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Probabilistic safety analysis of an accelerator—Lithium target based experimental facility

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Abstract

The international fusion materials irradiation facility (IFMIF) is aimed to provide an intense neutron source by a high current deuteron linear accelerator and a high-speed lithium flow target, for testing candidate materials for future fusion reactors.

An activity aimed at the safety assessment of the IFMIF plant as a whole has been carried out applying the probabilistic risk assessment (PRA) approach to identify and quantify in terms of expected frequencies, the dominant accident sequences related to the plant operation, and define the reference accident scenarios to be further analyzed through deterministic transient analysis, in order to verify the fulfilment of the safety criteria.

The accident sequences have been modeled through the event tree technique, which allows identifying all possible combinations of success or failure of the safety systems in responding to a selection of initiating events. The identification of accident initiators, provided by the failure mode and effect analysis (FMEA) procedure, is followed by the systems analysis based on fault tree technique, for the unavailability assessment of the safety systems: finally the accident sequence scenarios are assessed by RISK SPECTRUM software.

The study has allowed for the development of all accident sequences resulting from selected initiators relative to IFMIF plant and their grouping within sequence families, denoted as plant damage states, on account of the plant response and expected consequences. The frequency assigned to each family sequence is the sum of the contributors relative to all sequences ending into that particular plant state.

The outcome of the analysis shows that IFMIF plant is quite safe and presents no significant hazard to the environment: in fact all the sequences implying potential undesired effects as radioactive release to the outside, show very low frequencies, well below the limit for credible accident (1.0E−6/year). In addition, due to the novelty of the design and the large spreading assigned to the failure parameter probabilistic distributions (data utilized in the probabilistic analysis of this one of a kind plant are largely of a generic nature), an uncertainty analysis has been performed to add credit to the model quantification and to assess if the sequences have been correctly evaluated on the probability standpoint.

1. Introduction

The international fusion materials irradiation facility (IFMIF) is aimed at providing an intense neutron source by a high current deuteron linear accelerator and a high speed lithium flow target for testing candidate materials and components for fusion (JAERI, 2000a).

In the frame of the design phase called key element technology phase (KEP), jointly performed by an international team – including European Commission, Japan, Russian Federation and United States, under the auspices of the International Energy Agency (IEA) Implementing Agreement for a Program of Research and Development on Fusion Materials – from 2001 through 2003 to verify the most important risk factors, safety assessment of the whole experimental facility has been required in order to evaluate the risk associated with the plant operation (JAERI, 2000b). This paper discusses the safety assessments that were performed and their outcome: the analysis is finalized to the identification and quantification, in terms of expected frequency, of dominant accident sequences with the potential to hazard the plant.

At the beginning of a new project and particularly in the present case of an experimental facility, systematic methodologies should be settled to determine the events, due to the innovative characteristics of IFMIF plant. This concerns, for instance, the identification of the initiating events of accident sequences, in the absence of operational experience, as compared to commercial nuclear power plants.

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The traditional nuclear probabilistic safety assessment approach has been adopted to accomplish the task: the adopted methodology and calculation tool have been, respectively, the fault tree (FT) and event tree (ET) techniques, widely utilized in the PRA studies, and RISK SPECTRUM code, a PC software package for system risk and reliability analysis (RELCON, 2000).

At first a systematic component level failure mode and effect analysis (FMEA) procedure, commonly used in hazard identification process, provided a set of postulated initiating events (PIE) of accident sequences. Systems analysis based on FTs has been performed for all the identified front-line systems required to perform the safety functions in responding to each initiating event to successfully prevent plant damage or to mitigate the consequences. The accident sequence scenarios have been modeled through the ET technique which allows identifying all the different chains of accident sequences deriving from the selection of the initiating events.

2. Plant description

The use of an accelerator to generate neutrons results in a plant with four discrete subsystem facilities, as schematically shown in Fig. 1 (Martone, 1996):

1. test facilities, which allow to test and examine specimen for candidate fusion materials;
2. accelerator facilities, which deliver the high deuteron, beam current to the target by two 125 mA, 40 MeV accelerators operating in parallel;
3. target facilities, which provide a stable lithium jet in the target assembly for reaction with the deuteron beam to produce high-energy neutrons and for beam power removal;
4. auxiliary facilities, such as heat rejection system, electrical power distribution system, vacuum system, instrumentation and control, etc.

Martone (1996) and Burgazzi (2005) provide a detailed description of these facilities.

3. Methodology

Synthetically, the methodology embraced for the analysis consists of the following major tasks:

a. identification of initiating events or initiating event groups of accident sequences: each initiator is defined by a frequency of occurrence;
b. systems analysis: identification of functions to be performed in response to each initiating events to successfully prevent plant damage or to mitigate the consequences and identification of the correspondent plant systems that perform these functions (termed front-line systems): for each system the probability of failure is assessed, by fault tree model;
c. accident sequences development by constructing event trees for each initiating event or initiating event groups;
d. accident sequences analysis to assess the frequencies of all relevant accident sequences;
e. eventual grouping of the accident sequences into sequence families or plant damage states, basing on consequences and similarity of accident evolution and plant response.

These steps are detailed in the following.

4. List of initiating events

The initiating events considered in this study are limited to internal initiators – neither external events, such as earthquakes and floods, nor area events, such as internally caused floods and fires, are taken into account – that are assumed to occur during normal operation of IFMIF plant. A previous systematic FMEA procedure (Burgazzi, 2005) has defined a set of postulated initiating events (PIEs) for all the IFMIF facilities (target, test cell and accelerator facilities). Each PIE is defined by a code and frequency range: each initiating event is representative of a group of initiators having the same plant response in terms of possible consequences and mitigating feature intervention. The complete list is reported in Table 1.

The events are categorized by event likelihood of occurrence, according to Table 2.

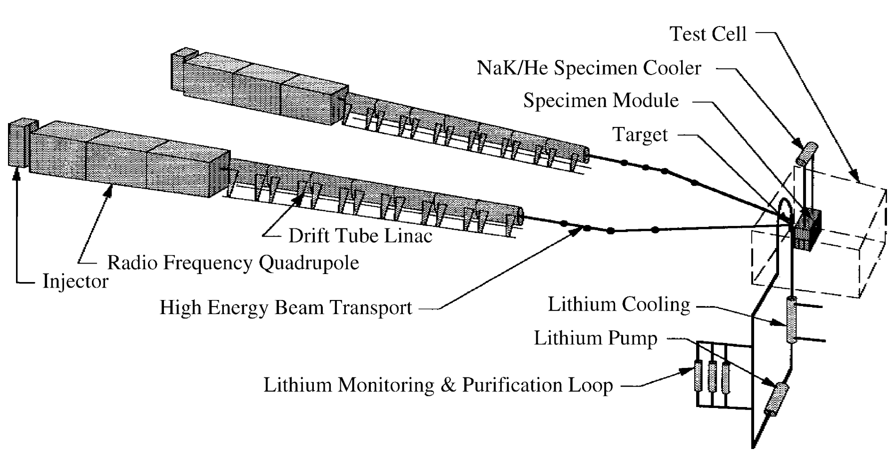

Fig. 1. Schematic layout of IFMIF.