Calculation of Core Damage Frequency for the Change of the Common Cause Failure Parameters According to the Testing Strategies

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1. Introduction

Common cause failure (CCF) probabilities are differently estimated according to testing strategies. There are two representative testing schemes; staggered testing and non-staggered testing schemes. For the cases where trains or channels of standby safety systems consisting of more than two redundant components are tested in a staggered manner, the standby safety components within a train can be tested simultaneously or consecutively. In this case, mixed testing scheme, staggered and non-staggered testing schemes, are used for testing the components. Kang et al.[1] derived the formulas for the estimations of the CCF probabilities of the components under the mixed testing scheme. This paper presents the sensitivity study results on the core damage frequency (CDF) of the SMART (System-integrated Modular Advanced Reactor) for the changes of the CCF parameters according to the testing strategies.

2. Estimation of common cause failure probabilities according to testing strategies

The probability of a CCF event involving k specific components ($1 \le k \le m$) in a CCCG of size 'm' for a staggered testing scheme, $Q_k^{(m)}$, is calculated by using the following equation [1, 2]:

$$Q_k^{(m)} = (\alpha_k^{(m)} / {}_{m-1}C_{k-1})Q_T \tag{1}$$

$Q_k^{(m)}$ of Eq.(1) is based on a symmetry assumption that the probabilities of CCF events involving similar components are the same [1, 2]. In Eq.(1), Q_T and $\alpha_k^{(m)}$ are represented as:

$$Q_T = \sum_{k=1}^{m} {}_{m-1}C_{k-1} Q_k^{(m)} \tag{2}$$

$$\alpha_k^{(m)} = n_k / (\sum_{j=1}^{m} n_j) \tag{3}$$

For the case of a non-staggered testing scheme, the following formula is used [1,2]:

$$Q_k^{(m)} = (k / {}_{m-1}C_{k-1})(\alpha_k / \alpha_T)Q_T \tag{4}$$

$$\alpha_t = \sum_{k=1}^{m} [k\alpha_k] \tag{5}$$

For the case of a mixed testing scheme, the probability of a basic event involving k specific components in a CCCG of size m for the mixed testing scheme, Q_k^{MIX}, can be expressed as [1]

$$Q_k^{MIX} / Q_k^{S} \approx q[{}_{m-1}C_{k-1} / ({}_{m}C_k - {}_{m-p}C_k)] \tag{6}$$

3. CCF data for the SMART PSA

As there is no CCF data for Korean nuclear power plants (NPPS), the generic CCF data have been used in the probabilistic safety assessment (PSA) of Korean NPPs. EPRI CCF data or NUREG/CR-5497 was mainly used for the previous PSA of Korean NPPs. EPRI CCF data and NUREG/CR-5497 were based on the operating experiences of USA NPPs from year 1970 to 1995. In the SMART PSA, US NRC 2005 CCF data [3] were used for incorporating the recent operating experiences of Korean NPPs. US NRC 2005 CCF data include the operating experiences of USA NPPs from 1991 to 2005. Fig.1 [4] indicates that there is a decrease in the number of CCF events for USA NPPs from 1985. Fig.2 [5] tells us that the average availability of USA NPPs has been increased from 1987. It is difficult to explicitly identify the relation between the availability of NPPs and the occurrence rate of CCF events. However, operating experiences of USA NPPs show that the increase of availability of NPPs results in the decrease of number of occurrence of CCF events. The recent average availability of Korean NPPs is comparable to that of USA NPPs.

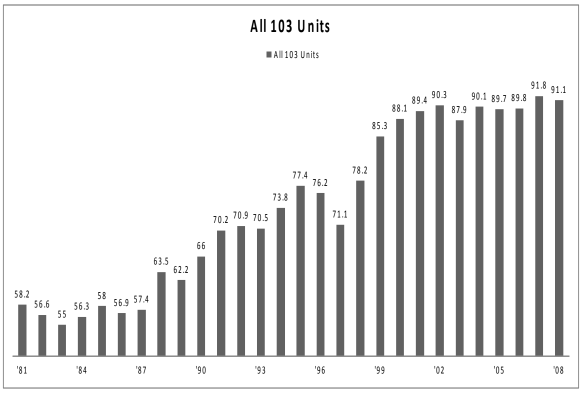

Fig. 2 Availability trend of USA NPPs

4. **Applications to the SMART**

The standby safety injection system (SIS) and the passive residual heat removal system (PRHRS) have four sub-trains. The PRHRS is designed to passively remove the residual heat from the secondary side of SG through natural circulation. Each SIS sub-train consists of one 100% motor driven pump, motor driven valve, check valves, associated piping, and instrumentation controls. Each PRHRS sub-train consists of one 50% heat exchanger, associated valves, piping, and instrumentation and controls.

As the detailed testing strategies of the SIS and the PRHRS were not decided, they were assumed to follow the mixed testing strategy based on the testing practice of four check valves of auxiliary feedwater system (AFWS) for Ulchin Unit 3 in Korea [1]. The AFWS of Ulchin Unit 3 consists of four sub-trains. Each train consists of two sub-trains and is tested in a staggered manner. However, check valves of sub-train within a single train are consecutively tested.

5. Concluding Remarks

By using Eq. (1), (4), and (6), CCF parameters of the components modeled for the SMART PSA were estimated and baseline CDF of the SMART was quantified. If all components of the SIS and the PRHRS were tested in a staggered manner, the CCF parameters of them were estimated lower than mixed testing case. In this case, baseline CDF decreased by 10% comparing to baseline CDF. Consequently, the effects on CDF for the change of testing strategy of the SIS and the PRHRS were not great.

NOMENCLATURE

α_k = fraction of the total frequency of the failure events that occur in the system involving the failure of k components due to a common cause

${}_mC_k$ = (m)! / [(m-k)!*(k)!]

n_j = sum of the *j-th* element of the impact vector

p = the number of components in the same CCCG within each train

q = obtained by dividing m by the number of trains tested in a staggered manner

Q_T = total failure probability of a component in a CCCG due to all independent and common cause events

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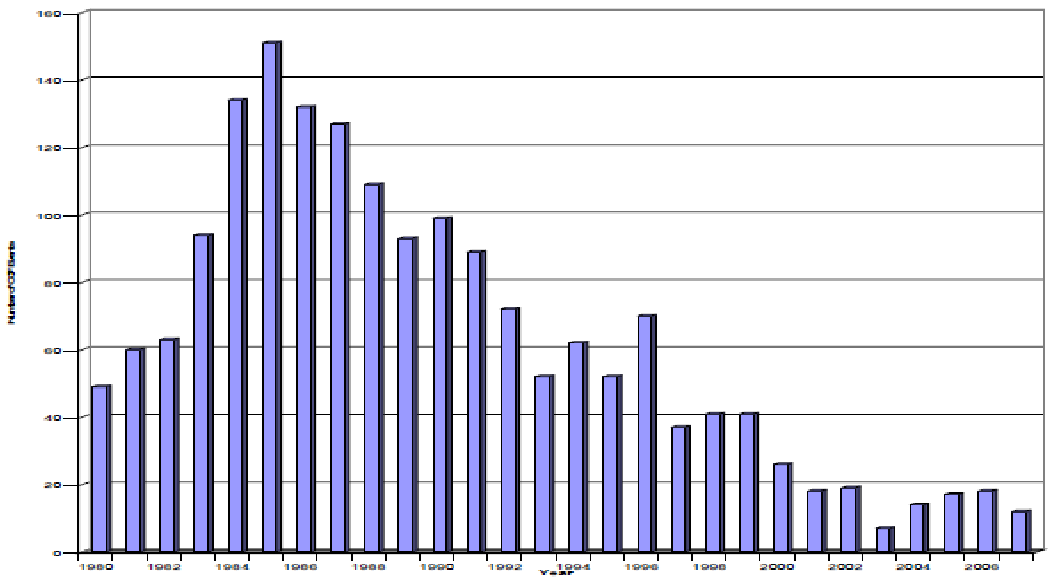

Fig. 1 Trend of number of CCF events for USA NPPs