterations of the guidelines were needed to arrive at a consensus.

The Safety Analysis Guidelines describes rules and methods to be applied for accident safety analysis of ITER in preparation of NSSR.   It focuses on accident analysis and therefore does not cover the analysis of normal operation nor the analysis of external events. It particularly addresses general rules for selecting, classifying and analyzing the NSSR reference accident sequences.

The objectives of the safety analysis are:

- to determine if and demonstrate that the ITER design has sufficient provisions to withstand accident sequences without violating the dose/release limits and other safety principles established for ITER and documented in GSEDC and GDRD. As noted above, ITER dose/release limits are based on the general principle that event sequences with more severe consequences should have lower frequencies. Therefore, event sequences are classified into the five categories (Table 3), and it is to be demonstrated that the consequences of any sequence are strictly below the limits of its category.
- to show that the response of the plant and of the systems important to safety are adequate, and to define the loading and performance requirements that must be considered in the design of these systems.

An adequate balance is needed between analysis breadth (coverage) and depth (detail). Therefore, the overall approach is to select a limited set of reference sequences for which a full-scope transient/consequence calculation will be performed and to demonstrate that this reference set properly covers or bounds the entire spectrum of possible sequences. Systematic methods have been used to support this accident identification and selection process to ensure that a comprehensive range of accidents have been considered.

The actual analyses were undertaken by a geographically dispersed set of JCT and HT analysts. To ensure a uniform set of input data and assumptions and internal self-consistency, a number of documents and tools were used, including:

- safety analysis guidelines, as noted above,
- safety analysis data list providing a uniform set of design and analysis data to be used in the safety analysis.

- accident analysis specifications that provided the basic scenario, equipment performance assumptions, results required, etc.,
- standard template for documentation of accident analyses.

With these and the high level of cooperation and dedication of the analysts, two complete, extensive rounds of accident analyses were completed for the EDA (NSSR-1 and NSSR-2). The difference between them reflects the evolution of the design, improved analysis tools and data, experience gained by the analysts, and results obtained to guide future analyses.

SUMMARY AND CONCLUSIONS

Apart from the technical safety aspects of ITER itself, one of the problems faced during the EDA was how to proceed with safety design and analysis approaches when there was no site selected and siting could be needed by any of the diverse Parties participating, each with different safety regulations and established practices. Also, the safety design assessments and analyses would be carried out by a geographically diverse group consisting of HTs and the JCT.

Key elements that has allowed the ITER safety team to proceed effectively in reaching agreement on how to proceed were:

- using technology independent or applicable internationally agreed standards and guidance to the greatest extent possible, such as ICRP,
- adapting internationally agreed standards and guidance to fusion in general and an experimental facility in particular, such as the IAEA Safety Series,
- developing consensus within the HT and JCT safety team when international guidance needs to be interpreted or does not exist.

The complex, multi-site, multi-national nature of the work demanded a strong, central planning by the JCT. This included very global outlines of the safety objectives and work needed during the EDA, the documentation set to be produced as a final deliverable, the intermediate documents needed to guide the safety design and analysis, and the very detailed planning and coordination of R&D, analyses and documentation. Some key documents produced include:

- General Safety and Environmental Design criteria and its implementation at the plant, system and component levels in the General Design Requirements Document,
- Safety Analysis Guidelines, Accident Analysis Specifications and Safety Analysis Data List.

Both the exercise in developing these by consensus and their use by HTs and JCT proved essential for carrying out the EDA safety work.

The high level of interaction, cooperation and collaboration between the Joint Central Team and the Home Teams, and between the safety team and designers, and the spirit of consensus that has guided them have resulted in a safe design for ITER and a safety design and assessment that can meet the needs of the potential host countries.

Acknowledgments

This report is an account of work undertaken within the framework of the ITER EDA Agreement. The views and opinions expressed herein do not necessarily reflect those of the Parties to the ITER EDA Agreement, the IAEA or any agency thereof. Dissemination of the information in these papers is governed by the applicable terms of the ITER EDA Agreement.

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