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TIME-INDEPENDENT AND TIME-DEPENDENT CONTRIBUTIONS TO THE UNAVAILABILITY OF STANDBY SAFETY SYSTEM COMPONENTS*

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ABSTRACT

The unavailability of standby safety system components due to failures in nuclear power plants is considered to involve a time-independent and a time-dependent part. The former relates to the component's unavailability from demand stresses due to usage, and the latter represents the component's unavailability due to standby-time stresses related to the environment. In this paper, data from the nuclear plant reliability data system (NPRDS) were used to partition the component's unavailability into the contributions from standby-time stress (i.e., due to environmental factors) and demand stress (i.e., due to usage). Analyses are presented of motor-operated valves (MOVs), motor-driven pumps (MDPs), and turbine-driven pumps (TDPs). MOVs fail predominantly (approx. 78%) from environmental factors (standby-time stress failures). MDPs fail slightly more frequently from demand stresses (approx. 63%) than standby-time stresses, while TDPs fail predominantly from standby-time stresses (approx. 78%). Such partitions of component unavailability have many uses in risk-informed and performance-based regulation relating to modifications to Technical Specification, in-service testing, precise determination of dominant accident sequences, and implementation of maintenance rules.

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1. INTRODUCTION

The unavailability of standby safety-system components encompasses many contributions which include unavailability due to random failures that may occur during the standby period. Typically, this unavailability is either expressed as a constant or as a function of the failure rate and the test interval. In obtaining this value, the number of failures observed is used to obtain either the failure rate (considering the corresponding standby time) or a constant unavailability (considering the corresponding number of demands), but no analysis of the causes of the failures is made. The failures may be either due to stresses from demand or stresses during the standby period. Failures can be partitioned into these two types of stresses and, correspondingly, the component's unavailability can be obtained as a sum of time-independent and time-dependent terms. Such a derivation of component unavailability is very helpful in many applications of probabilistic risk assessments (PRAs) in decisions about the operability of equipment, surveillance testing, and maintenance.

In this paper, we discuss the following topics:

a) approaches to partitioning the component's unavailability into standby- and demand-failure contributions by dividing its failure records into standby stress and demand stress,

b) applications for motor-operated valves (MOVs), motor-driven pumps (MDPs), and turbine driven pumps (TDPs).

We used readily accessible data, e.g., nuclear plant reliability data system (NPRDS), in developing the approaches and demonstrating the applications. Previous attempts at separating component unavailability into time-independent and time-dependent contributions focussed on plant-specific maintenance records (Ref. 1, 2) which are difficult to obtain and resource-consuming to analyze.

2. COMPONENT UNAVAILABILITY MODEL: SEPARATION INTO TIME-DEPENDENT AND TIME-INDEPENDENT CONTRIBUTIONS

The unavailability of standby components from failures usually is estimated in probabilistic risk assessments (PRAs) using a model of the form:

q = constant (i.e. a probability of failure on demand), or;
$q = 1/2\lambda T$ (where λ is the failure rate and T is the time between tests of the component)

Other unavailability terms also may be added to the above, such as unavailability of the component due to repair of unplanned degradations or failures, or unavailability from planned outages. These failure models make no assumptions about the type of stress leading to the component's failure. For instance, if a component fails primarily from environmental stresses when it is in standby, and the constant failure probability model is used to assess its unavailability, regardless of its test period, the model may underestimate the contribution to risk for components having long test periods, and overestimate the contribution for those with short test periods.

In fact, a component's unavailability from failures may actually be of the form:

$$q = \text{constant (p)} + 1/2\lambda T$$

where the constant (p) represents the component's unavailability from demand stresses related to its usage, and the $1/2\lambda T$ term represents the component's unavailability from standby stresses related to the component's environment, and, therefore, is a function of the time between tests.

Applications that would benefit from this more comprehensive component unavailability model include the following ones: evaluating the impact on risk from extending surveillance test intervals for technical specifications and in-service testing; using generic failure probabilities more appropriately, especially for components with very long or very short test intervals; gaining insights for dominant accident sequences, especially those involving infrequently tested valves; and, perhaps, providing insights for scheduling preventive maintenance.

3. ANALYSIS APPROACH

In discussing the analysis approach, MOVs will be used as an example; the approach was the same for all types of components, with only minor exceptions. The NPRDS MOV records for 16 plants, 5 systems at each plant, and 5 years of data at each plant, were reviewed to categorize the data as standby stress or demand stress. Each record was placed in one of four categories: standby-stress-related; demand-stress-related; indeterminate events; or inappropriate events. Those records where the cause of failure could be easily determined fell into either the standby-stress or demand-stress categories. Those event records that had insufficient information to so categorize them were placed in the indeterminate category. Records that represented events that were of no risk consequence, as modeled in PRAs (i.e., minor external leaks whose repair was delayed until the next plant shutdown), categorized as inappropriate.

Next, the data were grouped by usage or application, such as the operating environment (i.e., the MOV regulates a liquid as opposed to steam or gas), the type of system (i.e., the MOV is in the AFW, or is part of the HPSI), and the size of the MOV (i.e., 2 to 4 inches, or 13 to 24 inches).

Following this, denominator information was obtained to estimate the failure probability of demand stress and the standby stress failure rate for each of the application categories, so that both a failure probability and a failure rate could be estimated for each. This involved counting the number of valves in the data population of each application category. The denominator for the failure probability of demand stress of an application category is the total number of demands for all MOVs in the data population of that category. The denominator for the standby stress failure rate of an application category is the total MOV on-line time for all MOVs in that category.

The failure probability of demand stress for an application is estimated by dividing the number of MOV demand failures in the category by the number of MOV demands in the sample period for the category. The standby-stress failure rate for an application category is estimated by dividing the number of standby-stress failures for the category by the total MOV on-line time for MOVs in the category. To obtain accurate counts of failure, the failures in the indeterminate category were partitioned according to the fraction of standby- and demand-stress failures in the original partition. The resulting numbers of standby- and demand-events then were added to the failure counts in each category.

Several considerations were noted while partitioning component unavailability in this way. First, demand is difficult to count without recourse to detailed plant operating records. To compensate, the failure probability of demand stress was estimated by multiplying a generic failure probability by the fraction of events that were determined to be related to demand stress. This procedure was justified by assuming that the generic failure probability was likely to have been estimated originally using all failures, including demand-stress and standby-stress failures, so multiplying by the fraction of failures estimated to be demand-stress ones essentially provided a reasonable estimate of the failure probability of demand stress.

The second consideration involved the potential for subjectivity in dividing the data into standby stress and demand-stress categories. To compensate for potential subjectivity, we devised a set of key words and key-word combinations that would tend to identify a failure record as either standby-stress or demand-stress related. In addition, the indeterminate category was added to avoid guessing when there was insufficient information in the event record to reasonably assess the cause of failure. Finally, computer software using the key words and key-word combinations was developed to cross-check the data analysis and focus attention on those areas where the partitioning might be less objective than desired.

Several other considerations, particular to the NPRDS data base, were also noted. First, component counts using NPRDS information needed to be carefully done, since components that were replaced during the sample period were counted twice, once for the original component and once for its replacement. We checked the component counts against the system P&IDs in the plant FSARs. Second, the failure severity recorded in the NPRDS records does not always match the definition used in PRAs. Each record was independently evaluated for failure severity as used in PRAs. Finally, not all plants report completely to NPRDS, which is apparent from the numbers of records submitted in the sample period. To compensate, the MOV on-line times (denominators) were adjusted for those plants where incomplete reporting was suspected.

4. ANALYSIS RESULTS

Table 1 shows the results of partitioning the NPRDS data, and estimating demand-stress failure probabilities and standby-stress failure rates for several categories of MOV application.

Table 1
MOV Estimated Failure Probabilities and Failure Rates

Application Category	% Demand Stress	% Standby Stress	DS Failure Prob.*	SS Failure Rate
All MOVs	22	78	2.2E-4/d	2.3E-6/hr.
All PWR MOVs	21	79	2.1E-4/d	2.2E-6/hr.
All BWR MOVs	22	78	2.2E-4/d	2.4E-6/hr.
Liquid Environment	19	81	1.9E-4/d	2.3E-6/hr.
Gas/Steam Environ.	57	43	5.7E-4/d	2.2E-6/hr.
2 to 12 inch MOVs	22	78	2.2E-4/d	**
13 to 20 in. MOVs	21	79	2.1E-4/d	**

* All failure probabilities for demand stress were estimated using a generic failure probability of 1E-3/d multiplied by the fraction of failures in each application category that were evaluated as demand-stress related.

** Denominator data (MOV time on-line) could not be obtained for these estimates. However, based on the fractions that were related to standby stress, they likely range from 2.2E-6/hr. to 2.4E-6/hr.

The most striking feature of the table is the consistency of results among the application categories. The standby stress failure rates for all categories vary only from 2.2E-6/hr. to 2.4E-6/hr. Most of the demand-stress failure probabilities range from 1.9E-4/d to 2.2E-4/d, except that for MOVs operating in a gas/steam environment, estimated as 5.7E-4/d. It is not known why there is this difference. One possibility is that, if the actual MOV demands were counted, the demand-stress failure probability would come closer to the other values. We note that the estimate of failure rate for this application category is no different than the estimates for other categories. If there were a difference due to particular environmental stresses from this application category, it should show up as a difference in failure rates, not as a difference in demand-stress failure probabilities.

Table 2 gives the results of partitioning the NPRDS data, and estimating demand-stress failure probabilities and standby-stress failure rates for several motor- and turbine-pump applications.

Table 2
Motor- and Turbine-Pump Estimated Failure Probabilities and Failure Rates

Application Category	% Demand Stress	% Standby Stress	DS Failure Prob.	SS Failure Rate
All Pumps	59	41	5.9E-4/d *	1.6E-6/hr.
All Motor Pumps	63	37	6.3E-4/d *	1.4E-6/hr.
All Turbine Pumps	22	78	6.6E-4/d**	4.0E-6/hr.
PWR Motor Pumps	69	31	6.9E-4/d *	1.0E-6/hr.
BWR Motor Pumps	48	52	4.8E-4/d *	2.4E-6/hr.

* Demand-stress failure probabilities of motor pumps are estimated as the product of the fraction of failures identified as demand-stress related times a generic motor-pump failure probability of 1E-3/d.

** Demand-stress failure probability of turbine pumps is estimated as the product of the fraction of failures identified as demand-stress related times a generic turbine-pump failure probability of 3E-3/d.

The results for motor pump are not as consistent across application categories as were the MOV results. Overall, approximately 60% of motor pump failures may be related to demand stress, and about 40% to standby stress. However, for turbine pumps, the split is closer to 20% to 80%. From the standpoint of how they fail, motor pumps and turbine pumps appear to fail from different mechanisms. The former seem to fail from usage-related stresses slightly more often than from environmentally related stresses, while the latter fail predominately from environmentally related stresses.

5. CONCLUSIONS AND RECOMMENDATIONS

In this paper, data from the nuclear plant reliability data system (NPRDS), were used to partition component unavailability into standby stress (i.e., due to environmental factors) and demand stress (i.e., due to usage) contributions, rather than searching plant-specific data bases maintained at a nuclear plant site. The ability to use a database like NPRDS significantly reduces the efforts involved in making this division and makes such evaluations practical.

The applications carried out for MOVs and pumps provide the following important insights:

a) MOVs appear to fail predominantly from environmental factors; the relative contribution of standby-stress related failures is more or less unchanged for different sizes of MOVs.

b) MOVs operating in gas/stream environment, as opposed to liquid one, have a relatively higher contribution from demand-stress failures. This finding implies that frequent testing of MOVs operating in gas/steam may be less effective in controlling their unavailability.

c) Motor-driven pumps appear to fail slightly more frequently from demand stresses than standby-time stresses, while turbine pumps appear to fail predominantly from standby-time stresses. This may imply that there should be slightly different testing requirements for controlling their unavailability.

The partitioned data on component unavailability have potential uses in risk-informed and performance-based regulation. The data should allow risk-informed assessment of requests for extending test interval, and should result in more precise determination of dominant accident sequences in a PRA, especially those involving components with very long or very short test intervals. In theory, partitioning unavailability data would establish optimum test intervals for the components, although it may not be practical to test at the optimum frequencies.

Also, procedures can be developed to partition the reliability data expected to be collected under the Reliability Data Rule, so providing the NRC and licensees with partitioned component unavailability data for risk-informed regulation.

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