Reliability Engineering and System Safety 170 (2018) 215–225

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Calculating nominal human error probabilities from the operation experience of domestic nuclear power plants

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ARTICLE INFO

Keywords:
Nuclear power plant
Probabilistic safety assessment
Human reliability analysis
Operation experience
Investigation report
Nominal human error probability

ABSTRACT

It is evident that human reliability analysis (HRA) practitioners require a large spectrum of HRA data that are indispensable not only for understanding the cause of a human error but also for estimating its human error probability (HEP) under a given task context. Accordingly it is very important to collect HRA data from diverse sources as much as possible, which should be done based on a firm technical underpinning. In this regard, Park et al. proposed a novel framework that allows us to systematically calculate the number of task opportunities from the investigation reports reflecting the operation experience of domestic nuclear power plants [1]. In this study, based on the proposed framework, the nominal HEPs of 15 task types are quantified based on the number of task opportunities calculated from the 13 investigation reports stemming from diverse human errors. Although there are several limitations to be technically resolved, the results of this study are meaningful because we are able to take the first step in securing HRA data from investigation reports that reflect the operation experience of domestic NPPs.

1. Introduction

Traditionally, the safety of nuclear power plants (NPPs) has been evaluated by many techniques that were developed from two opposite but complementary viewpoints: deterministic and probabilistic assessment [2,3]. Of them, from the probabilistic perspective, the most disseminated technique is the PSA (probabilistic safety assessment) or PRA (probabilistic risk assessment). The underlying idea behind the PSA technique is to evaluate all of the risk contributions of potential events that can have undesired consequences with regard to the status of NPPs (e.g., core damage or a large release of radioactive material) [4]. Therefore, according to Mosleh, the PSA can inform us of the safety (or risk) level of NPPs by providing insights that are helpful for: (1) identifying the cause and progress of potential events that can result in the undesired consequences, (2) quantifying the probability of the undesired consequences due to the potential events, and (3) materializing optimized countermeasures to enhance the safety level (or to reduce the risk level) of NPPs [5].

In this regard, since these potential events can be initiated by diverse causes including internal events (e.g., the rupture of a coolant pipe or the mechanical failure of safety critical systems), and external events (e.g., an earthquake, typhoon, flood, and high wind), it is necessary to precisely calculate their failure probabilities (or occurrence frequencies) in a systematic manner. In addition, given that the degradation of human performance (i.e., human errors) can also cause the failure of safety critical systems [3, 5–7], many kinds of human reliability analysis (HRA) techniques that allow HRA practitioners to reasonably estimate the human error probability (HEP) of a specific task have been developed for several decades.

However, in order to properly support the purpose of the PSA, HRA practitioners need to know diverse information (called HRA data) including not only the nominal HEP of a certain task type but also the effect of error-forcing contexts (e.g., PSFs, Performance Shaping Factors) on the associated HEP. This is because HRA practitioners have to manage a large spectrum of safety critical tasks to be conducted by human operators. For this reason, many researchers have attempted to extract HRA data from several available sources, such as event investigation reports (e.g., a near miss or incident report; hereafter referred to as an investigation report) and full-scope and/or partial-scope simulators [8–12].

Of them, the main source of HRA data appears to be full-scope simulators for the following reasons: (1) it is possible to directly observe the effect of PSFs on the associated HEPs, and (2) it is possible to emulate the task environment of the potential events being considered in the PSA, which have an extremely rare frequency in the real world [13, 14]. However, Park et al. claimed that the collection of HRA data from the analysis of investigation reports should be carried out in parallel with that of full-scope simulators because of several issues [15]. For example, it seems that there are times when full-scope simulators are insuffi-

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https://doi.org/10.1016/j.ress.2017.10.011
Received 20 October 2016; Received in revised form 20 October 2017; Accepted 20 October 2017

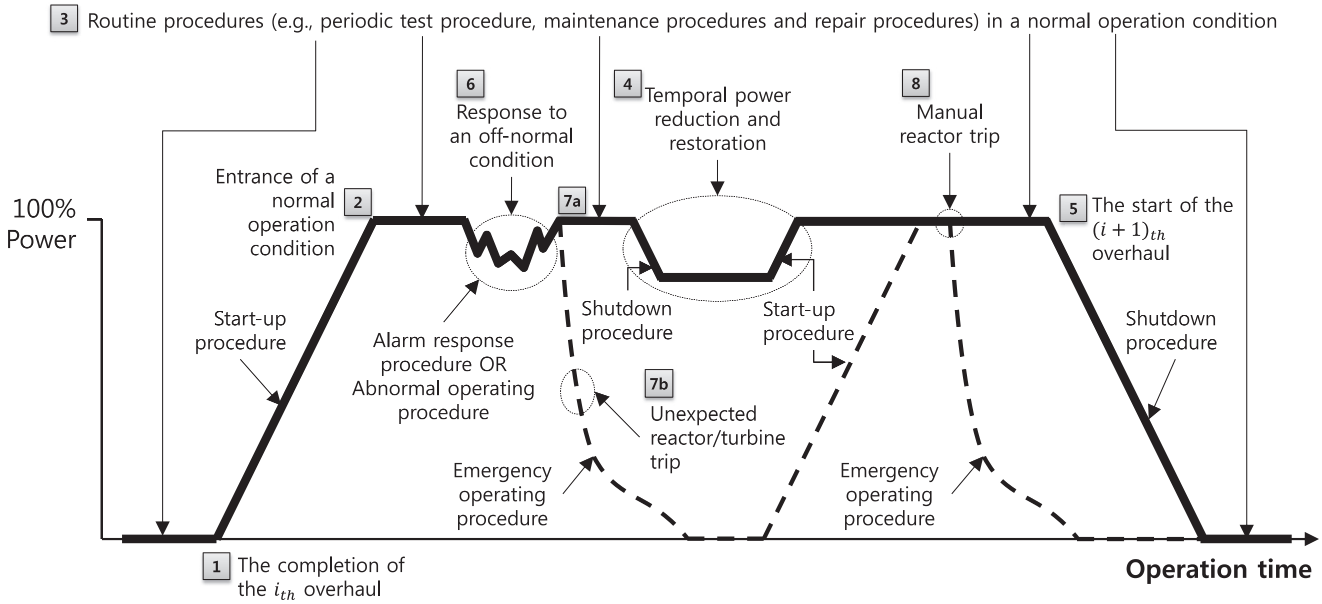

Fig. 1. Procedures being used for the operation of domestic NPPs, modified from [1].

Table 1
Quantifying a nominal HEP from operation experience, reproduced from p. 39 of Ref. [8].

Item	Contents
Task description	Fuel handling errors due to miscommunication
Error description	The shop manager failed to specify the enrichment that he could accept during the movement of a flask
Operation year	Four years
Task opportunity	200 movements per year
Nominal HEP	1.25E-4(=1/8,000)
Industry	Nuclear reprocessing plant
Data origin	Real data

cient for emulating actual working conditions, in which human operators have to deal with the required tasks in a real world (i.e., a fidelity problem). The more important problem is that full-scope simulators are not suitable for collecting HRA data for tasks to be conducted in a normal condition (e.g., a maintenance task that can cause the failure of a safety critical system) because they mostly dedicate to the emulation of off-normal conditions usually initiated by the internal events such as a steam generator tube rupture (SGTR) or loss of coolant accident (LOCA).

For this reason, Park et al. proposed a novel framework that allows us to systematically calculate the number of task opportunities from the investigation reports reflecting the operation experience of domestic NPPs [1]. In other words, the nominal HEP of a specific task can be soundly estimated if how many times human operators did historically conduct the required task. Based on the proposed framework, in this study, the nominal HEPs of selected task types are quantified from the investigation reports of domestic NPPs. To this end, a total of 193 investigation reports issued from January of 2002 to December of 2013 are reviewed in detail, which are extracted from the database NEED (Nuclear Event Evaluation Database) managed by the KINS (Korea Institute of Nuclear Safety), the nuclear regulatory body of Republic of Korea. From the review of these investigation reports, a total of 13 investigation reports stemming from (or largely attributable to) diverse human errors are selected. Consequently, the nominal HEPs of 15 task types are quantified based on the number of task opportunities calculated from the 13 investigation reports.

The structure of this paper is organized as follows. First, in order to clarify the background information of this study, the underlying idea of an HEP quantification from the analysis of investigation reports is briefly described in Section 2. Based on this underlying idea, in Section 3, the characteristics of the proposed framework that allows us to systematically calculate the number of task opportunities from investigation reports are explained. Then, in Section 4, the nominal HEPs of 15 task types are provided with the step-by-step application of the proposed framework to one of the 13 investigation reports, which deals with the unexpected trip of a reactor due to the manipulation of a wrong valve. In addition, the upper bound of nominal HEPs (i.e., 95 percentile) for 15 task types are estimated based on Bayesian update with Jeffrey's non-informative Beta prior. Finally, the contribution and limitations of this study are discussed with a concluding remark in Section 5.

2. Background information for calculating an HEP from the operation experience of domestic NPPs

Essentially, along with the general definition of probability, the nominal HEP of a specific task type can be calculated by Eq. (1) [8,16].

$$\text{HEP of the } i_{th} \text{ task } \left(\text{HEP}_i\right) = \frac{m_i}{n_i} \quad (1)$$

Here, the m_i and n_i denote the number of human errors observed during the performance of the i_{th} task type and the number of opportunities for the performance of the i_{th} task type, respectively. Accordingly, if we are able to soundly count both the m_i and n_i from various kinds of reports reflecting the operation experience of domestic NPPs (e.g., investigation reports), it is promising to get a more realistic value of a nominal HEP. In this regard, Table 1 exemplifies how to calculate the nominal HEP of a specific task type based on an empirical m_i.

As briefly outlined in Table 1, human error occurred because a shop manager who was in charge of moving a radioactive flask failed to handle it. Here, since this human error is the first one reported during four years of operation, the number of human errors for a radioactive flask movement task becomes one. In addition, the number of task opportunities for the corresponding task would be 8,000, which can be calculated by multiplying 200 (movement tasks/year) by 4 (years). This means that the nominal HEP of the radioactive flask movement is 1.25E-4 because the values of the m_i and n_i in Eq. (1) are 1 and 8,000, respectively. In