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Human error probability estimation by coupling simulator data and deterministic analysis

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ABSTRACT

Operator error in diagnosis and execution of task have significant impact on Nuclear Power Plant (NPP) safety. These human errors are classified as mistakes (rule base and knowledge based errors), slip (skill based) and lapses (skill based). Depending on the time of occurrence, human errors have been categorized as i) Category 'A' (Pre-Initiators): actions during routine maintenance and testing wherein errors can cause equipment malfunction ii) Category 'B' (Initiators): actions contributing to initiating events or plant transients iii) Category 'C' (Post-Initiators): actions involved in operator response to an accident. There have been accidents in NPPs because of human error in an operator's diagnosis and execution of an event. These underline the need to appropriately estimate HEP in risk analysis. There are several methods that are being practiced in Probabilistic Safety Assessment (PSA) studies for quantification of human error probability. However, there is no consensus on a single method that should be used. In this paper a method for estimating HEP is proposed which is based on simulator data for a particular accident scenario. For accident scenarios, the data from real NPP control room is very sparsely available. In the absence of real data, simulator based data can be used. Simulator data is expected to provide a glimpse of probable human behavior in real accident situation even though simulator data is not a substitute for real data. The proposed methodology considers the variation in crew performance time in simulator exercise and in available time from deterministic analysis, and couples them through their respective probability distributions to obtain HEP. The emphasis is on suitability of the methodology rather than particulars of the cited example.

1. Introduction

The human errors in the performance of desirable diagnosis and actions during an accident situation have significant contribution to the risk. The actual estimates of the fractional contributions of human error to system failures have varying quantitative values. However, many analysts have indicated that the fraction could be as high as 50% for full-power operations (IAEA TECDOC-565, 1990) and as high as 70% for low power and shutdown state of Nuclear Power Plant (Himanen, 1995). The fact that the contribution of human error could be high in over all risk, it is important that Human Error Probability (HEP), is correctly estimated for the purpose of Probability Safety Assessment (PSA). In order to accomplish this requirement, it is necessary to select a suitable method for estimation of HEP.

The human errors have been categorized as (IAEA 50-P-10, 1995): (i) Category 'A' (Pre-Initiators) – These consist of actions associated with maintenance and testing which degrade system availability. They may cause failure of a component or component group or may leave components in an inoperable condition. Some examples of pre-initiators are mis-calibration of sensors, valve misalignment, incorrect part fitting during maintenance and working on wrong component. (ii) Category 'B' (Initiators) – These are actions contributing to initiating events or plant transients. They are implicit in selection of initiating events for PSA. (iii) Category 'C' (Post-Initiators) – These are the actions involved in operator response to an accident. The post-initiators are generally classified into procedural safety actions, aggravating actions and recovery actions. Category 'C' actions have always been at the center of HEP because they are critical for NPP safety.

The human error is classified under three types (i) Mistakes – The action is intended to be performed as planned but wrong

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course is taken thinking it to be correct. Mistakes could be rule and knowledge based. Example of rule based mistake is misapplication of a correct procedure or correct application of a badly/wrongly written procedure. The knowledge based mistake could be due to non existence of a procedure for an unusual situation and reliance on gathered experience and knowledge over time (ii) Slip – These are associated with familiar task which do not require much of conscious thinking. They lead to commission of errors. (iii) Lapses—Lapses are also linked to tasks not requiring conscious effort. They lead to omission of errors.

The pioneering Reactor Safety Study or popularly called the WASH-1400 (WASH, 1975) was the first to address the issue of Human Reliability contribution to system unavailability. The field of Human Reliability Assessment has gone through several stages of development and detailing. In the last two decades several methods have been proposed (Health and Safety Executive, 2009), and used in the nuclear industry. The HRA methods are broadly classified into three categories. These categories are i) Task Related, ii) Time Related, iii) Context Related. The task related and time related categories constitute the first generation methods while the context related category constitutes the second generation methods.

There have been few bench marking exercises for HRE estimation. In the study (Poucet, 1989), the HRA methods THERP, SLIM, HCR, HEART, Technica Empirica Stia Errori Operatori (TESEO), Absolute Probability Judgment (APJ) and Maintenance Personnel Performance Simulation (MAPPS) were compared. In the paper Boring et al. (2010), some of the observations have been mentioned. There was considerable variability in the estimates obtained from different methods (many order of magnitude difference). The inter method reliability was low. Also, the reliability of the results obtained by different experts from one method was also low. In another paper (Kirwan, 1997), empirical validation of three HRA methods, namely THERP, HEART and Justification of Human Error Data Information (JHEDI) was carried out. The paper Boring et al. (2010) mentions the lesson learnt in this study. It is pointed out that there were difficulties in consistently modeling error of commission in HEART and JHEDI, slips in HEART, diagnostic task in THERP and human machine interface task in THERP. These shortcomings bring home the point that no HRA method is comprehensive in its coverage of human errors and that each method represents strength and weaknesses in terms of its coverage and quantification. For the Cognitive Reliability Error Analysis Method (CREAM) it was noted (Kirwan, 1988) that “these approaches are potentially of most interest to psychologists and others who want to predict the more sophisticated error forms associated with misconceptions, misdiagnosis, etc. They attempt to explore the error forms arising from ‘higher-level’ cognitive behaviours”. There is not much literature which suggests extensive use of CREAM in NPPs. ATHEANA methodology is cumbersome, guidance is complex, costly to implement, uses expert judgment for quantification and hence may be less reliable (HSE, 2009). The document (HSE, 2009), gives a brief summary of 17 HRA methods along with their advantages and disadvantages.

2. HRA methods – a brief overview

The HRA methods Technique for Human Error Rate Prediction (THERP, Swain and Guttman, 1983) and ASEP (Swain, 1987) are the foremost of the task analysis based methods. Both these methods require the analyst to draw an Operator Action Tree (OAT) based on a detailed analysis of the task to be performed. The critical assessment of THERP and ASEP methods brings out the weakness of interpreting crew performance as a sequence of individual tasks. In addition, the use of look up tables for human error probabilities, generated through expert judgment, raises the issue of applicability of those values.

HEART (Williams, 1986) defined a rather limited set of tasks to describe activities within a NPP for use in the PSA. These are called generic tasks types (GTTs). The requirement of selecting out of 38 types of error producing conditions (EPC) in HEART without a close match of description, poses challenges.

The first time reliability curve (TRC) was proposed in the Handbook of Human Reliability (Swain and Guttman, 1983). The basis of the curve was expert judgment. Later with the development of NPP simulators, the simulator based studies led to the development of the Human Cognitive Reliability (HCR) (Hannaman et al., 1984) methodology which proposed that the crew non-response probability could be quantified using the HCR curve. The method proposed the inclusion of performance shaping factors, as well as the Skill, Rule and Knowledge framework for categorizing the crew response. HCR considers PSFs such as operator experience, stress level and quality of operator/plant interface. Application of this model requires thorough assessment of time window available, cognitive processing type and PSFs. This model defines the crew non-response probability as

$$P(t) = \exp\left[-\left\{\left(\left(t/T'_{\mathrm{m}}\right) - B_i\right)/A_i\right\}^{C_i}\right] \tag{1}$$

$$T'_{\mathrm{m}} = T_{\mathrm{m}}*(1+K_1)*(1+K_2)*(1+K_3) \tag{2}$$

t: time available to complete the action; T_{m}: median time taken by crew to complete task; T'_{m}: modified median time for completion of task.

The coefficients K_1, K_2 and K_3 are the PSFs. K_1 refers to operator experience, K_2 refers to stress level and K_3 refers to quality of operator/plant interface. The median time taken by crew is determined under nominal conditions. This is modified using performance shaping factors that are shown in Table 1. Under nominal condition $T'_{\mathrm{m}} = T_{\mathrm{m}}$, depending on the operator experience level, stress intensity during accident condition and quality of man machine interface T'_{m} is modified.

A_i, B_i, C_i: coefficients to identify the TRC for Skill, Rule and Knowledge framework.

These coefficients are shown in Table 2.

In the 1980s, the research attention shifted toward an examination of contextual elements that could trigger cognitive error mechanisms which could lead to unsafe crew actions. ATHEANA (Cooper et al., 1996) was the first major effort to develop a model for human performance based on this new paradigm. The principal premise of ATHEANA is that “plant conditions” and “performance-shaping factors” may produce an “error-forcing context” that could

Table 1
Performance shaping factors (PSFs).

Performance shaping factors	Coefficient
Operator experience (K_1)	
1. Expert, well trained	−0.22
2. Average, knowledge training	0.00
3. Novice, minimum training	0.44
Stress level (K_2)	
1. Situation of grave emergency	0.44
2. Situation of potential emergency	0.28
3. Active, no emergency	0.00
4. Low activity, low vigilance	−0.28
Quality of operator/plant interface (K_3)	−0.22
1. Excellent	0.00
2. Good	0.44
3. Fair	0.78
4. Poor	0.92