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Abstract

Passive systems are central in the safety design of new generation nuclear power plants (NPPs). In this paper, the variance decomposition method is adopted to identify key parameters which influence the uncertain behavior of the passive Residual Heat Removal system (RHRs) in the High Temperature Gas-Cooled Reactor (HTGR).

Keywords: Uncertainty and Sensitivity Analysis; Variance Decomposition; Passive Safety System; Residual Heat Removal system (RHRs); High Temperature Gas-Cooled Reactor – Pebble Bed Modular (HTR-PM).

1. Introduction

Generation IV nuclear reactor systems (e.g., High Temperature Gas Cooled Reactors (HTGR)) are involving innovative design solutions for improved reliability and safety. Sensitivity analysis can provide relevant insights on the response of the innovative system implemented to different inputs [Saltelli et al. (2000)]. In this paper, we adopt the variance decomposition method [McKay (1996)] for performing sensitivity analysis of Thermal-Hydraulic (T-H) model of a natural circulation passive systems designed for providing the decay heat removal function in a HTGR.

The operation of such passive systems relies on natural convection, with no need of support by external power sources as is the case for the active safety heat removal systems employed in the current and evolutionary reactor designs. Because of this, the magnitude of the driving force is relatively small, as compared to those driving the active systems, and is influenced by the operating state of the system [Zio et al. (2003), Pagani et al. (2005)]. Considerable uncertainties affect the parameters and factors (e.g. heat transfer coefficients and pressure losses) which determine the driving force for natural circulation of passive systems and there is a strong dependence on the physical conditions and plant configuration existing at the time of action request. All these aspects significantly influence the performance of a passive heat removal system and render the problem of assessing its reliability (or dually, its probability of failure) quite a difficult one [Pagani et al. (2005), Mackay et al. (2008)]. In this view, it is important to identify those key parameters which mostly affect the passive system safety function, and then have detailed investigations on their effects [Zio et al. (2003)]. In this work, the variance decomposition method of sensitivity analysis is applied to study the effects of the uncertainties in input to a numerical model for computing the maximum outlet water temperature $T_{w,out}$ reached during a set of accident scenarios in the Residual Heat Removal system (RHRs) of the High Temperature Reactor-Pebble Modular (HTR-PM) [Zhengy et al. (2008)].

2. Results and conclusions

The variance decomposition-based sensitivity analysis has allowed identifying 3 out of 37 individual input parameters as the most important contributors to the variance of the output safety parameter $T_{w,out}$ of the passive RHR system of the HTR-PM (the power W, the inlet temperature of air in the air-cooled tower $T_{a,in}$ and the water pressure in the pipes P_w). This confirms previous results obtained by the application of the Analytical Hierarchical Process with expert judgment [Yu et al. (2010)]. Furthermore, the analysis of groups of parameters has shown a clear preponderance of plant configuration parameters (i.e., power W, the number of pipes in the air cooler N_a, number of water cooling pipes for each loop N_w, etc.) with respect to the effects on uncertainties in the maximum outlet water temperature reached during the considered set of accidental scenarios in the RHRs of the HTR-PM.

In conclusion, the approach has been demonstrated coherent in comparison to other techniques (e.g., AHP), computationally fast (i.e., for each input parameter, the importance index is evaluated in few minutes on a Intel® Atom™ 330 Dual Core) and the results of the group sensitivity analyses allow underlining important physical and modelling aspects related to the system behaviour, that may turn useful when applied in the successive safety assessment analyses of the plant.

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