Verification of DBEs Selected for ITER EDA 1998 Design by GEMSAFE Methodology and Consideration for Siting Events

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Abstract. **Ge**neral **M**ethodology of **S**afety **A**nalysis and Evaluation for **F**usion **E**nergy Systems (GEMFASE) has been applied to the International Thermonuclear Experimental Reactor (ITER) design in the final stage of Engineering Design Activities (EDA) to select design basis events (DBEs) and to identify related safety features and requirements to ensure its safety. We have classified DBEs into three categories considering their occurrence probabilities and expected scales of their consequences. By the GEMSAFE methodology applied to the ITER final design, we have selected 21 DBEs: 8 in the category 1, 8 in the category 2 and 5 in the category 3. The selected DBEs were compared with the Reference Events which were addressed in the ITER non-site specific safety report (NSSR-2). As a result, it has been made clear that there is no significant differences between the GEMSAFE DBEs and NSSR-2 Reference Events. Furthermore, in the framework of the GEMSAFE methodology, we have proposed a concept of siting events selection with the suggestion for siting events as those that were beyond design basis events developed by using function-based safety analysis (FBSA) method.

1. Introduction

General ***M***ethodology of ***S***afety ***A***nalysis and Evaluation for ***F***usion ***E***nergy Systems (GEMFASE) [1, 2] has been applied to the safety analyses of fusion systems in design stages [3, 4, 5]. It has been also applied to the International Thermonuclear Experimental Reactor (ITER) design in the final stage of Engineering Design Activities (EDA) [6]. Very recently, the methodology was used to select design basis events (DBEs) of ITER EDA by the end of July 1998 and to identify related safety features as well as requirements to ensure its safety. We have classified DBEs into three categories considering their occurrence probabilities and expected scales of their consequences. By the GEMSAFE methodology applied to the ITER final design, we have selected 21 DBEs: 8 in Category 1, 8 in Category 2 and 5 in Category 3 [7]. Through this study, we have identified two kinds of RI sources* that can likely contribute as critical source terms in accident sequences. Then, there is the possibility that the DBEs related to the RI sources cannot be contented within DBEs depending on the uncertainty of the estimated amount of radioactive release and the related physical process of mobilization of the RI sources. These *critical* RI sources are identified as tritium and induced activity in *dust* and *plasma facing components (PFCs).* According to the current categorization of DBEs, the radioactive dust was regarded as immobile RI source. Although the mobility of the dust is matter of further detailed examination, it might challenge the baseline to fit the equi-risk curve, if we should regard the dust, even partially, as a mobile RI source. As for the induced activity and tritium in PFCs, they are also regarded as immobile RI sources. However, if we choose the combination of beryllium as structural material and water as coolant, the interaction of them under an accidental condition such as cooling pipe break may mobilize the tritium and induced activity.

2. Comparison between DBEs of GEMSAFE and Reference Events in NSSR-2

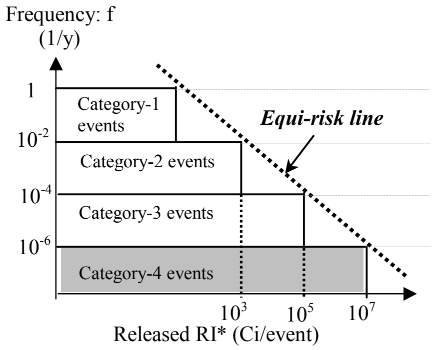
* Hereafter, we symbolize radiological hazard sources as RI sources standing for radio-isotopic (RI) sources.

We have compared the design basis accidents selected by GEMSAFE with the Reference Events listed in ITER non-site specific safety report (NSSR-2) [8]. The overall project defined safety goal for ITER is expressed in terms of dose and effluent/release limits for a set of categories defined on the basis of their expected annual occurrence. The categories are as follows. Category I: operational events; Category II: likely event sequences and its occurrence probability is one or more times during the life of the plant; Category III: unlikely event sequences with typical frequency 10^{-2}/y to 10^{-4}/y; Category IV: extremely unlikely event sequences with typical frequency 10^{-4}/y to 10^{-6}/y; then Category: Hypothetical sequences with frequency < 10^{-6}/y. The related design guideline of releases is shown in Table I. The release limits are based on the dose limit in GSEDC, assuming atmospheric, elevated release. As the release limits for different radiological species do not scale the same, the scaling of tritium and activation products beyond Categories differs.
In the GEMSAFE methodology the event categorization is made on *equi-risk* line in relation with the conditions of classified RI sources and boundaries. The released radioactivity is scaled just in Ci unit (Figure 1). By comparison of event categorization between GEMSAFE and NSSR-2, the baselines of them are very close. The marked differences are: (i) NSSR-2 assesses the release limits in terms of HTO and activation metal, while GEMSAFE uses Ci for all sorts of RI sources; (ii) strictly speaking, the release limits of NSSR-2 are not exactly on the equi-risk line; (iii) the integrity/failure of boundary is explicitly taken into account in GEMSAFE.

ITER/NSSR-2 has listed 28 ***Reference Events***, namely, 7 in ***Category II***, 8 in ***Category III***, and 13 in ***Category IV***. The description of each event in NSSR-2 has more component or design specific aspect compared to the GEMSAFE terminology, which is in more function-based and generalized expression.

TAB. I: EVENT CATEGORIZATION AND RELEASES FOR DESIGN GUIDELINE IN NSSR-2

Event Category	*I*	*II*	*III*	*IV*
Annual expected frequency		f > ~10^{-2}/y	10^{-2}/y >f > 10^{-4}/y	10^{-4}/y >f > 10^{-6}/y
Release limit of HTO	1g-T/y	1g-T/event	50g-T/event	100g-T/event
Release limit of divertor-FW activation products	10g-metal/y	0.5g-metal/event	25g-metal/event	2000g-metal/event



Class of RI Sources			Class of Boundary	
Class 1	Class 2	Class 3	Class 1	Class 2
Comparable to release under normal condition			Possibility of failure	
Released	Possibility of release		Failed	Possibility of failure
	Released	Possibility of release		Failed
		Released	*Large-scale fire, missile, failure of containment boundary*	

* *A mitigation factor of 10^{-2} by containment system is assumed.*

FIG. 1. Event categorization of GEMSAFE, which complies with equi-risk requirement, in relation with classification of RI source and boundary.

For example, three ***Category-II*** events in NSSR-2, that is, heat exchanger leakage, loss of divertor heat sink, divertor pump trip, are inclusively represented by a Category-1 event: "transient in cooling system related with Class-1 boundary integrity" in GEMASFE. Loss of plasma control in ***Category III*** (NSSR-2) corresponds to two Category-1 events (GEMSAGE): plasma power excursion and plasma heating system transient. Plasma disruption (Cat. 1 in GEMSAFE) is not regarded as an event beyond *Cat. I* in NSSR-2. Hydride bed transport accident (***Cat. III***, NSSR-2) may be categorized as "mobilization of Class-2 RI source with loss of fuel boundary" (Cat. 3, GEMSAFE). However, in GEMSAFE, the transport hydride bed is not taken into account, because it is depending on precise procedure of operation/maintenance. Cryostat air ingress of ***Cat. III*** in NSSR-2 is not identified by GEMSAFE, because the cryostat vessel itself does not constitute a material boundary to be protected under off normal condition. Related events are enveloped by VV failure and magnet transient in the GEMSAFE categorization. Loss of vacuum through one VV penetration in ***Cat. IV*** of NSSR-2 is understood as "Mobilization of Class-2 RI source" in Cat. 3 in GEMSAFE accompanied by related boundary failure. Loss of off-site power events identified in NSSR-2 are not explicitly in DBEs by GEMSAFE. The effect of loss of power supply is comprehensively included in the course of selecting DBEs as *Loss-of-Function* by using function-based safety analysis [1] of GEMSAFE. By the comparison, we can conclude that DBEs by GEMSFE well agree with the ***Reference Events*** of NSSR-2, although there are minor differences owing to design/component specification.

3. Consideration for Siting Events Selection

In the event categorization of GEMSAFE, Category-4 events are regarded as beyond design basis events (BDBEs) mainly due to the very low occurrence probability of them, i.e., $<10^{-6}$/y. Though we can assume that BDBEs would not occur, it may be better to consider following two points through siting evaluation in order to assure the safety margin against BDBEs and verify the proper isolation between the system and the public.

- As an event developed from a DBE, a BDBE should not result in an event with extraordinary large consequence. It means that an event should not deviate largely from an objective risk curve.
- Even for an event that would bring about the maximum source term, enough isolation between the system and the public must be assured.

Based on these points we propose the idea of the multi-grade selection of siting events in showing the relation with the critical RI sources identified by GEMSAFE. Table II shows the objectives and the selection procedure for each grade of siting events.

TAB. II: MULTI-GRADE SITING EVENTS

Primary-grade siting events	
Objectives	To assure the appropriateness of mitigation measure against events in the gray zone beyond DBE (10^{-6} ~10^{-8}/y). To assure isolation between the system and public.
Selection	For DBEs, first assure a loss of boundary integrity or RI controllability that could bring about maximum consequence or a failure of an active safety system. Then select events that would increase associated consequences. The events in this class are for scaling the effects caused by events evolved from related DBEs.
Secondary-grade siting events	
Objectives	To assure isolation between the system and public under the event that could bring about the maximum source term.
Selection	Select an event that could bring about the maximum source term under the assumption that we would not be able to expect the operation of any active safety systems equipped in the system. (Here of course we can rely on passive safety features, if any.)

Figure 2 depicts the siting events on the equi-risk curve.

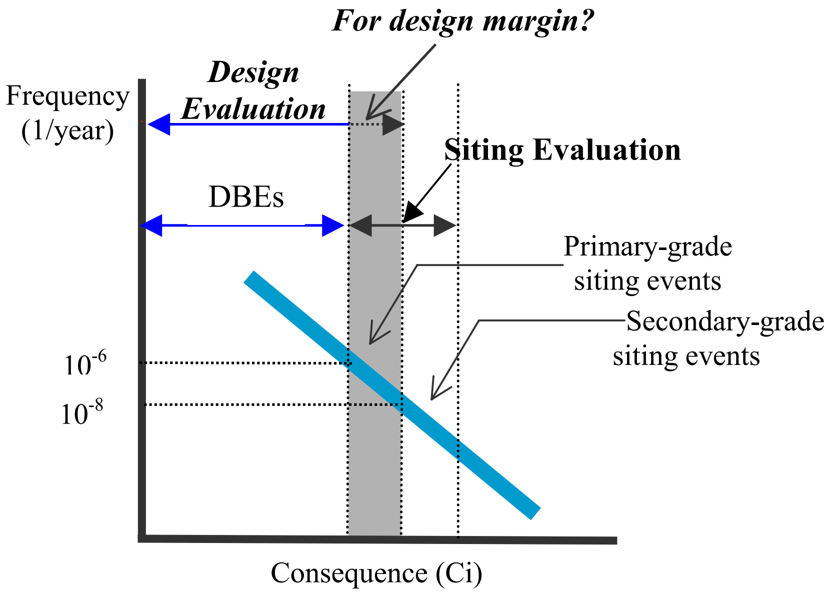


FIG. 2 Siting events on equi-risk curve

By the above proposed siting selection concepts, we can consider any category-4 event, which is an events in so-called "one-step beyond" the DBE domain, as the primary-grade siting events with occurrence probability of $10^{-6} \sim 10^{-8}$/year. For these candidates as the primary siting events, practically we needs further principle and method of screening. As for the secondary-grade siting event, we can choose a beyond design basis event (BDBE) ($\leq 10^{-6}$/year) with conceivable maximum source term. Candidate events are those which would bring about the mobilization of Class-3 immobile RI sources [7].

4. Conclusions

By the comparison, we can conclude that DBEs by GEMSAFE well agree with the *Reference Events* of NSSR-2, although there are minor differences owing to design/component specification. Design and component-specific consideration by GEMSAFE is desirable, while logical basis for selection of *Reference Events* is not always clear.
We have proposed candidates for siting events with the siting evaluation approach employing two-grades siting events.

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