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Original Article

Development of a Leading Performance Indicator from Operational Experience and Resilience in a Nuclear Power Plant

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A B S T R A C T

The development of operational performance indicators is of utmost importance for nuclear power plants, since they measure, track, and trend plant operation. Leading indicators are ideal for reducing the likelihood of consequential events. This paper describes the operational data analysis of the information contained in the Corrective Action Program. The methodology considers human error and organizational factors because of their large contribution to consequential events. The results include a tool developed from the data to be used for the identification, prediction, and reduction of the likelihood of significant consequential events. This tool is based on the resilience curve that was built from the plant's operational data. The stress is described by the number of unresolved condition reports. The strain is represented by the number of preventive maintenance tasks and other periodic work activities (i.e., baseline activities), as well as, closing open corrective actions assigned to different departments to resolve the condition reports (i.e., corrective action workload). Beyond the identified resilience threshold, the stress exceeds the station's ability to operate successfully and there is an increased likelihood that a consequential event will occur. A performance indicator is proposed to reduce the likelihood of consequential events at nuclear power plants.

1. Introduction

Every nuclear power station is subject to daily organizational stresses, which result from the cumulative strain of routine operation, maintaining regulatory and operating requirements, and supporting long-term reliable operations. In addition, operational conditions are periodically changed to accommodate safe refueling, perform shutdown maintenance activities, and restart for another cycle. The impact of these strains varies depending upon the age of the plant.

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One must also consider unexpected operational events that result in work that goes beyond normal plant operations, regulatory compliance, and typical maintenance activities. These conditions result in periods of time when individual and organizational workloads increase significantly, raising the likelihood of errors, which in turn, further increase personnel workloads.

"Safety culture" emphasizes the importance of developing and maintaining a strong Problem Identification and Resolution Program [1], typically referred to as a Corrective Action Program (CAP) where all incidents, risk significant or not, are to be reported. The term "safety culture" was first used in INSAG's 1988 "Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident," [2] where it is described as "that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance". All nuclear power stations in the United States have a Problem Identification and Resolution Program as required by regulation.

A plant's CAP is provided to employees, who use it to identify problems or issues and to record them in a problem report, formally known as a condition report (CR). The events that trigger these reports serve as sources of organizational stress, as they represent additional scopes of work beyond those required for maintaining regulatory compliance and reliable plant operation. Increasing numbers of CRs accompanied by CRs with high severity levels indicate that organizational resilience levels are being exceeded. Here, we define resilience as the intrinsic ability of an organization to adjust its functioning prior to, during, or following changes and disturbances, in order to sustain required operations for the current conditions of the plant [3].

Some condition reporting programs are considered "low-level," as the threshold required for generating a CR is very minor (e.g., editorial errors in procedures or minor errors in design drawings). Low-level CR programs are characterized by having high levels of granularity as criteria for the identification of a situation requiring the generation of a CR (i.e., thousands of items are identified in a single year covering virtually all plant organizations). Alternatively, some condition reporting programs are considered to be "high-level," as the generation of a CR must meet a certain, high criteria (e.g., only plant hardware issues are considered). Generally, most United States plants are characterized as low-level condition reporting programs, such that each typically generates in excess of 10,000 CRs each year.

The fact that even minor incidents reported in low-level condition reporting programs can combine with others and cause an accident brings forward the concept of high reliability organizations (HROs), which include nuclear power generation plants, naval aircraft carriers, air traffic control systems, and space shuttles. Studies of HROs have challenged the postulations of Perrow's Normal Accident Theory [4], in which he insists that "normal" or system accidents are inevitable in extremely complex systems. He states that given the characteristics of the system involved, multiple failures that interact with each other will occur, despite efforts to avoid them. He continues to say that operator error is a very common problem, many failures relate to organizations rather than technology, and big accidents almost always have very small beginnings. Such events appear trivial to begin with before unpredictably cascading through the system to create a large event with severe consequences.

HROs, and specifically nuclear power plants (NPPs), are complex, but have nonetheless maintained exceptional safety records over a long period of time. According to Weick et al [5], HROs are learning organizations characterized by a set of cognitive practices that enable people to work safely and eventually create mindfulness and reliability. These practices involve constantly tracking and investigating small errors, resisting oversimplification, sensitivity towards current operations, and committing to resilience.

HRO research can be said to represent a focal shift in safety research, from a focus on failure to a focus on success. The HRO perspective represents a valuable addition to safety research, and we believe that combining the HRO perspective with data that is readily available, specifically from the CRs contained in the CAP database, provides the necessary elements to produce a resilience curve and an associated resilience threshold. This can be applied at NPPs in order to identify areas where human errors are more likely to result in consequential events, to reduce human error rates, to consider organizational interaction factors, and to develop a leading performance indicator.

The application of resilience engineering is relatively new to the nuclear industry, but it has been used in general aviation, offshore oil and gas production, safety science, and healthcare, among others, and it has provided a substantial body of knowledge and experience [6–10]. In particular, Woods et al [10] compared the demand-stretch model of an organization with the stress–strain curve and resilience property from materials science. This prior work is largely qualitative, whereas here we present a quantitative application.

Section 2 describes the data used. Section 3 identifies the sources of stress and strain and presents the methodology used to develop the resilience model. Section 4 presents the resulting organizational resilience curve and threshold. Section 5 shows the application of the resilience threshold to develop a leading performance indicator to predict situations where the likelihood of consequential events is increased. Section 6 contains the conclusions and describes future work.

2. NPP operational data

We propose the use of the CAP database to evaluate human and organizational performance. Other studies have examined licensee event reports (LERs) to evaluate human performance, types of events, etc. [11–13]. These studies provide valuable ways of looking at the historical events. We believe that the inclusion of all plant specific events (LERs plus all the other events reported in the CRs) increases the statistical validity of the data and enables the specific and detailed study of a plant's operating experience and organizational behaviors.

In this study, the CAP database from an operating plant was analyzed to test the database's ability to yield measurable