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Abstract

Prior to the recent work performed by Oak Ridge National Laboratory (ORNL) relative to nuclear industry check valve performance, no information was readily available regarding the failure characteristics of check valves based on valve type (*e.g., swing check, lift check*). Although it had been recognized by component experts that the two most significant factors in determining check valve performance were valve design (*i.e., type*) and operating conditions, no industry data was available relative to the former. In cooperation with the Nuclear Industry Check Valve Group (NIC), ORNL has reviewed and analyzed check valve failures from the Institute of Nuclear Power Operations' (INPOs') Nuclear Plant Reliability Database System (NPRDS) according to several parameters, including valve type. Since the valve type identification is not inherently included within the NPRDS engineering record for each component, ORNL had to rely upon input from NIC, valve manufacturers, and catalogs to supply the missing information. As a result of this effort, approximately 77% of the check valve failures occurring during the 1991-1996 study period and nearly 62% of the overall installed population were identified according to type. This data provided the basis to perform previously unavailable cross-correlations between parameters such as valve type versus failure mode and failure cause.

Design characteristics and service applications differ markedly among check valve types, resulting in discernible differences in performance. This paper focuses on the performance characteristics of swing and lift type check valves since failure and population distributions have shown these to be the two most common types employed in a wide range of nuclear plant applications. Analysis results for these two valve types are presented according to extent of degradation, system, failure mode, affected area, and failure cause. Selected results are also included for five other types of check valves by extent of degradation and system of service.

Performance assessments and reliability predictions based on more specific sets of parameters such as valve type will be of use not only to valve/system designers, but to other operational organizations as well. Instead of using "generic" failure rates from standard reference sources which generally ignore valve design characteristics, data derived from the study of performance histories on a more specific level should result in a significant impact on future plant operations, including inservice testing (IST), maintenance, and probabilistic risk assessments (PRAs). This data should provide a means to calculate more appropriate relative (and ultimately absolute) failure rates for check valves.

Introduction

Prior to a study done by ORNL on check valve failures occurring during 1991 (1), no information was available on an industry-wide basis relative to check valve performance versus valve type or design. That study, based on an analysis of information derived from the NPRDS database (and coded by ORNL according to a number of parameters), incorporated data on specific valve type obtained from available sources, including valve manufacturers, catalogs, and NIC review of the ORNL-characterized failure data. It was felt that this data was extremely important, since earlier studies (2,3) had suggested significant performance variations based largely on valve design and service conditions. This approach was necessary since valve type information is not inherently included in the NPRDS database. A supplement to the 1991 study was issued for failures occurring during 1992 (4). NIC also reviewed the characterized failure data for this time period, and again provided input relative to valve type identification based on the valve manufacturer and model number data included in the failure reports. Data thus gained from all available sources resulted in identification of over 85% of the failures occurring during 1991-1992 as well as nearly 62% of the overall installed population of 20,748 check valves (1991 population).

The data presented in this paper covers a time period of 1991 through 1996, inclusive. Valve type data gained during the analyses of 1991 and 1992 failures and 1991 population was used to identify as many as possible of the failed valves for those failures occurring after 1992 (resulting in 77% of the check valve failures occurring from 1991 through 1996 being identified according to type). Table 1 shows the overall population distribution by type for both the failed and installed population. Population data from 1991 was chosen for convenience as a basis for data normalization in the analysis.

Table 1. Check Valve Failure and Population Distribution by Valve Type

Valve Type	1991-1996 Failure Distribution	1991 Population Distribution
Swing	30%	28%
Lift	31%	19%
Unknown	23%	38%
Tilting disc	7%	5%
Duo/double disc	6%	5%
Stop	1%	2%
In-line	<1%	<1%
Other	<1%	2.5%
total	100%	100%

Analysis

NPRDS check valve failure data from 1991 through 1996 was reviewed, filtered, and characterized according to several parameters, including extent of degradation, failure area, failure mode, failure cause, and system. As in previous studies (1,2,4), a normalization technique was used for some calculations to account for check valve population effects. For purposes of this analysis, a simplified estimation of the number of component service years (valve-years) was used. This value was estimated by multiplying the number of valves in the 1991 population (20,748) by the number of years in the study period (6), resulting in a total of 124,488 valve-years of service. This is obviously only an approximation, since this approach assumes that all valves stayed in service during the entire study period and that the population did not change. For purposes of determining *relative failure rates*, however, the approach is justified since it was determined that any net change in the population distribution during this period would be small and therefore relatively insignificant. A more rigorous analysis would be used for the determination of absolute failure rates or where more precision was necessary.

Figure 1 shows the relative failure rate and extent of degradation* by valve type for all 1991-1996 failures. The chart includes all valve types considered in the study (except in-line valves, which are not shown due to their small population) so that it can be seen how swing and lift type valve performance compares with that of other designs. Figure 1 shows that when all failures of all check valves were considered, lift type valves exhibited the highest overall relative failure rate, at about 1.6 times greater than average. Tilting disc valves and duo/double disc valves also had higher relative failure rates than did the population as a whole. Swing check valves exhibited a relative failure rate close to unity, while those valves characterized as stop, unknown, and other had relative rates below average. If only significant failures were considered, tilting disc valves had the highest relative failure rate of any type, at 1.6 times average. Lift, swing, and duo/double disc valves were about even in terms of relative failure rates for significant failures at around 1.1-1.3 times the overall average. Stop, unknown, and other types also had the lowest relative rates for significant failures. The majority of failures was moderate in nature for all valve types.

Since service environment is the other crucial parameter in determining check valve performance, failure rates by valve type and system were also plotted. Figure 2 shows the relative failure rates by system and valve type for significant failures for the ten systems with the highest overall failure rates for significant failures. Only systems with ≥ 1000 valve-years during the 1991-1996 period were considered and only significant failures were reviewed since these would be the most representative of the failure modes considered in most PRAs. It is interesting to note that lift type valves accounted for the highest relative failure rates for significant failures in the CCW, Diesel Starting Air, and ESW systems. Also notable is that tilting disc valves had the highest relative failure rates in HPCI, RCIC, and Feedwater systems. Tilting disc valves in the HPCI system resulted in the highest relative failure rate, at over eight times the average for all failures. Swing type valves accounted for the highest relative rates in Containment Isolation, Main Steam, and

* "Extent of degradation" refers to the extent to which valve performance was affected, not to any resultant system or plant effect. Failures involving internal leakage or loose or damaged internal parts would usually be considered *moderate*, while those involving detached or broken parts, restricted motion, or stuck open or stuck closed would normally be considered *significant* in nature.

Suppression Pool Support systems. These results clearly illustrate the importance of considering valve type and system when assigning failure rates for probabilistic type activities, establishing maintenance programs, etc. Figure 2 also shows the overall relative failure rate by system. Table 2 contains data on the total number of significant failures and estimated valve-years by system and valve type for the systems included in Fig. 2.

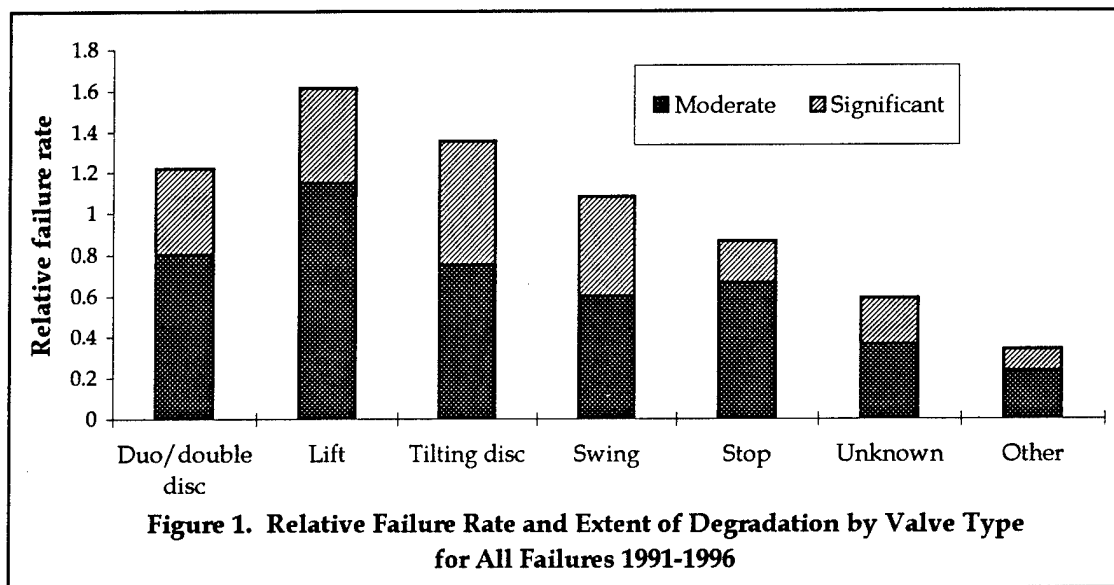


Table 2. Number of Significant Failures and Estimated Valve-Years by System and Valve Type for the Ten Systems with the Highest Overall Failure Rates for Significant Failures 1991-1996 (valve-years shown in parentheses)

	Duo/double disc	Lift	Other	Stop	Swing	Tilting disc	Unknown
AFW	0 [162]	9 [912]	2 [126]	0 [330]	12 [2982]	7 [954]	12 [2754]
CCW	2 [1074]	30 [1716]	0 [12]	1 [216]	21 [2898]	3 [342]	5 [2616]
Containment Isolation	1 [132]	9 [1152]	0 [0]	1 [78]	14 [684]	0 [0]	1 [1410]
Diesel Starting Air	0 [72]	47 [1860]	0 [162]	0 [36]	2 [756]	0 [0]	11 [3054]
ESW	23 [1986]	20 [852]	0 [6]	0 [120]	26 [2574]	6 [1320]	18 [2838]
Feedwater	0 [12]	3 [294]	0 [66]	1 [120]	15 [1416]	24 [1596]	9 [3078]
HPCI	1 [36]	2 [558]	0 [0]	0 [24]	0 [474]	5 [108]	15 [1068]
Main Steam	2 [12]	8 [612]	0 [84]	0 [372]	79 [3210]	1 [144]	20 [2970]
RCIC	2 [30]	11 [708]	0 [0]	0 [18]	7 [504]	2 [84]	4 [1026]
Suppression Pool Support	0 [12]	0 [24]	2 [144]	0 [0]	10 [702]	0 [0]	11 [1578]

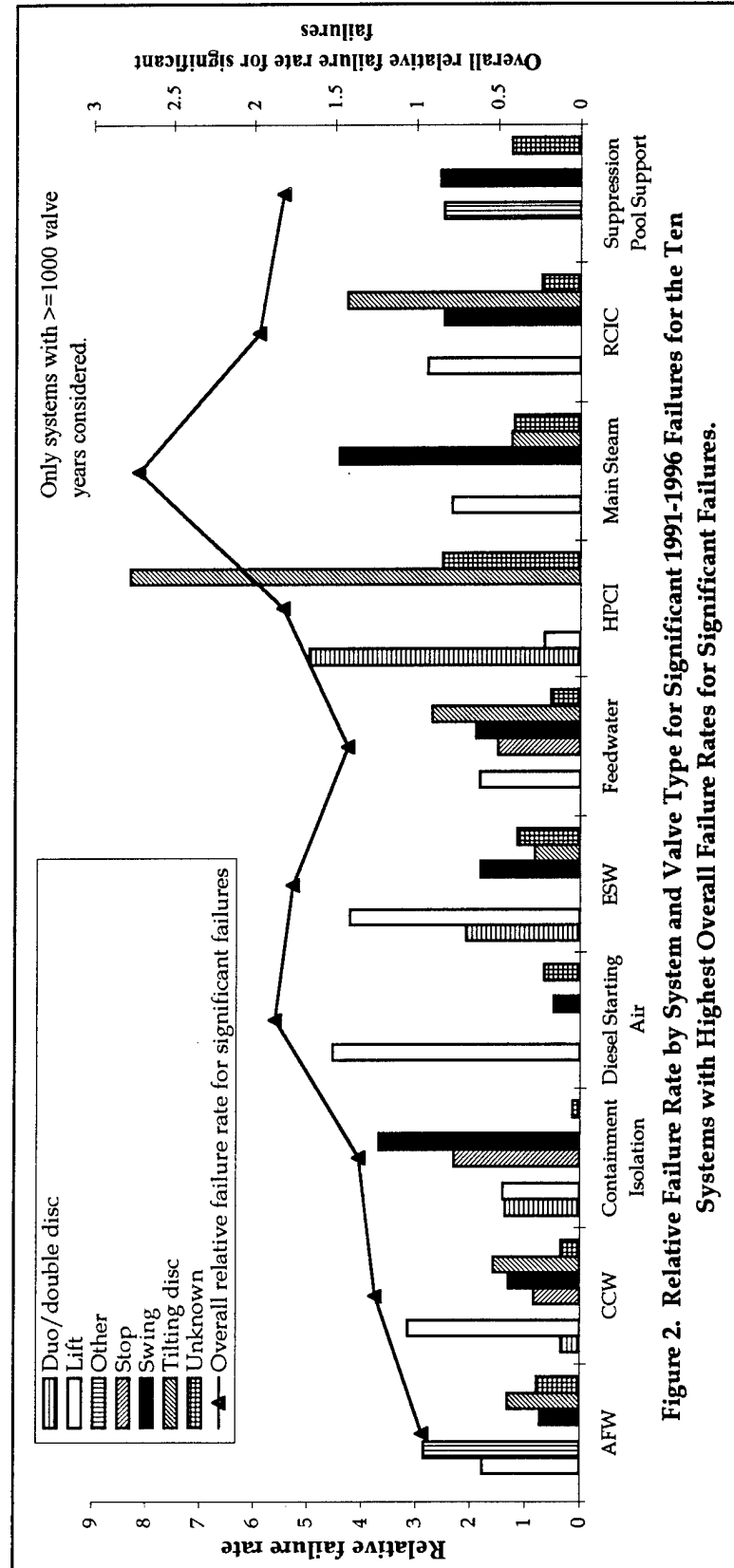
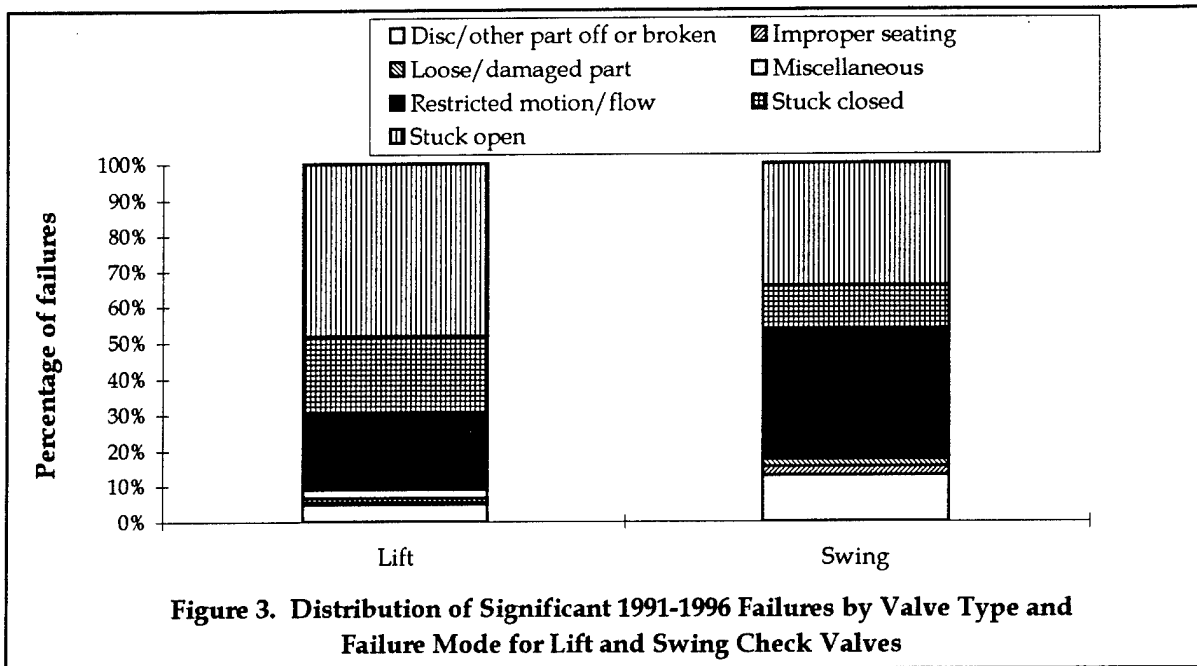


Figure 2. Relative Failure Rate by System and Valve Type for Significant 1991-1996 Failures for the Ten Systems with Highest Overall Failure Rates for Significant Failures.

Although a performance analysis of all check valve types would be both valid and useful, the remainder of this analysis will focus on swing and lift types. Considering all 1991-1996 failures by valve type and failure mode for these two types, it is evident that a large percentage of the NPRDS failures reported were due to internal leakage. For all failures, 44% of the records for swing check valves and 69% for lift type valves were characterized by ORNL as improper seating (i.e., internal leakage in most cases). Table 3 shows the number of failures by failure mode for all failures. An important finding here is that both valve designs are fairly unlikely to stick closed, with $\leq 6\%$ of all failures for either type being attributed to this failure mode. For a swing check valve, it has been determined that most stuck closed cases have involved either a problem with an external penetration (e.g., external closure weight), failure of a vacuum breaker valve to open at a specified torque, or unrelated debris lodged inside the valve (5). For lift type valves with very tight internal clearances, however, most of the stuck closed cases involved a stuck piston due to lodged foreign material and/or corrosion particulate, generally from the system itself and often exacerbated by carbon steel valve internal materials. Both valve types are nearly three times more likely to stick open than closed, but for all failures the percentage of stuck open cases was still relatively low at $\leq 15\%$ for either type. The component population distribution is unknown at this time relative to normal state (i.e., normally open vs. normally closed), however, so that the applications effects cannot be completely assessed. Figure 3 shows the failure distribution by valve type and failure mode for lift and swing type valves for significant failures only. Only one failure mode code was assigned per failure.

Table 3. Number of Failures by Valve Type and Failure Mode for All 1991-1996 Failures (percent of failures by failure mode for each type shown in parentheses)

Valve Type	Failure Mode						
	Disc/other part off or broken	Improper seating	Loose/damaged part	Misc.	Restricted motion/flow	Stuck closed	Stuck open
Swing	32 [6%]	243 [44%]	40 [7%]	34 [6%]	90 [16%]	30 [5%]	85 [15%]
Lift	8 [1%]	400 [69%]	8 [1%]	9 [2%]	36 [6%]	35 [6%]	80 [14%]



The distribution of failures by valve type and affected area for significant failures of swing and lift type valves is shown in Fig. 4. As expected, for lift type valves, the affected areas usually involved the seat/plug area and/or foreign material in the case of significant failures. The swing type design exhibited a more even failure distribution, with significant failures most likely to involve the hinge pin area, seat area, penetration area, and only slightly less likely to involve the disc stud/hinge arm area. Multiple area codes may have been assigned for each failure.

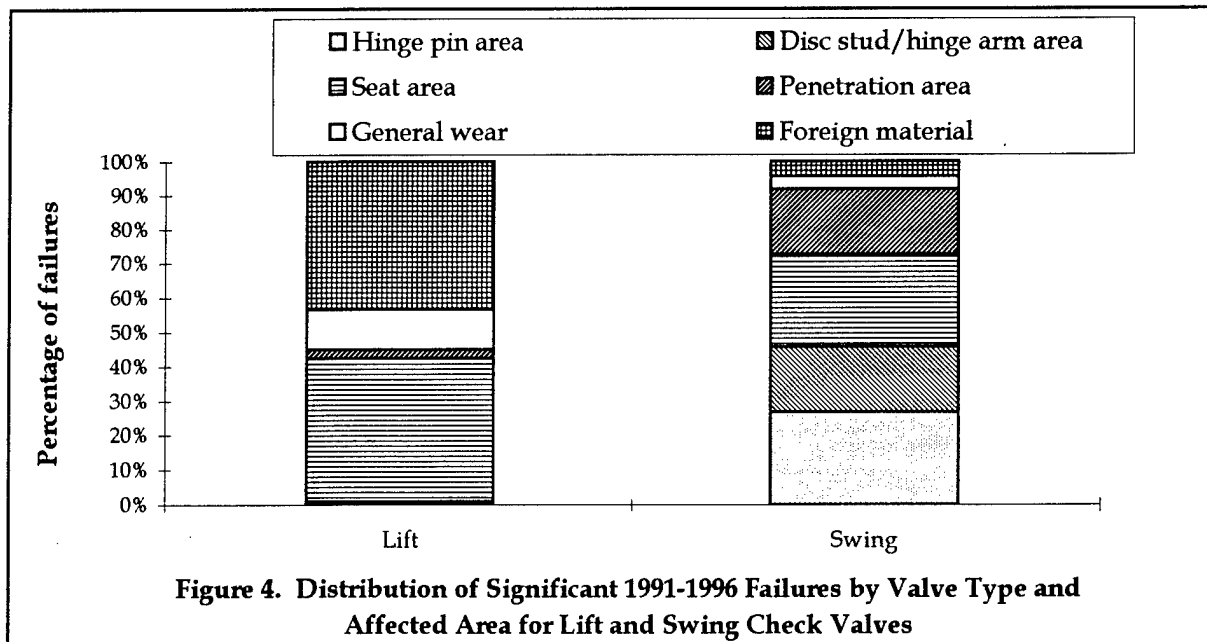
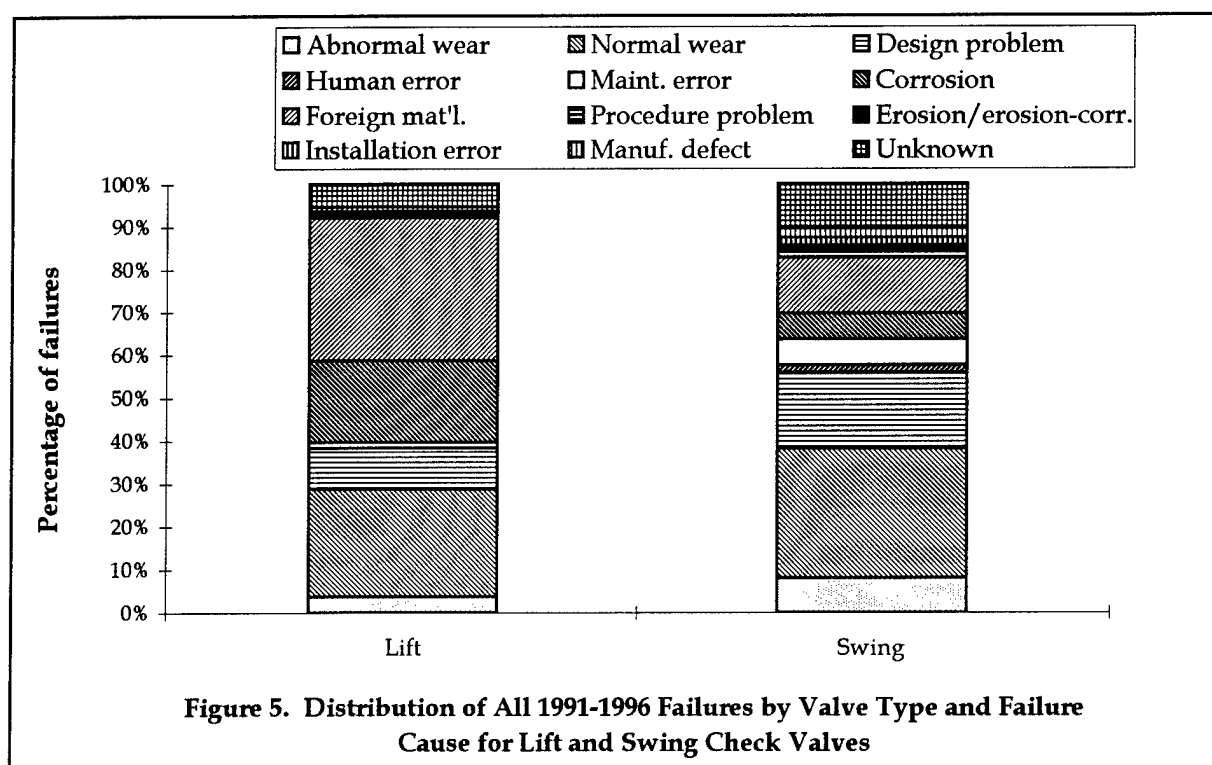
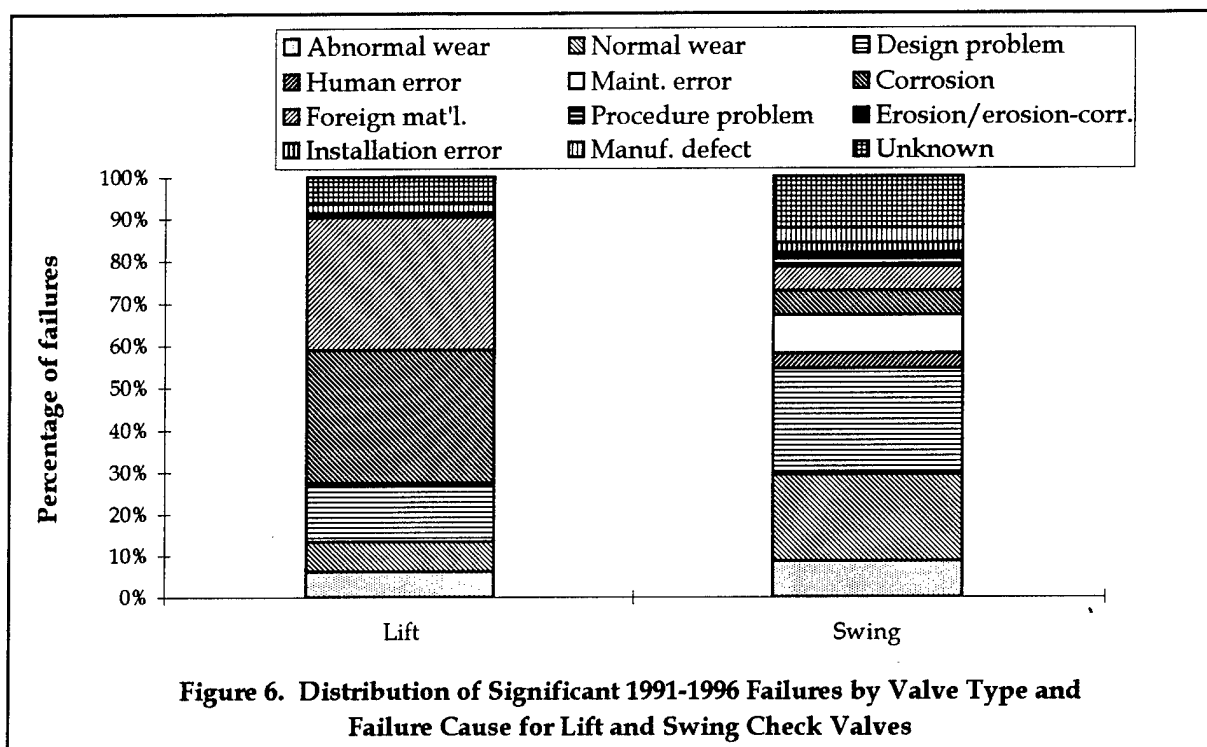


Figure 5 shows the distribution of all failures by valve type and failure cause for swing and lift type valves and Fig. 6 shows the same distribution for significant only failures. When all failures are considered, lift type check valves have been found most likely to fail due to foreign material contamination, normal wear, and/or corrosion. Considering all failures, failures in swing check valves occurred primarily because of normal wear, and less so due to design problems, foreign material contamination, and/or for unknown or unspecified reasons. When only significant failures are considered, more than half the lift check failures were associated with foreign material contamination and/or corrosion. Significant failures in swing check designs occurred due to a greater variety of reasons, but were often associated with design problems and normal wear. Table 4 contains a tabular representation of these results. Multiple failure cause codes may have been assigned for each failure.





**Table 4. Number of Failures by Valve Type and Failure Cause
(percentage of failures by failure mode for each valve type in parentheses)**

Failure Cause	All Failures		Significant Failures	
	Swing	Lift	Swing	Lift
Abnormal wear	58 [8%]	33 [4%]	27 [9%]	18 [6%]
Normal wear	216 [30%]	217 [25%]	66 [21%]	21 [7%]
Design problem	125 [17%]	83 [10%]	79 [25%]	40 [14%]
Human error	12 [2%]	0 [0%]	11 [3%]	0 [0%]
Maintenance error	43 [6%]	11 [1%]	29 [9%]	1 [<1%]
Corrosion	44 [6%]	163 [19%]	18 [6%]	92 [32%]
Foreign material	93 [13%]	290 [33%]	18 [6%]	92 [32%]
Procedure problem	10 [1%]	3 [<1%]	6 [2%]	1 [<1%]
Erosion/erosion-corrosion	11 [2%]	7 [1%]	5 [2%]	1 [<1%]
Installation error	13 [2%]	4 [<1%]	7 [2%]	1 [<1%]
Manufacturing defect	15 [2%]	8 [1%]	11 [3%]	6 [2%]
Unknown	75 [10%]	47 [5%]	39 [12%]	19 [7%]

Conclusions

Analysis of NPRDS check valve failures occurring from 1991 through 1996 has shown that although check valves have in general been good performers, performance differences do exist among valves of various designs. With regard specifically to swing and lift type valves, lift type valves exhibited a higher overall relative failure rate considering all failures, while the relative failure rate for significant (in terms of extent of component degradation) failures was about even for the two types. Considering both design and service conditions, considerable differences in performance were discovered among valves of various types. For example, lift type valves accounted for the highest relative failure rates for significant failures in the CCW, Diesel Starting Air, and ESW systems. Tilting disc valves had the highest relative failure rates in HPCI, RCIC, and Feedwater systems. In fact, tilting disc valves in the HPCI system resulted in the highest relative failure rate, at over eight times the average for all failures. Swing type valves accounted for the highest relative rates in Containment Isolation, Main Steam, and Suppression Pool Support systems.

The most common failure mode for check valves regardless of design was improper seating (i.e., in most cases, internal leakage). Forty-four percent of all failures involving swing type valves and sixty-nine percent of failures of lift type valves were attributed to improper seating. An important finding is that both swing and lift type valves are fairly unlikely to stick closed, although lift type valves are more likely to fail in this mode apparently due to inherent characteristics of that design. Both types are nearly three times more likely to stick open than closed, but only around 15% of all reported failures for both types were attributed to this failure mode. When only significant failures are considered, more than half the lift check failures were associated with foreign material contamination and/or corrosion. Significant failures in swing check designs occurred due to a greater variety of reasons, but were often associated with design problems and normal wear. These results clearly show the need to consider a number of characteristics when assigning reliability estimates for check valves rather than simply relying on the traditional "off the shelf" reference sources for generic check valve data. With the availability of a substantial amount of industry data, it is no longer acceptable to use standard book values for failure rates based on pooled data for all valves. At a minimum, consideration should be taken of the specific valve type, its service conditions (e.g., system), and failure mode of interest since performance can vary significantly depending on these factors. Further, the more accurate the reliability estimate required, the more specific the parameter set should be. For example, valve size, age, and manufacturer and/or model could also be considered in estimating the expected reliability of a certain valve. The findings presented herein should be of interest not only to PRA analysts, but also to valve and system designers, since valve misapplication has been shown to be a contributing problem in a number of failures.

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