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Analysis of operator human errors in hydrogen refuelling stations: Comparison between human rate assessment techniques

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ABSTRACT

The use of hydrogen as an energy carrier for road transport appears to be an optimal solution for the reduction of greenhouse gas emissions. Nevertheless, the development of this technology depends on the growth and diffusion of production, storage and refuelling infrastructures together with accurate risk analyses to appropriately design the safety and management systems used in these plants. Moreover, to improve safety standards, it is also important to focus attention on the estimation of hazards related to human factors, as this is one of the major causes leading to accidental events, especially in complex industrial technology. The paper reports a case study relevant to operator errors that occur during maintenance procedures on safety venting devices in refuelling station hydrogen storage systems performed using first- and second-generation Human Rate Assessment (HRA) techniques. HEART (Human Error Assessment and Reduction Technique) methodology, a first-generation HRA method, which was modified on the basis of the fuzzy set concept, was employed to evaluate the probability of erroneous actions. The obtained results have been compared with results obtained using CREAM (second-generation) methodology. The critical analyses of the obtained results have also allowed to provide procedural recommendations and suggestions regarding safety equipment and procedures which can be adopted to reduce the risk of accidents.

1. Introduction

The last ten years have observed wildly fluctuating and steadily growing fuel costs, greater environmental awareness and concern about the effects of pollution on health. Among the solutions to the environmental aspects, current European policy and research programs have focused greater attention on the use of hydrogen as zero-emission alternative vehicle fuels. However, there are some economic, technological, structural problems involved; these include:

- The actual high cost of hydrogen production,
- The non-optimised performance of "on-board" hydrogen storage systems,
- The high reactivity of hydrogen,
- The safety required in production, storage and fuelling stages.

Furthermore, a strong incentive will be possible if an adequate number of refuelling stations becomes available for large scale distribution using high safety standards.

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In this field, considering that human errors are the most commonly identified causes of accidents, especially with complex industrial technology, it is also important to perform accurate safety analyses to foresee possible faults related to human factors to reduce the occurrence of accidents to the lowest possible level and minimise the corresponding consequences.

In any technological application, workers contribute in an essential way to maintaining safety by controlling processes, not only during the design phase but also during the operational phase. However, humans can make errors, thereby creating dangerous situations and even accidents. Estimates as to how often human error is the primary causal factor in industrial and transport accidents vary somewhat, but typically range between 50% and 90%.

Within the H2 Incidents database, human error contributing to particular hydrogen incidents is typically due to one or more of the following factors:

- Lack of personnel training on specific equipment, systems and operating scenarios,
- Inadequately training of personnel regarding the properties of hydrogen and the potential consequences of their actions,
- Inattentive and complacent actions by personnel operating hydrogen and related equipment, and
- Personnel not following written procedures.

This finding is confirmed in [1], where accidental events are categorised under five major classes, and 'maintenance' and 'operator error' appear as the 'primary cause' of faults. Moreover, in [2], maintenance and testing phases are noted as being especially vulnerable to human error that can seriously influence system safety. Examples include the insertion of an incorrect component, miscalibration, and failure to align the system back to its operational configuration.

On the basis of the above information, hydrogen technologies should be designed to accomplish two primary objectives: total safety assurance and the minimisation of human errors [3].

Kirwan [4] emphasises that one of the primary goals of human reliability analysis is to provide a means of properly assessing the risks attributable to human error based on the following three overall phases:

- Identification of possible errors,
- Deciding how likely the errors are to occur,
- Enhancing human reliability by reducing the likelihood of this error (Human Error Reduction).

A number of methods and techniques are available with which to perform a structured analysis of human reliability for a specific industrial setting in which an HRA is undertaken.

For hydrogen refuelling risk assessment, expert opinions are usually employed to adjust human error models that are often based on Probabilistic Risk Analysis (PRA), which originated in the Nuclear Industry [5,6]. Any method including accident analysis that seeks to gather expert opinion must be staffed with individuals that are able to understand factors related to any of the wide-ranging fields related to the design and operation of a complex industrial system, and this is not easily feasible when innovative systems are examined. Therefore, HRA are sometimes limited to the identification of human errors without to proceed to occurrence probability evaluations necessary for further quantitative safety studies.

Recently, in this field, our research group has undertaken risk analyses of hydrogen refuelling stations [7]. In this paper, we attempt to highlight the importance of the human errors during maintenance procedures on safety venting devices in refuelling station hydrogen storage systems, which can cause failures. Due to a lack of data regarding hydrogen refuelling plants, not many operating manuals or technical regulations are available; thus we have formulated some hypotheses regarding operator tasks.

Human error assessment has been performed using HEART (Human Error Reduction and Assessment Technique) [8], which is classified as "first-generation" technique, as modified by fuzzy theory. This method proved to be simple and versatile technique for human error evaluations in various safety studies relevant to complex systems [9,10].

The results were compared with those obtained using a second-generation methodology, termed CREAM (the Cognitive Reliability and Error Analysis Method) [11], which has been modified in fuzzy form by other authors, as reported in [12].

The critical analyses of the obtained results have also allowed to provide procedural recommendations and suggestions regarding safety equipment and procedures which can be adopted to reduce the risk of accidents.

2. Description of the safety devices in a refuelling storage unit

The reference plant is a hydrogen power park [13,14] that was designed to provide thermal and electrical power as well as gaseous hydrogen for car refuelling. For more detail, the reader is referred to [14]; only the safety devices used in storage systems are described here. The hydrogen, which is produced in situ, is compressed using a three-stage compressor and stored in three storage vessels at different pressures. The maintenance process relevant to the safety relief devices examined in this paper relate to three storage systems designed for the plant; the components of one of the three hydrogen storage systems, that are necessary to describe operator maintenance tasks, have been reported in Fig. 1.

The storage pipeline is equipped with pressure gauge (PG1) connected to pressure transducer (PT1) and solenoid valve (VS2), which is actuated by a Programmable Logic Controller (PLC). The latter unit is also used to control the major safety functions of the station, including regulation of the storage–dispenser interactions. Each storage vessel is protected by pressure relief devices that ensure that the maximum allowable pressure is not exceeded. Such devices consist of a redundant system provided by a mechanical valve (VM2) and a solenoid valve (a VS3 pilot solenoid valve with manual override), which operate when increasing pressure exceeds the opening pressure and in the event of control system malfunction (Fig. 1). In particular, at 5% of overpressure, the