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A practical methodology for modeling and estimation of common cause failure parameters in multi-unit nuclear PSA model

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ABSTRACT

When assessing the risk related to Nuclear Power Plants in terms of impacts on the population health and on the environment, multi-unit issues should be taken into account. The specific aim of a Probabilistic Safety Assessment at site level is to deal with the dependencies existing between the units on that site. One of important dependency factors is the potential existence of the inter-unit common cause failures (CCF) that could affect identical systems (with or without interconnections) present in each unit. As they are identical this makes them potentially sensitive to "inter-unit" CCF, in addition to "intra-unit" CCF that are usually modeled for redundant systems.

In this paper, we propose a practical methodology for modelling and estimation of CCF in a multi-unit PSA context. Two methods of modelling multi-unit CCF are firstly presented. A methodology for collecting and analyzing multi-unit CCF data is then proposed. This method is developed by extending the original impact vectors approach to the multi-unit context. Finally, in order to estimate the multi-unit CCF parameters in the case of incomplete data, we propose a CCF simulation method. The application of this method is considered in three different cases and compared with Bayesian and mapping up methods.

1. Introduction

When assessing the risk related to Nuclear Power Plants in terms of impacts on the population health and on the environment, multi-unit issues should be taken into account. The specific aim of a Probabilistic Safety Assessment (PSA) at site level is to deal with the dependencies existing between the units on that site [1–10]. One of important dependency factors lies in failures that could affect identical systems (with or without interconnections) present in each unit. As they are identical this makes them potentially sensitive to "inter-unit" common-cause failures, in addition to "intra-unit" common-cause failures that are usually modeled when systems have redundancy. Up to now, the current practice of collecting and analyzing the CCF data is often based on the impact vectors approach according to the ICDE coding guideline (International Common cause Data Exchange) [11] and NUREG/CR-6268 [12]. However, this method is proposed and considered in the PSA context for only a single unit. Furthermore, in some recent works about the multi-unit PSA model developing [1,2,10], the estimation of inter-unit CCF parameters in the vision of site level is not covered, especially in case of partial or total absence of CCF events. A possible method could be using inter-unit CCF values mainly based on the use of expert judgments and generic or observed CCF data developed for intra-unit CCF modeling. But these parameters may not necessarily be applicable for a use at the site level. Actually, the observed data for a CCF groups of 4 components in a single unit may not be suitable for a CCF group of 4 components composed by two groups of two components in two units as differences in operating or maintenance conditions may exist. Therefore, for the CCF modeling in a site level PSA, a methodology for the estimation of intra and inter-unit CCF parameters in the vision of site level is necessary, especially to incorporate correctly the existing intra-unit CCF data observed from the operating feedback data.

In this paper, we propose a practical methodology for modelling and estimation of multi-unit CCF in a multi-unit PSA model. Fig. 1 presents the mains steps of the proposed methodology. In each step, the alpha factor model is used for illustration.

In step 1, for modelling multi-unit CCF, two alternative methods (Seabrook method and traditional method) can be used in multi-unit PSA depending on the kind of impact of multi-unit CCF on identical systems with or without interconnection.

In step 2, collection and analysis of CCF data must be done in the multi-unit context. The original impact vectors approach is extended by adapting the OPEX analyzed in single unit to multi-unit vision. This is done by revising the impact vector factors (impairment, shared cause and time factors).

In step 3, the CCF parameters are estimated from the extended impact vectors. This estimation method depends on the availability of CCF data. When multi-unit CCF data are available, the Maximum Likelihood

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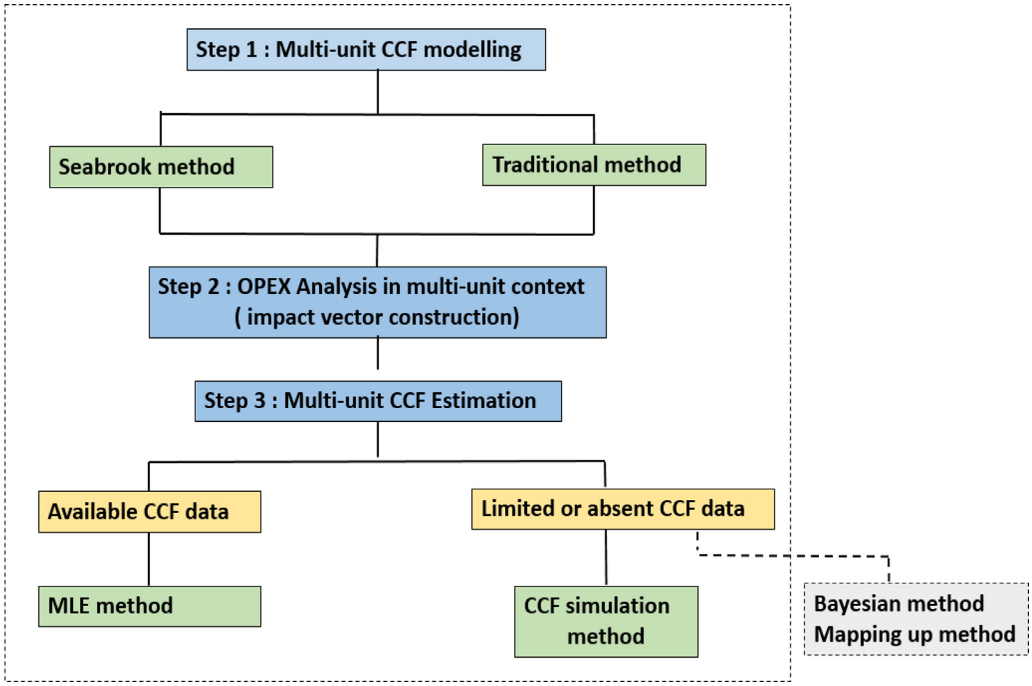

Fig. 1. Practical methodology for modelling and estimation of multi-unit CCF in a multi-unit.

Nomenclature

CCF	Common Cause Failure
CCBE	Common Cause Basic Event
CCFG	Common Cause Failure Group
CDF	Core Damage Frequency
CVCS	Chemical and Volume Control System
MLE	Maximum Likelihood Estimation
DG	Diesel Generator
OPEX	Operating Experience Feedback
EDF	Electricity of France
PSA	Probabilistic Safety Assessment

Estimation (MLE) method is used. When multi-unit CCF data are limited or totally absent, a CCF simulation method is proposed, as an extension of the method originally developed by the authors for use in single unit PSA context [13].

This present article is organized as follows. Section 2 presents in detail two methods of modeling multi-unit CCF of systems subject to intra and inter-unit CCF. In Section 3, the methodology of collecting, analyzing experience feedback data at site level is described. Sections 4 presents the estimation of multi-unit CCF parameters in case of complete data. Section 5 presents the simulation approach and illustrate its application by considering three different cases often encountered in practice when multi-unit CCF data is limited. These three cases are the following:

– Case 1: Independent failure and intra-unit CCF events are available but inter-unit CCF events are absent,
– Case 2: Independent failure events are available but intra-unit and inter-unit CCF events are totally absent,
– Case 3: Independent failure and the CCF data events are totally absent.

In each case, in order to highlight the advantages of the CCF simulation method, we compared this method with two alternative estimation methods (Bayesian and mapping up methods) which could be also applicable in the context of multi-unit PSA model.

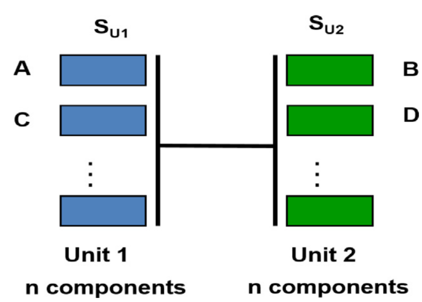

Fig. 2. Systems with unit cross tie.

Finally, some conclusions and perspectives are given in Section 6.

It is noted that, throughout the paper, we take the twin-unit PSA model as the basic one to demonstrate clearly our proposed methodology without loss of generality. It can be also applied to the multi-unit PSA model in a more general context.

2. Modeling CCF in multi-unit PSA models

In this section, we consider in detail the possible solutions for modeling intra and inter-unit CCF in a site PSA for two types of systems, identical systems with cross ties and identical systems without cross ties and for two types of CCF events impact at the site level, inter units CCF affect all the components of the systems at once or may affect only some of the components of the systems.

2.1. Identical systems with cross ties

These systems are identical and present in each unit; interconnections exist and a system in one unit can be backed up by the same system in the other unit (Fig. 2). For these systems, two cases are possible. In the first case, the system in one unit is in fact designed to support both units, for example, the service water supply system. In the second case, the system of each unit has redundancies that can be used to back up the twin unit. This case can be illustrated via the CVCS charging pump