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Uncertainty evaluation of reliability of safety grade decay heat removal system of Indian prototype fast breeder reactor

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A R T I C L E I N F O

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A B S T R A C T

Deterministic and probabilistic safety assessment of nuclear power reactor technology is very important in assuring that the design is robust and safety systems perform as per requirement. The parameters required as input data for such analysis have uncertainties associated with them. Their impact is to be assessed on the results obtained for such analyses and it affects the overall decision making process.

Safety Grade Decay Heat Removal System (SGDHRS) is one of the safety systems in fast breeder reactors and itremoves decay heat after reactor shutdown. It is a critical safety system; hence failure frequency for SGDHR is targeted to be less than 1.0×10^{-7} per reactor year. By bringing diversity in some of the components of SGDHRS, such as sodium-to-sodium decay heat exchanger (DHX), sodium to air heat exchanger (AHX) and valves, one can achieve the targeted low failure frequency of SGDHRS. We perform uncertainty analysis of the reliability of such SGDHRS here. Uncertainty in failure rate (of components of SGDHRS) is assumed to follow the log-normal distribution with error factor of three. Monte Carlo method of sampling is used in MATLAB environment. Results are obtained in terms of mean, median and standard deviation values of failure frequency. Percentile and confidence interval analysis of mean values are also obtained. These provide 95 and 98 percentile and confidence interval values of 98%, 99% and 99.8%. It is found that error factor of failure frequency of SGDHRS is found to be less than 3 in all the cases except the one in which DHX, AHX and Valves are designed with diversity in design. It is to be noted here that error factor of all input parameters distribution is taken as 3.

1. Introduction

Prototype Fast Breeder Reactor (PFBR) is an Indian pool type fast breeder reactor that is mixed oxide fuelled and has a capacity of 500 MWe. It has two primary loops with two pumps and 4 Intermediate Heat Exchangers (IHXs). The secondary circuit has 4 loops with two steam generators (SGs) each. The tertiary circuit is steam water circuit. This reactor has been provided with two diverse decay hear removal systems: Operating Grade Decay Heat Removal System (OGDHRS) and Safety Grade Decay Heat Removal System (SGDHRS). Secondary circuits and steam-water system is used by OGDHRS for decay heat removal. After reactor shutdown, decay heat is removed through special condensers connected to the steam generator by passing the turbine generators. Reliability of OGDHRS is in the range of 0.1–0.01. As per safety standards of present day fast reactors, reliability of Decay Heat Removal (DHR) should be very high, i.e., its failure frequency should be less than 10^{-7} per reactor year. Introduction of SGDHRS improves the reliability of DHR function. This system consists of four special thermo-siphon loops operating in natural convection mode. Each loop consists of a sodium to sodium heat exchanger (DHX) dipped in the primary sodium hot pool and sodium to air heat exchanger (AHX). Air dampers of the AHX casing control the air flow through AHX. A failure of OGDHRS (due to component failures in the secondary or steam water circuit or loss of offsite power (LOP)) results in switching on of SGDHRS.

Reliability analysis of SGHDRS is reported by Arul et al. (2006). Fault Tree (FT) method is used to perform reliability analysis. It was found that for four identical loops, probability of failure of SGDHRS is 5.2E-06/demand (or frequency of 3.6E-06/ reactor year for seven demands per year). Introduction of diversity in the design of some of the components of the two loops (out of 4 loops) results in achieving the desired target.

Uncertainty evaluation of reliability of SGDHRS is reported here. The basic components that have been compiled in nuclear industry have uncertainties in failure rates (Bisseau et al., 1982; Eide and Calley, 1993). It is imperative to perform uncertainty analysis and assess the spread in the results of failure rates. So uncertainty analysis is imperative to get a reasonable confidence in the results obtained from reliability analysis. Best estimate analysis of severe accidents is permitted (CFR 50, 1974) if it the uncertainty in calculations is quantified and, in addition, IAEA also recommends that deterministic analysis be supported by probabilistic analysis.

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Nomenclature

AHX	sodium to air heat exchanger
DHR	Decay Heat Removal
DHX	sodium to sodium heat exchanger
FT	Fault Tree
IAEA	International Atomic Energy Agency
IHX	Intermediate Heat Exchanger
LOP	loss of offsite power
OGDHRS	Operating Grade Decay Heat Removal System
PFBR	Prototype Fast Breeder Reactor
SG	steam generators
SGDHRS	Safety Grade Decay Heat Removal System
ry	reactor year

Distribution of uncertainty is assumed as lognormal distribution and error factor is taken in the range of 3–10. Failure rates are sampled (for each basic event) from the lognormal distribution using Monte Carlo method with total samples being 30,000.

Work of Arul et al. (2006) reports the details of the system and safety analysis. Salient features of that study are reported here for convenience.

2. Reliability analysis

A simple functional diagram of SGDHRS is shown in Fig. 1. It can be seen that decay heat can be removed through two paths. First path is core to hot pool, hot pool to secondary system through IHX, and then secondary system to sodium–water (SW) system through special steam condenser bypassing the turbine. The

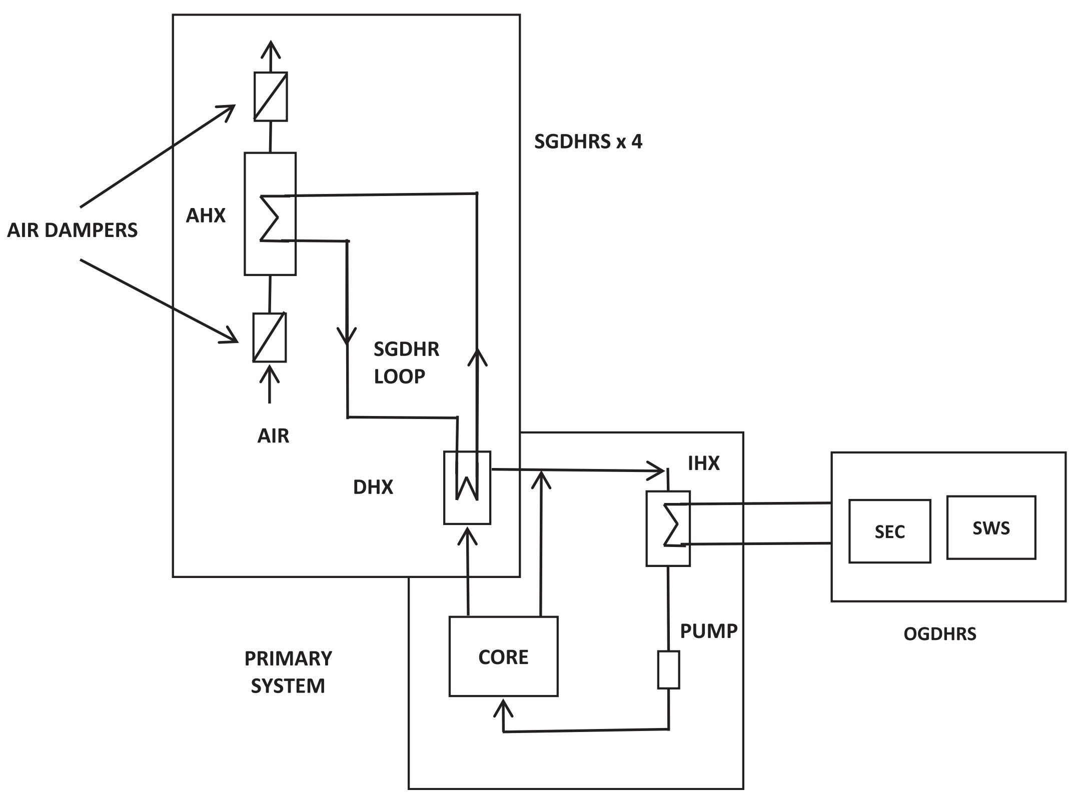

Fig. 1. Functional block diagram of DHR systems.

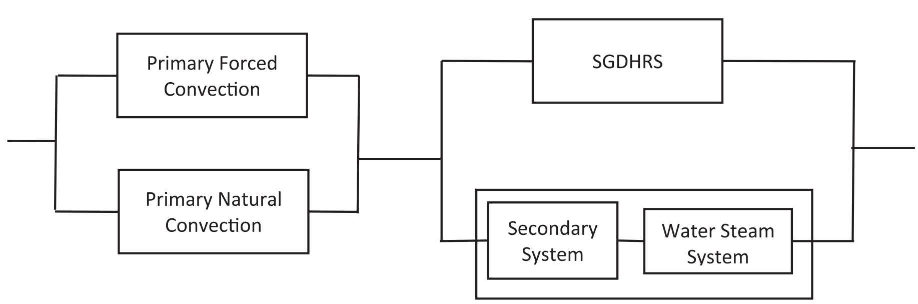

Fig. 2. Overall reliability block diagram for decay heat removal function.