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Quantification of Human Performance Through
the Use of Nuclear-Power-Plant Experience

Robert E. Hall, Deputy Head
Engineering & Risk Assessment Division
Brookhaven National Laboratory
Upton, New York 11973

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ABSTRACT

There is wide agreement throughout the commercial nuclear industry that there is a severe shortage of data on man-machine success or failure rates. At the same time, the need to adequately integrate human performance and system's analysis in the evaluation of nuclear power plant availability and safety is recognized as a dominant need. Therefore, if we are to successfully address the industry's current requirements, we must optimize the use of all existing data. This paper discusses the problem and suggests useful ways of utilizing available nuclear data and presents a conceptual format to better collect actuarial data on the most critical, from a safety perspective, aspects of the man-machine interface in a nuclear power plant.

Key Words: Man-machine data, human performance data, reliability, and human error.

INTRODUCTION

Recently the commercial nuclear power industry has experienced an increase in the application of human factors engineering to the design, operation, testing and maintenance of the U.S. Nuclear Regulatory Commission (USNRC) facilities. This rapid growth has brought with it the increased need to utilize available human performance information to help in the evaluation of the man-machine interface and its effects on both availability as well as safety of the power reactor. As future plants are designed and as current plants are modified based on human factors reviews, the use of actuarial type data to set the baseline of past performance and predict future performance of the system, which includes the human, becomes the dominant need of the industry. It will be the purpose of this paper to discuss the use of nuclear power plant operational data in this review arena along with their inherent short falls.

In addition to focusing the evaluations of design changes, the use of data also is necessary if we hope to quantify human performance in a probabilistic risk assessment (PRA). It has been pointed out by the President's Commission on Three Mile Island⁽¹⁾ that the human can be a dominant contributor to the success or failure of the nuclear

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system. Mr. Robert M. Bernero, Director of the USNRC Division of Risk Analysis, stated at the 1981 IEEE Standards Workshop on Human Factors and Nuclear Safety that approximately 50% of the risk to the public is due to human error.⁽²⁾ In this case, the man-machine failure of interest would be inadvertent releases of fission products to the biosphere. Due to the potential unacceptable consequences of such an event, PRA's are by necessity concentrating, quite heavily, on the quantification of human error. Since the direction of the USNRC is apparently moving towards an increased use of PRA results in the licensing arena (i.e., the proposed safety goals,⁽³⁾ as well as the upcoming National Reliability Evaluation Program (NREP)), the use of generic human performance data as well as, where practical, plant specific information becomes increasingly important. Throughout this paper the author will be discussing the concept of quantitative human performance analysis. It should be noted that this approach does not necessarily mean an absolute numerical value on a specific individual's performance. Instead, what the author is specifying is a quantification or in some cases a semi-qualitative evaluation to allow the analyst to relatively rank the probability of human action given a set of input variables. It is important to note that in this relative type of analysis the precision of the input data on performance does not necessarily have to be high. What is needed is high resolutions and repeatability of the information. Only in this way can design tradeoffs be adequately performed and can PRAs be utilized effectively in optimizing plant availability as well as public safety. The remainder of this report will address the type of data needed in an analysis of a high consequence/low probability event. Available data sources will be discussed further with an emphasis on interim ways to extract actual operating information. Based on current industry needs along with the limited available information, conclusions will be drawn as to the usefulness of actuarial data as applied to present modeling capabilities.

APPLICATIONS OF DATA

The application of data to the evaluation of man-machine interfaces and their ultimate affects on plant response in off normal conditions should be reviewed in light of a simple model. Once a model is developed that shows the interfaces between each of the data needs, the analyst can move forward in applying the information in the high consequence/low probability area. It should be noted that the author considers the low probability event by definition to be of rare occurrence; and, therefore, concludes that no current nor practical near-future actuarial data can be directly available to the industry without the use of an interfacing model. Given this premise, we can move forth with developing a basic data model that will show the level and needs of information in a predictive analysis.

If we are to collect and utilize data we must first define what is meant by "Error." When looking at human performance in a highly technological system such as a nuclear power plant, we can divide the types of errors into three categories. These categories are baselined to

the review of the safety and availability impact of the depicted human actions through the use of man-machine consequence sensitivity studies. A detailed explanation of this approach can be found in Ref. 4. In this manner, data in the areas of most concern to the nuclear power industry can be selected for further analysis. The three categories that are recommended follow fairly closely those discussed during the 1981 IEEE Standards Workshop on Human Factors and Nuclear Safety⁽²⁾ and are shown in Figure 1.

Figure 1. Definition of Human Error

The procedural based actions can be described as those events that are fairly well documented in standard procedures and tech specs and are performed by the operators or maintenance personnel on a task by task basis with discrete manipulations of equipment. In this level the importance of the written procedure dominates human performance. However, due to the high levels of redundancies built into current nuclear power plants, the single procedural type error performed on a component of the system does not generally dominate. Only when we see multiple errors performed by the human in a sequential fashion do we push the procedural type of error to the range that can in fact affect core integrity. It is these multiple errors that are of higher importance, based on plant response, as compared to procedural errors as defined here.

Lastly and potentially of greatest interest but the most difficult to collect data on, are the top level human errors that occur because of an incorrect decision. These decision, cognitive, errors which occur in the most part by a misdiagnosis of an off-normal event within the power station. Current experience in the nuclear industry can support the conclusion that it is this cognitive type of error that can directly impact core performance and eventually the release of fission products to the environment. This type usually includes group decisions over extended periods of time as compared to the singular procedural error. It is this time-reliability relationship that has the future potential to allow us to evaluate cognitive errors independently from procedural. As an illustrative example, the author poses the following:

Given a severe off-normal condition within the power station, the operator⁽⁵⁾ must first review those indicators at his disposal and then diagnose the problem with the facility. If, at this level, the diagnosis is in error, then all subsequent actions based on procedures can be also in error; even though they are correct as referenced to the diagnosis to the problem. In this fashion, from the initial actions of the human to bring the unusual occurrences to a closure, the multiple levels of redundancies and diversities of the station can and most probably will be violated.

If on the other hand, given the same occurrence and the diagnosis is correct but in performing the normal procedural task the individual makes multiple errors, the same systematic consequences may occur.

If the individual⁽⁵⁾ diagnoses the problem correctly and does not make multiple errors, but in turn makes a procedural error, the potential of removing all redundancies and diversities from the system is highly unlikely and the consequences are limited. It is therefore the author's opinion that the need for operational information at the present time lie within the cognitive or decision making as well as the multiple error level. This does not say that data on procedural type responses is not of use, since, through modeling efforts (see Ref. 5), we can sometimes extrapolate the single events. It should be noted, however, that the application of such a model by necessity introduces even greater uncertainties into the results.

DATA SOURCES

This paper discusses, as its title suggests, operating information as extracted from the Licensee Event Report (LER) system currently maintained by the USNRC. The reader should note, however, that in addition to this actuarial data, sources of derived information are available. As most individuals in the nuclear industry know, one of the most complete sources of procedural based information can be found in NUREG/CR-1278.⁽⁶⁾ In this case, individual errors are recorded as derived from expert opinion based principally on military experience. In addition, the concept of expert opinion and the use of information from the expert opinion approach to develop generic data has been carried forward in two recent experiments. The first conducted by D.E. Embrey⁽⁷⁾ attempts to utilize expert opinion to develop specific performance shaping factors (PSFs) that can be used to evaluate human performance at the procedural multi-failure and potentially cognitive area. It should be noted that this particular experiment is still in its formative stages but holds great promise for the collection of meaningful information in the near future. The second application was conducted on April 14&15, 1982. In this attempt at collecting expert opinion information on failure rates which includes both component failure as well as human error, under the sponsorship of the NRC, EG&G Idaho, Inc. convened individuals from within the nuclear industry on a panel. In the area of human error, for the first time screening values were developed which have the potential applicability in both cognitive as well as procedural calculations. The use of such screening values when applied correctly can in fact reduce the number of human

events to those that are of major importance, (i.e., impact availability and/or safety) and thereby focus the need for the detailed analysis. This concept of screening is enveloped by our definition of error tied to consequences.

Another potential valuable source of data comes from the experimental use of simulation devices. These simulators can be, depending on the information being collected, either of a full scope such as present day licensed operator training machines, or part task devices. To date there has been an evolving interest in the applicability of plant specific training machines to the collection of performance data of power plant operators. This approach holds promise for the future in expanding our limited data base. However, at present the use of such simulators is, by design, limited. Since the training simulators have been constructed on a plant specific level for training the control room operator in a relatively limited scope of events, the use of the data extracted from training sessions should be used only at the procedural and multiple error level. Since the training simulator has not been designed to mathematically deal, in a correct fashion, with all transient conditions, we must be skeptical of human response data in the regime of cognitive behavior since this is beyond the design scope of the training machine. Due to this, the development of simulators with advanced plant models are needed if we are to fully take advantage of simulation techniques of data collection.

This now brings us to the area of use of the LER system as an actuarial data base for human performance values. If we accept the fact that the need for precise numerical values on specific failure events is not always needed when performing a relative statistical evaluation of the man-machine design, the LER system proves to be a valuable but limited source of data.

When reviewing the events within the LER system, the analyst can extract the number of errors that have been reported for a given safety system. By acknowledging the fact that the data within the system is limited to those as prescribed by NUREG 0161⁽⁸⁾ we can review the human interactions with those specific safety systems. This form of a modified task analysis, as presented in NUREG/CR-1880⁽⁹⁾ allows the analyst to convert the human errors of direct safety significance to a failure per demand or a failure per unit time whichever is applicable. This simple exercise, although time consuming, can apply the relationship of

$$HER* = \frac{\text{Number of Human Errors from LERs}}{\text{Number of Opportunities for the Specific Error}}$$

At this point it should be noted that given the limitation that the data is applicable only to those safety systems reported, we must turn and look at the accuracy of the reporting itself. The LER system is dependent on a key word access method and therefore when searching the data for human involvement the initial output is only that listed

*HER = Human Error Rate

within the cause code title of personnel error. If, in fact, events have involved human error, but are not correctly reported as such the first screening will not pick them up. Because of this, it is at times necessary to review all potential human events within the time frame and categories of interest. This type of an approach, as reported in NUREG/CR-2417,⁽¹⁰⁾ can and has extracted between 5 and 8 times as many human errors within the data system as has been initially classified as human error. In this way a significantly increased number of data are available. Therefore, the application of the LER file, utilizing the simple model described above, allows the technician to access readily available nuclear actuarial data.

The analysis, as discussed above, is time consuming and uncertain, but does lend itself to applications within the statistical framework. The collection of plant data can and should, in the future, expand its role in the evaluation of human error. However, at this point in time we, as engineers, must use all information available to us as tools to aid in decision making. The LER file, although flawed, can prove useful as one interim solution to our needs.

The data needs and available sources are presented in Table 1 and 2.

Table 1. Data Importance Based on Use

USE	COGNITIVE ERROR	MULTIPLE ERROR	PROCEDURAL ERROR
Design Review	X	X	X
P R A	X	X	

Table 2. Available Sources of Present or Near Future Data

SOURCES	COGNITIVE ERROR	MULTIPLE ERROR	PROCEDURAL ERROR
Expert Opinion	X	X	X
Simulation (Training)		X	X
Simulation (Advanced)	X	X	X
Actuarial		X	X

CONCLUSION

Human error data in the evaluation of high consequence/low probability events must be used with caution. The currently available data on error that is directly applicable to the commercial nuclear industry is sparse and uncertain, but when applied in a statistical manner can give important relative insights on man-machine performance.

When the analyst is attempting to utilize existing data, a clear and concise definition of what constitutes a human error is essential. The author suggests a definition, which has proven successful, that links error to plant availability and safety. In this fashion, the analyst can prune the number of errors by anchoring the study to consequences. When this is done, human error can usually be placed in three bins. First, and of most importance, cognitive error; second, and of next importance, multiple error; and, lastly, procedural error, which is of least importance. It should be noted that the bin of most importance has the least available data and represents the most difficult type of data to collect. If the analyst reviews the data with a consideration of physical time available for human action and constructs a modified task analysis, potential interim data becomes available that might have normally been masked.

Although there are serious deficiencies with data on human error, there is no choice at present but to cautiously utilize them. Engineering is always an optimization process based on incomplete data; these data can aid in the design, modification and review of the man-machine interface.

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