CHECK VALVE FAILURE EXPERIENCE IN THE NUCLEAR INDUSTRY

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ABSTRACT

Check valves are critical components in the operation of current generation nuclear power plants and may serve an increasingly critical role in the designs of future advanced passive light water reactors. Recognizing that check valve failures can result in significant operating transients, increased maintenance costs, and/or decreased system availability, the nuclear industry has taken a proactive approach to failure detection and prevention. As part of the Nuclear Regulatory Commission's (NRC's) program to evaluate the effects of age and wear on nuclear systems components, Oak Ridge National Laboratory (ORNL) has analyzed hundreds of check valve failures in safety-related applications. This research, combined with efforts by industry, regulatory, and codes and standards organizations, has provided insight into check valve performance history and may be used to provide a basis for evaluation of changes to utilities' inservice test and inspection practices.

BACKGROUND

Significant check valve failure events occurring in the mid-1980s directed industry and regulatory attention to the potential consequences of degradation or loss of these "passive" components. To address the subsequent discovery of generic check valve deficiencies, the NRC issued several guidance documents related to check valve problems and performance, inspection programs, research, cooperation with industry groups, development of codes and standards, evaluation of the NRC staff and regulatory requirements, and industry efforts. The NRC also initiated a utility inspection program intended to evaluate check valve activities at each nuclear power plant.

The industry responded to these deficiencies by creating the Nuclear Industry Check Valve group (NIC) to deal with check valve-related issues. This organization committed itself to understanding check valve problems and to enhancement of valve performance, maintenance, and testing practices. Subcommittees were established to address particular areas of concern, such as nonintrusive examination, applications and maintenance, and performance data analysis.

In 1990 the American Society of Mechanical Engineers Operations & Maintenance Committee Working Group on Check Valves (ASME OM-22) was formed. The Working Group (WG) initiated a literature search on historical failure research in an effort to improve check valve performance and reliability through revision of the Code requirements for inservice testing (IST). The WG found that while some studies had been performed on check valve failure patterns, they were not generally oriented toward providing the kinds of information required for ASME Code development activities. In fact, the study initially chosen by the WG to provide a basis for development of disassembly and examination interval
requirements (as a potential function of component or plant age) was later determined to be misleading, due primarily to valve population effects.

Results of this review of historical failure analysis studies combined with a preliminary review of the failure data itself resulted in ORNL's efforts to conduct a more thorough failure history analysis (Casada, 1993). The primary goal of this study was to evaluate failure data to identify any significant correlations of failure rates with component age, plant age, or other parameters while considering the effect of the number of valves in service during the analysis period (i.e., population effects). The work was performed under the Nuclear Plant Aging Research (NPAR) project funded by the NRC.

FAILURE ANALYSIS AND RESULTS

Original ORNL Analysis - 1984–1990 Data

The original analysis performed by ORNL consisted of a review of nearly 5000 check valve failure records from the Institute of Nuclear Power Operations' (INPO's) Nuclear Plant Reliability Data System (NPRDS) database entered through May 1990. Preliminary manual review of the failure narratives resulted in elimination of those failures occurring prior to 1984 (when significant improvements in NPRDS reporting requirements were implemented), as well as the exclusion of those events not involving valve internal parts damage (e.g., external leakage), valves incorrectly coded as check valves, nonfailures, and minor seat leakage. The resulting analysis database consisted of 1227 failure records occurring during the time period 1984 through 1990.

Failure records remaining for analysis were then characterized according to specific parameters inherent in the NPRDS database, such as system, nuclear steam supply system (NSSS) vendor, valve size, valve age, manufacturer, and plant age. Other parameters not included in the database were also characterized by reviewing the failure narratives. These included failure mode, failure area, extent of degradation, general and specific detection methods, and normal system operating status. The ORNL analysis focused on failures involving degradation of valve internal parts. A "failure" for purposes of this study was defined as a degradation of one or more valve functions (e.g., failure to open, failure to close, loose/broken parts).

After the failure records were manually reviewed, characterized, and recorded in database format, exhaustive data manipulations and cross-correlations were performed. Calculations were performed using data normalized according to the population of check valves existing during the analysis period to enable the establishment of relative failure rates. NIC also provided a forum for utility review of much of the characterized data through actual site visits and interviews, further substantiating the validity of the analysis.

Analysis of the 1984–1990 failure data yielded somewhat unexpected results (Casada, 1993):

- In response to the original OM-22 questions regarding age effects, it was discovered that there was minimal relationship found between failure rate and valve or plant age.
Large valves were found to be more likely to degrade, and more likely to degrade significantly, than smaller valves. (Extent of degradation was characterized as either "significant" or "moderate," depending on the effect of the failure on the valve, not the system or plant.)

Valves used in service water, main steam, feedwater, and diesel starting air systems were found to be two or more times as likely to fail as the valve population as a whole.

Valves used in normally operating systems did not experience significantly higher overall failure rates than those used in support of shutdown or for testing only.

Other conclusions from the study, that were perhaps more anticipated, included:

- Significant differences in failure rates by manufacturer were found; however, factors such as specific application and service environment, which likely had significant impact on the results, could not be evaluated.

- Although boiling water reactor (BWR) plants exhibited higher overall relative failure rates, this was clearly the result of the fact that BWRs are better structured to detect failures programmatically [e.g., through inservice testing (IST) programs], and not due to inherently higher failure rates.

- Degradation of disc stud and/or hinge arm areas was the least likely area to be detected programmatically and was also generally significant in terms of extent of degradation.

**Analysis Updates**

Desiring to gather additional information and to identify any performance trends, the NRC requested ORNL to update the original failure analysis for two additional study periods, 1991 and 1992. Analysis for 1991 has been completed, while that for 1992 is currently in progress. A somewhat augmented approach was undertaken for the 1991 study, building from experience gained from the 1984–1990 analysis. An important difference in the two studies was the incorporation of specific valve type data for 1991 (e.g., swing, lift/piston, tilting-disc check valves), since this parameter was recognized as being perhaps the most significant in terms of failure correlation. Since specific valve type is not inherent in the NPRDS database, gathering of data was done by utility questionnaire, vendor manual review, and other available resources. The utility questionnaire, administered by the NIC Subcommittee on Performance Data Analysis, also provided an opportunity to solicit input on special valve design features, installation orientation, application, inclusion in site check valve program(s), and other design data. Approximately 61% of the plants responded to the questionnaires, resulting in identification of nearly 88% of the failures being characterized according to specific valve type (McElhaney, 1994).

Another notable difference in the analyses for 1984–1990 and for 1991 was the filtering process used to exclude valves from further analysis. While both studies excluded failure reports involving no internals degradation, nonfailures, and noncheck valves, the 1991 (and subsequent) analysis included most failures involving seat leakage. As a result, more "moderate" type failures were included in the 1991 study. Although this approach somewhat invalidates direct comparison between the two periods, it was felt that a better representation was gained of actual check valve performance. Comparison of data based on "significant" failures for the two periods is considered to be valid.
Results of the 1991 study differed only slightly from those in 1984–1990 (McElhaney, 1994). Significant findings from the 1991 study that were consistent with the earlier study included the following:

- The relationship between failure rate and valve or plant age was not strong.
- BWR plants exhibited a slightly higher failure rate than did pressurized water reactor plants (PWRs) but had a large percentage of failures detected programmatically.
- Failures involving improper seating comprised the largest percentage of failures. The percentage of failures involving this failure mode increased from 45% in 1984–1990 to 64% in 1991 but was probably largely affected by the different filtering processes employed in the analysis.

Other findings that differed from the 1984–1990 study were:

- Although larger valves continued to exhibit a failure rate greater than that of smaller valves, the failure rate for valves in the smallest group (≤ 2-in.) increased.
- In terms of significant degradation, valves in high pressure coolant injection, suppression pool support, reactor core isolation cooling, and diesel starting air systems exhibited the highest relative failure rates.
- Systems that were identified as being used only in testing or in response to transient/emergency conditions showed a slightly higher failure rate than did shutdown support or normally operating systems.

The first data available relative to specific valve type for 1991 resulted in a failure distribution of 35% lift/piston check, 33% swing check, 12% unknown valve type, and the remainder composed of tilting-disc, duo/double disc, stop, in-line, and other. (It was not possible, however, to establish relative failure rates, since information does not yet exist regarding the population distribution by specific valve type.) Insight gained from this data, however, includes correlations such as valve type vs. failure mode and failure cause.

Figure 1 shows the distribution of significant 1991 failures by specific valve type and failure mode. It is clear from this chart that certain types of valves are susceptible to certain failure modes. For example, failures of lift/piston check valves tend to be manifested by sticking open or closed, while swing check valves are more prone to failure by restricted motion/flow or by sticking open. This was intuitively predicted by industry experts based on differences in design of the two types of valves, but no data was previously available to support the assumptions. The ORNL analyses have proven to be valuable sources of information for issues related to check valve design, application, maintenance, and testing.

Performance Trending

One of the primary purposes of analysis updates based on 1991 and 1992 data is to track industry response to the check valve issues identified in the mid-1980s. Also, results of the 1991 study compared with those of the previous period show that some data taken from any one period can, by itself, be misleading. A significant performance indicator that can be trended is the failure distribution by general detection method. Figure 2 shows the trending results by general detection method for significant failures from 1984–1990, 1991, and 1992 (1992 data is preliminary). Based on the increased trend in failures
detected programmatically (and corresponding decrease in failures discovered by abnormal equipment operation), the data suggests that the nuclear industry has improved its failure detection practices. Percentages of failures detected by miscellaneous or unclear methods have also been shown to decline, indicating a general improvement in utilities' NPRDS reporting practices.

![Diagram of check valve failures](image)

**Figure 1:** Distribution of Significant 1991 Check Valve Failures by Specific Valve Type and Failure Mode

**FUTURE INDUSTRY DIRECTION**

Information gained from the ORNL analyses has become a catalyst for change in the industry approach to most check valve-related issues. Probably the most significant impending change is that of the "condition monitoring approach" to IST endorsed by OM-22 (and currently in the final approval process prior to being published in the O&M Code). This approach, in conjunction with the "maintenance rule," will allow utilities to focus resources on problem areas based on system/component failure/availability indicators by using the best available information to determine the most appropriate means of monitoring component condition. Already, NIC has begun to establish a performance database based on the ORNL methodology and data and has agreed to assume responsibility for future failure analyses beginning with 1993 data (Hart, et al., 1994).
It is anticipated that individual utilities will collect information on the performance of the components in their plants to support requests for extension of inspection and test intervals. Accordingly, the NRC is funding ORNL to establish an independent database based on ORNL's performance analysis research that will provide a basis for NRC evaluations of individual utility requests for extension. Additionally, opportunities may arise to use the same information to assist the ASME in reformulating its requirements for the frequency of testing and inspection, and may also be used to support the prioritization and details of NRC inspection plans and guidance. It may also be possible to identify equipment and techniques to increase the effectiveness of tests and inspections, possibly allowing a reduction in their frequency while still maintaining a high level of confidence in the functionality of the components.

The ORNL data has already proven useful in the evaluation of designs for advanced passive light water reactors, which are dependent on the proper functioning of check valves to actuate their passive safety systems.

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REFERENCES


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AN ANALYSIS OF CHECK VALVE FAILURE EXPERIENCE IN THE NUCLEAR INDUSTRY

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Outline

➤ Background
➤ Analysis procedure
➤ Initial study period: 1984-1990
➤ Analysis updates/Trending
➤ Industry direction and future activities
Background

➢ San Onofre check valve failure event

➢ Guidance documents

➢ INPO SOER 86-03
➢ Generic Letter 87-06
➢ Information Notice 88-70
➢ Generic Letter 89-04
➢ NUREG-1352
Background (continued)

- Nuclear Industry Check Valve Group (NIC)
- ASME OM-22 Working Group on Check Valves
- Oak Ridge National Laboratory (ORNL) studies funded through Nuclear Plant Aging Research (NPAR) Program
Initial ORNL Analysis
1984-1990 Data

- Review of 5000 NPRDS failure records
- 1227 failure records analyzed
- Failures manually characterized according to certain parameters:

<table>
<thead>
<tr>
<th>Included in NPRDS database</th>
<th>Not included in NPRDS database</th>
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<tr>
<td>Plant age</td>
<td>System operating status</td>
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Analysis Procedure

- Study focused on internal degradation
- "Failure" = Degradation of one or more valve functions (failure to open, failure to close, loose/broken parts, etc.)
- Degradation characterized according to the valve, not system effect
- Relative failure rates established using data normalized according to inservice time (valve-years)
- NIC Utility review
Results of the 1984-1990 Study Were Varied

- Minimal relationship between failure rate and valve or plant age
- Large valves more likely to degrade, and more likely to degrade significantly
- Systems with high failure rates included Service Water, Main Steam, and Diesel Starting Air
- Failure rates did not vary significantly by system operating status
1984-1990 Results (continued)

- Factors affecting failure rates by manufacturer could not be evaluated
- BWRs more likely to detect failures programmatically
- Disc stud / hinge arm area degradation less likely to be programmatically detected
Analysis Updates

- NRC funded updates for failures in 1991 and 1992
- NIC utility surveys
- Inclusion of specific valve type in database
- Modification of screening process to include more "moderate" type failures
Results of 1991 Study

- Relationship between failure rate and valve or plant age not strong
- BWR plants had higher failure rate than PWRs, but more detected programmatically
- 64% of failures involved improper seating (affected by screening process)
1991 Results (continued)

- Failure rate for smaller valves (2-in.) increased
- HPCI, Suppression Pool Support, RCIC, and Diesel Starting Air valves had highest failure rates for significant degradation
- Systems used for testing or emergency response had slightly higher failure rate
Valve Type vs. Failure Mode

Distribution of significant 1984-1992 check valve failures by specific valve type and failure mode.
Performance Trending

- Track industry response to check valve issues
- Ensure validity of results
- Examples:
  - Trend in general detection method
  - Trend in extent of degradation
  - Trend in NPRDS reporting practices
Extent of Degradation Trend

Note that the screening method for NPRDS data was changed after 1990 to include more internal leakage type failures.

Failure trend by extent of degradation: 1984-1992
NPRDS Reporting Practices Trend

Average text length for NPRDS check valve failure narratives characterized vs. failure year
Future Industry Direction

- Condition monitoring approach to IST in O&M Code
- NIC performance database
- ORNL database augmentation
- Evaluation of utility requests for extension of inspection and test intervals
ORNL Activities

- Check valve analysis methodology applied to other components; e.g., pumps
- Design evaluation of advanced light water reactors
- Evaluation of inservice test equipment and techniques
Summary

- Over 2000 failure records characterized
- Data suggests positive trends in terms of failure detection, extent of degradation, and NPRDS reporting
- Database and methodology continuously improving
- Applicability to industry needs