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Sensitivity analysis of the model of a nuclear passive system by means of Subset Simulation

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Abstract

Passive safety systems are commonly considered to be more reliable than active systems, and for this reason are expected to improve the safety of nuclear power plants. However, their behavior and modeling are affected by considerable uncertainties. In this paper, the recently developed Subset Simulation method is employed to perform an efficient sensitivity analysis for identifying the key parameters which influence the uncertain behavior and, thus, the failure probability, of a nuclear passive system of literature.

Keyworks: Functional failure probability; nuclear passive system; uncertainty and sensitivity analysis; Subset Simulation; conditional distribution.

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1. Introduction

Modern nuclear reactor concepts make use of passive safety features, which do not need external input (especially energy) to operate and, thus, are expected to improve the safety of nuclear power plants because of simplicity and reduction of both human interactions and hardware failures [Mathews et al. (2009)].

However, the aleatory and epistemic uncertainties involved in the *operation* and *modelling* of passive systems are usually larger than for active systems [Burgazzi (2007)]. Due to these uncertainties, the physical phenomena involved in the passive system functioning (e.g., natural circulation) might develop in such a way to lead the system to fail its function (e.g., decay heat removal): actually, deviations in the natural forces and in the conditions of the underlying physical principles from the expected ones can impair the function of the system itself. In the analysis of such *functional failure* behavior, the passive system is modeled by a mechanistic code and the probability of failing to perform the required function is estimated based on a Monte Carlo (MC) sample of code runs which propagate the uncertainties in the model and numerical values of its parameters/variables [Fong et al. (2009)].

Within this framework, sensitivity analysis aims at determining the contribution of the individual uncertain parameters (i.e., the inputs to the mechanistic code) to the uncertainty in the outputs of the code and consequently to the probability of functional failure of the passive system [Saltelli et al. (2008)]. The analysis typically relies on *multiple* (e.g., many hundreds or thousands) evaluations of the code for different combinations of system inputs: this makes the associated computational effort very high and at times prohibitive in practical cases in which the computer code requires several hours (or even days) to run a single simulation [Fong et al. (2009)].

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In this work, the use of the recent Subset Simulation (SS) method [Au and Beck (2001); Au and Beck (2003)] is investigated to perform an efficient sensitivity analysis of the model of a nuclear passive system with a *limited* number of input samples drawn and associated low computational time.

In the SS approach, the functional failure probability is expressed as a product of conditional probabilities of some chosen intermediate events. Then, the problem of evaluating the probability of functional failure is tackled by performing a sequence of simulations of these intermediate events in their conditional probability spaces; the necessary conditional samples are generated through successive Markov Chain Monte Carlo (MCMC) simulations, in a way to gradually populate the intermediate conditional regions until the final functional failure region is reached. In this approach, the sensitivity of the passive system performance to the uncertain system input parameters can be studied through the examination of the conditional sample distributions generated by SS at different conditional probability levels: an informative measure of the importance of a given parameter in determining the failure of the system is the deviation of its conditional distributions from the unconditional one [Au (2005); Au et al. (2007)].

This method is tested on a case study involving the natural convection cooling in a Gas-cooled Fast Reactor (GFR) after a Loss of Coolant Accident (LOCA) [Pagani et al. (2005)].

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