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Human reliability analysis of the Tokai-Mura accident through a THERP–CREAM and expert opinion auditing approach ☆

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ABSTRACT

This paper presents a human reliability analysis (HRA) model that allows the incorporation of features related to facility conditions to determine human error probabilities (HEP) used in probabilistic safety analyses of process plants. We present an approach to show the predominance of human factors as an accident cause, as well as existing methodologies for HEP determination and their deficiencies in incorporating socio-technical elements that influence them. Such elements are: inappropriate design, training, procedures, communication, safety culture, management in the production process changes, emergency planning, accident investigation, environmental factors, maintenance workload and human–system interface. A mathematical model is proposed to incorporate these elements taking into account their contribution weights as well as measuring their degree of implementation in the plant. This creates a factor that can modify existing HEPs, giving values that better reflect plant reality. The model was applied to the accident that occurred in 1999 in Tokai-Mura, Japan. The modified HEP was 2 times greater than the nominal HEP. This shows that considering organizational factors thoroughly allows for a more realistic plant behavior modeling in face of abnormal events.

1. Introduction

The increasing globalization of world economy is turning the environment of organizations ever more complex, where scenario changes occur in a dynamic, nonlinear, unpredictable and fast-paced way, requiring organizations to have a continuing need for changes to adapt to new success conditions. Proper management of opportunities and threats created by these scenario changes have come to constitute a key factor for competitiveness and survival of organizations. A great improvement of technological aspects in comparison with human and organizational factors has been observed in recent decades. This mismatch is evident if one looks at accident histories at facilities that handle hazardous technologies, which shows that organizational factors have an increasing importance on accident causes (Hollnagel, 2004).

When compared to technological factors, human and organizational factors are characterized by their multidimensional nature and complexity due to nonlinear interactions that influence their behavior. A variety of quantitative and qualitative methods have been proposed to incorporate these factors into reliability calculations, but not as yet successfully, Papazoglou et al. (2003).

People are the common theme within organizations. They are fundamental components that hold complex systems together. Safe operations rely, among others, on their competence to respond quickly and appropriately to emergency situations. However, humans are fallible: human error has been a contributing factor in all major accidents, Sirrett (2013).

Human reliability analysis techniques, which allow quantification of human error probabilities (HEPs) used in nuclear installations, are THERP (Swain and Guttman, 1983), MERMOS (Bieder et al., 1998), CREAM (Hollnagel, 1998) and ATHEANA (NRC, 2000), in general. These HEPs are also used in quantitative risk analyses in the chemical, petrochemical, and aerospace fields, and in semi-quantitative risk analyses, as, for example, in LOPA (CCPS, 2001) in chemical process industries.

In industries dealing with hazardous technologies one can refer to some regulations that induce them to anticipate this learning,

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Nomenclature

ABIQUIM	Brazilian Association of Chemical Industries
AHP	Analytical Hierarchy Process
ATHEANA	A Technique for Human Event Analysis
CCPS	Center for Chemical Process Safety
CREAM	Cognitive Reliability and Error Analysis Method
CSB	Chemical Safety Board
EF	error factor
HEP	human error probability
HF	human factors
HRA	human reliability analysis
ILO	International Labor Organization
JCO	Tokyo Electric Company
LOPA	Layer of Protection Analysis
MERMOS	Méthode dÉvaluation de Réalisation des Missions Opérateur pour la Sûreté
OGP	International Oil and Gas Producers Association
OSHA	Occupational Safety and Health Administration
THERP	Technique for Human Error Rate Prediction

such as the Seveso II Directive (1996), used in Europe, OSHA regulations (used in the U.S.) and the 174 Resolution of the International Labor Organization (ILO 174). These regulations seek to establish risk quantification in order to offer society a numerical risk acceptability criterion. These risk-based regulations provide figures that allow one to decide whether to go ahead with plant designs.

In this context, one can consider that proposals to quantify human errors should be adapted to the conditions of each facility, for only in the microcosm is it possible to treat nonlinearities that bring complexity to the problem. This path enables to point in advance safety deterioration and the set of factors that are contributing to it.

The aforementioned techniques incorporate modifying factors of human performance to HEPs, which are mostly ergonomic, still without taking into account socio-technical factors relating to individuals and safety management. A thorough discussion on these issues can be found in Alvarenga et al. (2014).

As a way to fill the need for a model that allows the incorporation of contributing socio-technical elements to human error and in this sense help provide more realistic human error probabilities, we propose a model which takes into account influencing factors identified in the oil industry (OGP) and also the experience gained from operational incidents and accidents besides an auditing procedure. These influencing factors are to be taken into account in order to consider new factors that have not yet been considered in human error probability evaluation techniques. Also the interaction of these factors is addressed. The purpose of adding an auditing process is to consider the plant capability to respond to these factors. It is worth mentioning here that an analysis of one of the human errors in the Three Mile Island accident was performed by means of a hybrid THERP–ATHEANA approach in order to shed some light on the application of HRA techniques (Fonseca et al., 2013).

The purpose of this paper is to present the model discussed in the last paragraph. This paper is organized as follows: the proposed model is described in Section 2 and Section 3 presents the case study developed for the accident at the fuel element facility of the Tokyo Electric Company (JCO) in Tokai-Mura, Japan (Furuta et al., 2000). Conclusions reached and recommendations are presented in Section 4.

2. Description of the proposed HEP quantification model

2.1. Introduction

HEP assessment starts by considering a known human reliability technique for obtaining basic HEPs. Two natural candidates are THERP (Swain and Guttman, 1983) and CREAM (Hollnagel, 1998) because among other features, they have quantitative information to start with. However, the effort to adapt these basic HEPs to a given plant presents a series of shortcomings. For example, the performance shaping factors employed in THERP fail to treat many organizational aspects that are relevant, Alvarenga et al. (2014). A similar issue may be found about CREAM common conditions. The US Nuclear Regulatory Commission has issued a set of 16 main performance shaping factors (NRC, 2005, 2006) among which only 3 are of an organizational nature. Likewise, among the 11 common conditions identified in CREAM, only 3 are of an organizational nature, that is, Adequacy of organization, Working conditions, and Number of simultaneous goals. In this sense, alternatives have been sought for in order to modify basic HEPs in a more realistic way.

The foundations of the model proposed in this paper may be found in Papazoglou et al. (2003), Kariuki (2007) and Sousa et al. (2007). Particularly, the model proposed by Kariuki (2007) is the most suitable for understanding the foundations of our model.

The proposed model starts from existing HEPs and introduces factors that allow for reflecting actual plant conditions (Fig. 1). It is seen from Fig. 1 that we start with a reference parameter (the nominal HEP represented by a confidence interval defined by the 5th and the 95th percentiles, in general) and modify it in levels. Notice that two levels may be identified: the first level addresses the assessment of 12 elements influence and it generates Grade 1, which shows the relative importance of an element in relation to the remaining ones.

The second level is a plant-specific level (shaded area in Fig. 1) and it generates two grades, Grade 2 and Grade 3. Grade 2 gives the weight of each factor or element based on external expert opinion and Grade 3 takes into account the incidence weights (that is, operational experience, when available). Notice that each grade gives different attributes that do not overlap.

The auditing process also does not overlap because the purpose of the auditing process is to explicitly unravel the plant state.

Finally an adjusted HEP is obtained by taking into account the three grades and the auditing process.

2.2. Level 1 quantification

The OGP model (OGP, 2005) for the 12 elements displayed in Fig. 2 identifies three domains for human factors: facilities and equipment, people, and management systems. These domains overlap and cannot be separated or removed from the model.

The facilities and equipment domain includes consideration of physical characteristics and work space, design and maintenance of equipment, and reliability.

The people domain includes consideration of individual attributes, skills, perceptions, and factors relating to fitness, stress, and fatigue. Some attributes, such as personality, cannot be changed, while other skills and attributes can. Computers and control