Papeles del Psicólogo / Psychologist Papers, 2018. Vol. 39(3), pp. 183-190
https://doi.org/10.23923/pap.psicol2018.2869
http://www.papelesdelpsicologo.es
http://www.psychologistpapers.com

HUMAN SAFETY PERFORMANCE IN HIGH RELIABILITY ORGANIZATIONS: THE CASE OF THE NUCLEAR INDUSTRY

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En las últimas décadas, el estudio de la seguridad en organizaciones de alta fiabilidad no ha prestado la suficiente atención al papel de las personas y su contribución a una operación fiable. Debido a ello, la literatura sobre comportamiento humano de seguridad es escasa e inconexa. El presente trabajo integra el conocimiento existente sobre las personas y su comportamiento de seguridad en industrias de alta fiabilidad, más específicamente en la industria nuclear. Para tal fin, se proporciona una revisión de la literatura donde se acota y clarifica el concepto de "desempeño de seguridad", y al mismo tiempo se presentan las últimas investigaciones y modelos sobre el mismo.
Palabras clave: *Alta fiabilidad, Desempeño de seguridad, Gestión de seguridad, Gestión de riesgos, Accidentes.*

Over the last few decades, the study of safety in high reliability organizations has not paid enough attention to the human role and its contribution to a reliable operation. Therefore, the literature about human safety performance is scarce and disjointed. The present paper integrates the existing knowledge on workers' safety performance in high risk industries, specifically in the nuclear industry. In order to do this, we provide a literature review in which the concept of "safety performance" is clarified, and at the same time, we present the most recent research studies and models on this concept.
Key words: High reliability, Safety performance, Safety management, Risk management, Nuclear power plants, A- ccidents.

Today the energy sector faces emerging challenges and economic demands that put at risk the normal and safe operation of nuclear power plants around the world. An example of this is that the deregulation measures of the energy markets have increased the organizational mergers and intensified the competitiveness between companies. This increased competitiveness leads companies to consolidate cost-saving policies, such as the reduction of qualified operating personnel or the outsourcing of certain functions that were previously performed and controlled within the plants and/or companies (Itoigawa & Wilpert, 2005). According to Itoigawa and Wilpert (2005), these measures that deal with the increasing competitiveness can contribute to a considerable loss of work knowledge and skills in the nuclear operation.

In addition, we must bear in mind that the nuclear industry has been composed (and is composed) in its vast majority of professionals in technical disciplines (engineering, mechanics, electronics, physics, etc.), so there is a propensity towards the constant concern for technology as the main source of safety. This usually means the attention and study given to the human factor and its contribution to safety remain in the background, but how important is human behavior really in nuclear power plants? The accidents of Three Mile Island (TMI) and Chernobyl demonstrated that the human system is of vital importance, since it has the capacity to determine both a safe operation and an accident with serious consequences. Later, the Fukushima Daiichi accident made it clear that once an accident has occurred (in this case the primary causes were external), human performance is essential in order to deal with it and contain it as much as possible (Martínez-Córcoles, 2017). Thus, human behavior is of vital importance both in avoiding actions that may trigger undesirable effects, and in demonstrating organizational resilience once the event has inevitably been triggered.

Unfortunately, studies on human safety performance in the nuclear sector are scarce and their results disconnected. Therefore, the objective of this paper is to provide a review of the literature on human safety behavior in the nuclear industry. To do this, in the following sections, we will provide an introduction to high reliability organizations and their characteristics, we will give a tour of the literature concerning the study of safety performance in the nuclear industry, and finally we will expose the most important contributions of this literature, as well as future lines of research.

HIGH RELIABILITY ORGANIZATIONS

The rapid development of new technologies has greatly changed the nature of work, increasing the complexity of systems in a wide variety of organizations (Hendrick, 1991).

Received: 9 marzo 2018 - Accepted: 30 abril 2018
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Among these complex systems are those defined as "high risk" or "high reliability", cataloged in this way because an accident caused within them can lead to a human and/or environmental catastrophe of incalculable consequences. Examples of this type of organization are nuclear power plants, chemical plants, oil companies, or the commercial aviation industry, among others.

Given the complexity in their technology and the potential inherent risks, these organizations require an appropriate fit between the technical and human subsystems (Perrow, 1984), which represents a major challenge for the study of safety. That is, not only is it possible that an accident could be caused exclusively due to the failure of technology or the cause could be solely human error, but also the interaction between technology and people can lead to undesirable events.

Research on safety in complex socio-technical systems has progressed through two predominant and polarized trends. The first is known as the Normal Accident Theory, proposed by Charles Perrow (1984) after the Three Mile Island nuclear accident (TMI) in 1979. The basic argument of this approach is that the complexity of the technologies of these organizations, as well as the close and complex interdependence between the technology and humans, lead to unpredictable interactions and results, causing unavoidable or "normal" accidents. The second is the approach known as the Theory of High Reliability Organizations (La Porte, 1996; Roberts, 1990, 1993; Rochlin, 1993) which argues that organizations can avoid accidents and can become highly reliable by creating appropriate management practices. While both perspectives (as well as the debate between them) have been tremendously useful in understanding how these organizations manage safety, their scope of study has been limited to general organizational management practices, and therefore, they have largely ignored the more specific and detailed study of human safety performance. The following section takes us further into the nuclear industry, given the importance of people's performance in maintaining a reliable operation despite the inevitable complexity and volatility of the power plants.

THE NUCLEAR INDUSTRY AND THE ROLE OF PEOPLE

According to Frischknecht (2005), the development of the nuclear industry can be divided into three distinct stages: the technological phase, the ergonomic and human performance phase, and the safety culture phase.

The technological phase

Nuclear technology began with the first controlled nuclear fission in Chicago in 1942. From that moment, specialized engineers began to create chain fission reactions, taking the concept to an industrial level. Technology and the technical aspects were used to maintain the nuclear process at the necessary level of safety and reliability. People were trained to control the process and to intervene in case of emergency. They were expected to adapt to the operating process of the reaction, although they were not considered at any time to be part of the system but rather support.

Ergonomics and human performance phase

The TMI nuclear accident in 1979 raised doubts about the human role in the nuclear generation process. In this accident, the reduced human (mental) capacity to respond under stressful situations was proven. Thus, the ergonomics of the control rooms became a matter of great importance for scholars and professionals.

Different supports for the operator were introduced, such as parameter visualization systems, and the ergonomics related to the procedures were examined and improved. The aforementioned accident also revealed the tremendous influence of the operators' knowledge on the safety level of the plant. Thus, the facilities improved the training during the following years, constructing simulators identical to the control rooms as a basic instrument in the learning and training of the operators.

Given that in those years the nuclear industry was dominated by engineers, it was these professionals who determined what the human limitations were. Their views formed the basis for improving the safety of the plants. From the point of view of an engineer, the absence of faults or errors was interpreted as an indicator of quality and safety and, therefore, the prevention of technical failures and human errors improved the reliability and safety of the plants. Therefore, the investigation of undesired events (in order to avoid them) became an important aspect, and analysis tools were developed with special emphasis on the evaluation of events caused by human error.

In this way, operators were considered as components of the system, which could act correctly or fail. Thus, the analysis of human reliability emerged as a new discipline to predict the probability of human error. In this phase, the importance of people was recognized in the nuclear generation process, even though they were considered as weak elements of the system.

Safety culture phase

The Chernobyl accident in 1986 revealed that not only the performance of individuals contributes to maintaining safety in the nuclear industry. The influence of the plants, of a whole set of organizational factors, on the people and their resulting attitudes, was identified as a key factor for safety.

The concept of "safety culture" was introduced as the headline of a post-Chernobyl meeting by the International Atomic Energy Agency (IAEA) (more specifically by the nuclear safety monitoring group or "INSAG"), and was developed two years later (1988). Although the accident was caused mainly by human actions influenced by organizational constraints, it was still the engineers who mainly discussed the accident. Therefore, it was they who applied the term "safety culture" to the nuclear industry, defining the concept and making the first assessment attempt in 1991 (INSAG, 1991). Thus, the IAEA took the initiative to develop the concept and its evaluation through the creation of a specialized group for the evaluation of safety culture in plants.

From 1995 to today, the concern for the study of safety culture, as well as its assessment in plants all over the world has grown rapidly, even being considered the cornerstone around which all human safety performance in the plant revolves. According to theorists and professionals of the applied world, in order for power plant employees to behave in a safe manner, it is necessary to create a safety culture that instills certain values and beliefs in the workers (for example, the value of safety having absolute priority above any other aspect). In this way the aim is that over time these values will take root in each of the employees to achieve a safe performance in any task or situation.

Current situation

The two nuclear accidents mentioned so far (TMI and Chernobyl) proved that the nuclear catastrophe is a real possibility. Since Chernobyl, there has been intense international collaboration between operators (through the World Association of Nuclear Operators) and between regulatory bodies (through the IAEA and the Nuclear Energy Agency), knowing that another nuclear accident is possible. After the Chernobyl accident, the sensitivity regarding the potential risks increased considerably, and the technological safety systems were improved gradually. The emphasis on safety excellence was possibly what marked the next 25 years after that catastrophe, with no serious accidents in the industry.

However, the Fukushima Daiichi accident in 2011 left the nuclear industry shocked again, since on this occasion the primary cause of the disaster was external to the organization. This time the trigger was not a technological failure or a human error, but an external natural event (a huge tsunami caused by a previous earthquake that hit the plant). However, although it was not anticipated that a wave of such magnitude could enter the coast where the installation was located, the subsequent events were not anticipated either, such as the prolonged lack of electricity autonomy when the plant no longer had external power supply and the diesel engines lost the ability to function properly (due to flooding); or the venting of explosive gases into rooms of a small size.

Thus, to sum up the three largest nuclear accidents in history, we can argue that (1) the accident of TMI (1979) demonstrated the important role played by human performance (human behavior) in safety; (2) the Chernobyl accident (1986) proved the importance of creating and maintaining a safety culture that provides workers with safe behavior; and (3) in the Fukushima accident (2011), the importance of human anticipation of potential problematic and unwanted scenarios was revealed, as well as organizational resilience and restraint capacity once the accident had occurred.

Engineering is a fundamental aspect, but undoubtedly it is not everything when we talk about safety in the nuclear industry (Wilpert, 2007). Regardless of the technical causes in the accidents that we have just mentioned (the design of the facilities, the state of the safety and emergency equipment, etc.), we can see that the performance of the workers is of vital importance in maintaining a safe operation (both to prevent accidents, and to react to them). Therefore, if people are so extremely important in ensuring a safe operation, the importance given to them and the underlying human and social processes should be comparable to that given to the technology. It is precisely this reason that drives this work to combine knowledge about people and their safety performance in highly reliable industries, more specifically in the nuclear industry.

WORK PERFORMANCE AND SAFETY PERFORMANCE

According to the renowned role theory proposed by Katz and Kahn (1966), the performance of workers can be of two different types. On the one hand, the worker's behaviors can be intra-role, that is, the organization expects the worker to behave in a specific way with respect to his role (depending on his position) and the worker perceives these expectations about what he must do following that defined role. According to Van Dyne, Cummings and Parks, (1995) intra-role behaviors are "those that are required or expected as part of the execution of the duties and responsibilities of the assigned role" (p. 222). On the other hand, extra-role behaviors are those that are outside of what the organization expects the workers to do, given the exclusive functions of their role or position, but that the workers also do, contributing to the organization's objectives.

Katz and Kahn's famous role theory was the starting point from which the different theories of work performance have shown a broad consensus in defining two constructs equivalent to those cited in the previous paragraph. These constructs are task performance and contextual performance (Borman & Motowidlo, 1993; Motowidlo & Van Scotter, 1994). Task performance can be defined as the effectiveness with which workers carry out activities that contribute to the most technical and central part of the organization, either directly, implementing behaviors as part of the technical process, or indirectly, promoting these by providing materials or services (Borman & Motowidlo, 1993). To give an example, cases of these behaviors for firefighters would be carrying out rescue operations, guiding rescue operations, or applying fire ventilation procedures. On the contrary, contextual performance is defined as the behaviors or activities that contribute to the social, organizational, and psychological aspects of the organization, and that serve as a catalyst for the activities related to the more technical tasks and their processes. These behaviors are of a voluntary nature and considered as informal, and include the behaviors that are not an exclusive part of the work or tasks of the position, such as helping and cooperating with other members of the organization to achieve the objectives that it sets.

This duality (task and contextual performance) continues to be the most used in performance models. However, some studies are critical, saying that performance cannot simply be reduced to behaviors that contribute to achieving the objectives of the organization, but should also be extended to those behaviors that are negative for achieving them and which also occur in the daily life of organizations (e.g., Griffin and López, 2005). These are what are known as "counterproductive behaviors". Anti-social behavior, deviations, and even physical or verbal violence are some examples of these behaviors (Griffin & López, 2005). Often these behaviors have been studied in isolation, without being included within the more global models that complete the set of behaviors that comprise performance. However, there are some exceptions. Specifically, in a review by Rotundo and Sackett (2002) where studies of counterproductive behaviors were taken into account, it was shown that the performance model was not only formed by those behaviors that were beneficial for the company, but also by those that went against its objectives. Thus, they determined a model with three constructs, which were: "task performance", "citizenship performance", and "counterproductive behaviors", extending the dual model of Borman and Motowidlo. According to Robinson and Bennett (1995), counterproductive behaviors are those voluntary behaviors that harm the welfare and/or good functioning of the organization.

Within the study of safety, the term *safety performance* has often been used to refer indistinctly to two completely different concepts. On the one hand, it refers to safety outcomes, which have been treated as safety performance, such as the number of accidents or the number of injuries per year. On the other hand, it refers to the behaviors of individuals related to safety (e.g., Burke, Sarpy, Tesluk, & Smith-Crowe, 2002), or actual safety performance. However, distinguishing between behaviors related to safety (safety performance) and outcomes is extremely important, because the antecedents of each of these can be completely different. In fact, numerous studies show how safety-related behaviors precede the outcomes (Christian, Bradley, Wallace, & Burke, 2009). In this paper we consider, as do many other authors (e.g., Zohar, 2000, 2002), safety performance to be the set of behaviors of individuals that contribute to the achievement of good results in safety, and therefore, a construct independent of safety outcomes.

There are two main advantages when measuring safety performance instead of outcomes: (1) Conceptualizing safety performance as individual behaviors provides researchers with a measurable criterion more closely related to psychological factors than accidents or the number of injuries (Christian et al., 2009), which is important if we wish to be able to predict individual behaviors. (2) Safety performance can be predicted more accurately than the outcomes, which usually have a low average (especially in high reliability organizations) and an asymmetric distribution (Zohar, 2000). In a similar way to the general job performance, safety performance behavior can be operationalized by the frequency with which employees participate in these behaviors (Burke et al., 2002; Parker & Turner, 2002).

One of the most widely used safety performance models is that of Griffin and Neal (2000), which is based on the model of Borman and Motowidlo (1993) mentioned above. According to these authors, the two constructs defined in the Borman and Motowidlo model can be used to differentiate the types of safety performance as well. In this way, and based on the definitions of both constructs, these authors used the term "safety compliance" as an equivalent of "task performance", defining it as those activities central to safety that must be carried out by individuals to maintain the workplace in a safe condition. These behaviors include following safety procedures and standards, as well as using individual protection equipment. "Safety participation" is the counterpart to "contextual performance" and refers to behaviors such as participating in safety-related activities voluntarily or attending meetings dealing with issues related to the safety of the organization. These behaviors do not directly contribute to safety in the workplace, but they help develop an environment where safety becomes a priority. Perhaps the fact that this two-dimensional model has been one of the most used in terms of safety is precisely due to the robust theoretical basis from general organizational performance that supports it.

However, as is the case with general work performance models, safety research has obviated counterproductive behaviors in more global models such as the one just mentioned. If we look closely at previous empirical studies in this field, we can observe that, for example, risky behaviors or "deviance" have been variables studied, but in isolation from any other type of performance (without being included in broader models that consider other types of behavior) (Griffin & López, 2005). In line with the approach of Rotundo and Sackett (2002), Martínez-Córcoles, Gracia, Tomás, Peiró, & Schöbel, (2013) suggested for the first time that a safety performance model does not cover all important behaviors if it only considers the behaviors that promote safety, but not those that may be detrimental to it, which are sufficiently dangerous to cause a catastrophe of great magnitude. These behaviors are called "risky behaviors" and are defined as the behaviors that increase the probability of an accident occurring (Martínez-Córcoles & Stephanou, 2017). Some examples of these behaviors are deviations from fixed organizational behavior (e.g., by procedures, regulations and expectations), or simplifications and shortcuts in the operation.

Thus, comparing multiple confirmatory factor analyses, Martínez-Córcoles et al. (2013) tested a safety performance model, which consists of the following three constructs: safety compliance, safety participation, and risky behaviors (Figure 1). Each of these three types of performance is described in more detail below.

Safety compliance

Safety compliance is extremely important in the nuclear industry. The potential danger of this industry is such that the regulations and procedures guide virtually any activity carried out by workers. Complying with these regulations, as well as with the procedures is extremely important, since it guarantees the safety levels required by the organization and by the different regulatory bodies. The IAEA considers safety compliance the basis for achieving good safety outcomes (INSAG-15, 2002).

Although nuclear plants take into account and work on compliance behaviors (through safety culture audits, training seminars, etc.), this has been barely studied. Some researchers note that the main source of adequate safety compliance is the level of formalization of procedures (e.g. Park & Jung, 2003; Reason, 2008), as well as the management and leadership (e.g., Dien, 1998; Gauthereau & Hollnagel, 2005). However, no empirical study has explored the causes of compliance in this sector, to determine with some assurance how compliance can be fostered, with the exception of two investigations carried out in the Spanish nuclear industry. In these two studies, the important role of empowering leadership is demonstrated (Martínez-Córcoles et al., 2013) as well as the formalization of procedures as complementary sources of expectations that clarify the role of workers and consequently increase their safety compliance (Martínez- Córcoles et al., 2014).

Safety participation

Some studies indicate that even if safety compliance is exemplary in the plant, it does not seem to be enough to guarantee a high level of safety (Dien, 1998). In other words, strict compliance does not guarantee that accidents will not occur or be caused by human performance. In high reliability organizations, it is necessary for workers to remain alert and be aware of the possible risks and dangers (Wahlström, 2005). Conscious and continuous surveillance is an elementary condition in order to be able to identify and correct latent errors or hidden problems in complex systems (such as socio-technical ones) that have the capacity to incubate and finally produce accidents (Reason, 1990). However, far from inciting these aspects, daily compliance tends towards the routinization of behaviors, and therefore their automation.

Here lies the danger of what are known as "strong intrusions of habits" (Reason, 2008). Precisely, one way to enhance and/or maintain this alertness or awareness is to participate in safety meetings, exchange points of view, discuss safety issues with colleagues and, ultimately, develop a broader individual and group perspective of what safety is and what it encompasses and includes (Richter, 2003; Naevestad, 2008). To do this, it is important that the workers themselves are interested in attending and learning about safety, although this motivation can be enhanced from external sources (such as direct leadership). Safety participation is an elementary behavior in high reliability organizations, and should complement other behaviors such as safety compliance (Zohar, 2008).

Risky behaviors

Risky behaviors are those behaviors that at the time they are performed are not perceived as potentially dangerous enough to create a severe accident (since they do not have the capacity to trigger a visible and immediate adverse effect). However, given the complexity of these organizations, these behaviors (a priori perceived as harmless) can lead to a series of successive events (or chain of events) that culminate in a catastrophe. These behaviors described as "risky" usually occur when the production goal is very high and surpasses that of safety, since the workers perceive that the organization (e.g., their bosses) focuses on production, leaving behind some recommendations of "minor" safety that prevent working quickly and efficiently (Zohar, 2008). In other words, when priority is given to

FIGURE 1
THE THREE-DIMENSIONAL CONSTRUCT OF SAFETY PERFORMANCE BY MARTÍNEZ-CÓRCOLES ET AL., (2013

production objectives (over safety objectives) strict compliance with safety procedures is conceived, over time, as an inconvenience to performing the task on time. For example, not performing the STAR (Stop-Think-Act-Review) technique in the checking of a valve does not appear to pose a risk to someone with years of experience in maintaining those same valves. If we add to this a focus on production (normally at the expense of safety), this technique would mean a delay in solving the problem, and therefore the increased likelihood of a risky behavior (not carrying out the aforementioned safety procedure).

The vast majority of accidents and incidents in high reliability industries are attributed to risky behavior (Hollnagel, 1993; HSE, 2002), including the nuclear industry, where given their potential danger, these behaviors must be minimized.

DISCUSSION AND FUTURE LINES OF RESEARCH

The present work delimits and clarifies the concept of "safety performance" through an exhaustive review of the literature related to human safety performance in high reliability organizations, and more specifically in the nuclear industry. As previously stated, the most important advance in the study of safety performance in recent years is the extension of the model of Griffin and Neal (2000) to a three-dimensional model that includes the behaviors that pose a risk to safety in plants, proposed by Martínez-Córcoles et al., (2013). The addition of risky behaviors suggests that the application of this model may focus on counterproductive safety behaviors that were not previously identified as such. In this case, the model responds to an organization and management based on awareness and the early detection of any signal or act that could lead to imminent and serious consequences (Weick & Sutcliffe, 2007). This awareness-based management is the cornerstone on which the reliable functioning of this type of organization rests. So, the use of this performance model in the study of awareness-based management could be extremely important in answering emerging questions in empirical safety research, such as what is the real influence of such management on workers' safety performance. Although this new three-factor model is still recent, it has already inspired studies in other high reliability organizations located in different countries, as in the case of the Hellenic military special forces, where the three types of performance were also identified through confirmatory factor analyses (Martínez-Córcoles & Stephanou, 2017).

This literature review presents two theoretical implications of relevance. First, it offers more specific knowledge about the role of people and their contribution to safety in high reliability organizations. Although it is true that there is abundant literature on safety management in this type of organization, it is mainly based on broad theoretical and abstract organizational management models (e.g., Perrow, 1984; Roberts, 1990; Weick & Sutcliffe, 2007; Leveson, 2004) that overlook the study of individual safety performance. As far as we know, this review is the first to collect and integrate the literature that analyzes individual safety performance in high reliability organizations, specifically in the nuclear field. We believe that this review will result in future empirical studies that validate the most recent safety performance models discussed here, or that investigate the most important triggers of each of these types of behavior. Secondly, this paper gives a broader definition to the concept of "risky behaviors". While previous research has defined unsafe or risky behaviors exclusively as those that violate or fail to comply with safety procedures and standards, here they are defined not only as these behaviors, but also as the behaviors that do not involve a violation or deviation from the procedures but that increase the probability of an accident occurring (for example, ignoring safety recommendations that, while not registered in the safety procedures or regulations, involve a risk if not carried out). It would be especially advisable for future studies that include the variable "risky behavior" in the nuclear sector to take into account this broader definition in order to cover the behaviors that pose a risk, however harmless they may seem in principle (e.g., performance simplifications or standardized shortcuts). On a more practical level, this review offers a conceptualization of tangible safety performance and easy access for the professional, regardless of their academic and/or professional background. The aim is for professionals of the sector to consider the great importance of human behavior in plant safety, as well as to evaluate the most recent performance models for evaluative, training or regulatory purposes. For example, the three-dimensional model offers a reliable reference framework on which power plants can base a large part of their people management practices (selection, training, performance evaluation, etc.), guiding them towards safer behavior. Likewise, regulatory bodies could take this model into account when carrying out their audits and controls.

Although it is true that the study of safety performance is developing progressively, there are some important limitations that future investigations will have to overcome. In the first place, the entire review carried out in this work concerns the safety performance that has been studied up to the present day, which is mostly based on perceived—and therefore subjective—performance. Future lines of research should consider objective measurements based on the three recently validated constructs, to avoid the biases inherent to self-report measures such as social desirability or inflated responses. Likewise, it is worth noting the need for the three-dimensional safety performance model to be validated in other sectors considered to be highly reliable, such as commercial aviation, oil platforms, or healthcare. Although there is still a long way to go in the study of safety performance, there is already a growing academic interest in this line of research. The authors of this work hope that this review will provide a starting point for researchers interested in starting new lines of research on human performance in high reliability organizations.

CONFLICT OF INTERESTS

The author declares that he has no conflict of interest with regard to this article.

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