Survey of Operating Experience to Identify Structural Degradation of Nuclear Power Plant Components

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Abstract

An assessment of the information available in nuclear power plant Licensee Event Reports (LERs) pertinent to identifying failures due to age-related degradation was performed by the Nuclear Operations Analysis Center (NOAC) staff at Oak Ridge National Laboratory. LERs from commercial power plants submitted from 1969 to 1982 were surveyed yielding 3098 events considered age-related failures. Wear, corrosion, fatigue, vibration, stress corrosion, and erosion were the identified structural failure cause mechanisms in over half of the events. The study contains data on failed components, the age-related failure mechanisms responsible, the severity of the failure, and the failure detection methods of failures from possible age-related causes.

1. Introduction

The objective of this study was to review the currently available sources of light water reactor operating experience information contained in the Licensee Event Reports (LERs) to identify and evaluate age-related events. The review focused on time-related degradation mechanisms which affect mechanical, structural, and electrical systems and/or components which could result in compromising a safety function. The results are published in NUREG/CR-3543 "Survey of Operating Experience from LERs to Identify Aging Trends" [1]. The study was performed as part of the overall Nuclear Plant Aging Research (NPAR) Program being conducted by the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC).

This study utilized LER data only to determine failed components, the age-related failure mechanisms responsible, the severity of the failure, and the failure detection methods which contributed to a reportable occurrence.

2. Search Methodology

The NOAC maintains a keyworded file of LER abstracts, accessible through the Department of Energy (DOE) RECON database. Keywords are assigned to identify the specific plant, reactor type (BWR/PWR/HTGR), affected systems, components, and proximate cause(s) of an event, if the information is available in the LER. Using an exclusive RECON keyword search process, 7256 abstracts were obtained. Additional detailed review produced 3098 unique events considered to be age-related equipment failure. This represents about 11% of all reportable events in the years 1966 to 1982. Over 50% of these occurred in the years 1979 to 1982.

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3. Age-Related Failure Mechanism Analysis (Table 1)

3.1 Wear

Wear was identified as a failure mechanism when information was not available to be more specific. Seventy-seven plants reported 522 failures caused by *wear*. These events occurred in almost all plant systems, but a larger fraction of *wear* events pertained to monitoring systems (airborne radioactivity and radwaste monitoring) compared with other mechanisms.

The components and parts for which wear was most often reported included monitors (sample pumps), isolation valves (valve seats), and penetrations (seals). *Wear* reported for pumps (124 events) included worn parts such as impellers, bearings, seals, belts and packing. The detection of wear failures was primarily by routine testing or inspection (59%) and operational abnormalities (35%).

3.2 Corrosion

Of the 3098 events, 414 (13%) identified *corrosion* as the failure mechanism. This does not include stress corrosion, which is discussed separately. Corrosion events were reported for almost every system for which LERs are filed. The largest numbers of reports pertained to the service water system (49 events), main steam supply system (43), safety injection (39), liquid radwaste system (28), emergency power system (23 events, almost all relating to diesel generators), and containment isolation system (21).

The components and parts most affected by corrosion were pipes, valves and welds. Steam generators and other heat exchangers represented a large number of reports due to tubing corrosion.

Most corrosion events were discovered during routine testing or inspection, nondestructive testing, or routine surveillance (such as plant walk-throughs).

Several corrosion-related problems currently being addressed in operating power plants include corrosion induced in cooling-water systems handling raw water and severe corrosion in chemical waste treatment and boric acid systems.

Steam generator tube failures were generally described as *corrosion* or *stress* corrosion; consequently, such failures were reported under either category.

3.3 Contamination

Three types of contamination failures were defined in this study:

1. External contamination - representing externally generated material which may cause failures due to external effects or may be ingested by equipment and cause internal problems.

Table 1. Failure mechanisms for age-related events

Failure mechanism[a]	Number of events	Failure mechanism[a]	Number of events
Wear	522	End of life	226
Corrosion	414	Contamination (electrical contacts)	205
Contamination, internal	382	Vibration	165
Contamination, external	331	Stress corrosion	110
Fatigue	324	Erosion	102
Crack	259	Other miscellaneous mechanisms	58

[a]While not all are actual failure mechanisms, these classifications were assigned where no definitive failure mechanism was included in an LER.

2. Internal contamination - contaminants to a system or component that are internally generated which may include corrosion products, wear debris, and other effects.
3. Contact corrosion/contamination - Electrical contacts have unique problems with contamination and were examined separately. In addition to being susceptible to external contamination, they commonly generate oxidation coatings that can cause failure. Generally LERs only report "failure due to dirty contacts," so distinctions between the two types of contact contamination could not be made.

3.3.1 External contamination

Externally generated contamination was responsible in 331 reported events at 73 units. These events occurred in 39 systems, with 7 systems accounting for 52% of the events including containment heat removal, service water, fire protection, and emergency power system cooling water.

Valves were involved in a large number of the external contamination events. The valve parts involved were mostly valve seats, housings, operators and shafts. Pumps were the second most common failed component, with strainers, housings, impellers, and associated piping mostly affected. Monitors were also involved in a large number of these failures due to contamination effects on filters, blowers and sensing elements. Heat exchanger contamination events were dominated by coil blockage due to silt and marine growth. Detection of external contamination events was primarily accomplished by two means — routine testing or surveillance (55%), and operational abnormalities (36%).

3.3.2 Internal contamination

Internally generated contamination resulted in 382 events involving 77 plants. Events were reported for 47 different systems, with 10 systems accounting for 65% of the events. A large number of containment isolation system events (73) occurred, mostly due to valve seat contamination on containment isolation valves. Emergency power system events occurred in lubricating oil and air start systems, plus heat exchanger contamination on diesel generators.

On a part basis, a total of 166 internal contamination events involved valve seats, valve operators, and shafts. Diesel generator events involved contamination of parts such as filters, governors, heat exchangers, piping, valves/valve operators and air start motors.

Detection of internal contamination events was primarily during routine testing or surveillance (72%), with an additional 24% discovered due to operational abnormalities. The events were also evenly divided between those considered as immediate (catatrophic) failure (51%) and degradated failures (49%).

3.3.3 Contact corrosion/contamination

The project examined 205 events reporting contact contamination. The failed parts involved included contacts in various types of switches, relays, circuit breakers and monitors.

Seventy percent of the contact contamination events were considered catastrophic failures in nature, mostly because most electrical equipment of this type is considered to either operate or fail completely.

Sixty-eight percent of these events were discovered during routine testing or surveillance and another 28% from operational abnormalities.

3.4 Fatigue

Fatigue was reported as the failure mechanism for 324 events examined in this study.

Fatigue, as reported by LERs, may include both thermal and mechanical fatigue failure. In many cases the LER is not detailed enough to determine the underlying cause except by inference from failure location (e.g., charging lines experience vibration conditions, feedwater nozzles experience thermal cycling). The majority of the 324 fatigue failures were reported in the CVCS system, coolant recirculation system, ECCS, and RHR system.

Fifty-two percent of the 324 fatigue events involved piping and pipe fittings mostly weld failures including recurring problems with socket welds. Other components with frequent failures included pumps (continuously operating high-pressure pumps which provide an environment likely to result in mechanical fatigue failures), valves, and diesel generators. Detection of fatigue events was accomplished primarily by routine testing/inspection (68%) or operational abnormalities (27%). The severity of the events was considered degraded in 75% of the reports and catastrophic for 25%.

3.5 Crack

Although cracking is not an actual failure mechanism, 259 events listed cracking as a cause of failure. This indicates one of the limitations of LER information, that is, lack of detail. These events occurred in 40 different systems with the largest number of reports concerning safety injection (29 events), CVCS (27), coolant recirculation (22), reactor coolant cleanup (21), and main steam (20) systems. The failed components/parts were piping (welds), pumps, valves and steam generators (tubing). Detection methods were primarily routine testing or surveillance (55%) and operational abnormalities (41%).

The lack of detail concerning these events is important because of the number of events involved. The 259 crack events compares to only 165 vibration events and 110 stress-corrosion events. Reassignment of the crack events to these specific mechanisms (if additional information were available) could change the failure data presented here.

3.6 End of Life

This class of events is where the only information available in the LER was that the component failed due to "natural end of life," without any further information. Two-hundred twenty-six events were classified as *end of life* because no other mechanism could be discerned from the LER.

Of the 226 events, the systems involved included fire protection systems (12%), airborne radioactivity monitoring system (7%), emergency power system (6%), reactor protection system (5%), containment isolation system (4%), and process and effluent radiation monitoring (4%). Another 37 systems were involved with 1 to 8 failures each.

The components and parts involved in events that were reported as *end of life* were largely equipment that the plant expects to replace periodically. The major components included smoke detectors, radiation monitors, filters, and certain valves. The parts involved were mostly sensing elements, charcoal filter cartridges, packing and seals. Sixty-four percent of the events were detected during normal testing or inspection; another 33% were discovered due to operational abnormalities.

3.7 Vibration

Vibration was reported as the failure mechanism for 165 events at 57 plants. The events that were classified as *vibration* included two groups of failure. In one group, the vibration resulted in loose parts (nuts becoming unthreaded, loosened couplings, wiring connections losing contact, etc.) The other group includes events where vibration was stated as the failure cause with no more information given. If it was clearly a vibration-induced fatigue failure, the report was classified as *fatigue*. If not, the event was classified as *vibration*.

Two systems each accounted for 15% of the vibration events — the emergency power system and the RHR system. The emergency power system events primarily involved diesel-generator subcomponents including hoses, governors, piping, and control components (switches and relays) and fasteners (bolts and screws). The RHR system events involved heat exchangers, piping, valves, valve operators, and fasteners.

Detection of the vibration-related failures was accomplished during routine testing or inspection in 78% of the events, with 21% being discovered due to operational abnormalities. Sixty-one percent of the failures were considered degraded equipment operation, and 39% involved immediate (catastrophic) failures.

3.8 Stress Corrosion

The study reviewed 110 events in which *stress corrosion* was identified as the mechanism causing the failure. Stress corrosion was generally not identified immediately by the operating staff. An LER will often state that a failure *may* be due to stress corrosion. In other cases, an updated LER will indicate that results from a laboratory inspection of the failed component identified the specific mechanism as *stress corrosion*. For this reason, it is likely that a portion of the events reported as corrosion, cracking, or fatigue may actually be the result of *stress* corrosion. Also, a large number of events identifying crack as a failure mechanism could be stress corrosion events.

One-hundred ten events were identified by 47 plants, mostly in the main steam supply system, reactor coolant cleanup system, containment heat removal system, ECCS, and coolant recirculation system.

Most of the events were stress corrosion of piping welds. Twelve stress corrosion events were reported for steam generators, including tubing, fasteners, and nozzles.

Detection of stress corrosion damage was generally accomplished in normal testing and/or inspection (71%), primarily during nondestructive testing.

3.9 Erosion

In 102 events *erosion* was identified as the failure mechanism. Some reports used the term corrosion/erosion, either because plant personnel were unsure of the exact cause of the event or because it was due to the combination of mechanisms. Nuclear power plants have experienced erosion in two areas — the first is erosion of service water piping, particularly tubing and elbows, due to silt; others reported problems with erosion in saltwater cooling systems. In many cases, the LERs do not identify a specific contaminant.

The second area of erosion frequently reported is in piping, fittings, and valves due to steam and two-phase water/steam flow — mostly in relief valves, control valves, and drain lines for steam piping. Some erosion was also reported in liquid lines at pump discharges.

Detection of erosion was primarily via operational abnormalities (66%) or routine inspection and surveillance (27%). The majority of the events resulted in leakage, so the events tended to announce themselves.

4. Summary

The ECCS, emergency generator, containment isolation, and CVCS and liquid poison systems were responsible for 28% of the LERs listing an age-related failure cause. This result is not unexpected as plant Technical Specifications are predominantly concerned with maintaining operability of these key systems. Consequently, almost all failures in these areas are reportable, leading to a large percentage of LERs originating with these four systems.

On a component basis, valves made up 20% of the total failed components, and over one-third of these (7.8%) were containment isolation valves. In most cases, foreign material or wear on the valve seat was identified as the root cause of leakage.

Pipe failures comprised over 14% of the age-related incidents reported. Most weld failures appeared to be caused by (1) vibration-induced fatigue of inadequately supported piping, (2) temperature-cycling stresses on improperly fitted welds, and (3) weld defects. Pipe wall failures were caused mostly from erosion by the process fluid (wet steam, borated water) or heat-mechanical stress.

Forty-two percent of pump failures involved impellers, wear rings, shafts, bearings, housing, or couplings; 21% resulted from failure of seals or packing. The balance of pump events were failures of belts, mounting bolts, gaskets, and miscellaneous associated parts.

Timely detection of age-related degradation is a key factor in maintaining the readiness of safety-related systems to perform their function when required. Of the 3098 events determined to be age-related (not including drift), over 64% of the failures were detected by routine testing and surveillance performed in accordance with the plant Technical Specifications or maintenance program. Operating personnel detected 28% of the reportable failure events during normal operational checks and inspections.

About 62% of the failure severities were judged degraded; 38% were deemed immediate (catastrophic). No events could be judged to indicate incipient failure due to the nature of an LER — an occasion whenever plant operation falls outside the limits delineated in the respective Technical Specifications. Since incipient failures are normally detected by routine preventative maintenance (PM) activities, and are corrected, they are not normally reported. Consequently, LERs do not provide a reliable source of incipient failure information.

5. General Conclusions

This Study utilized the LERs to determine failed components, the age-related failure mechanisms responsible, the severity of the failure, and the failure detection methods for reportable occurrences due to possible age-related failures. The data are by no means *statistically* accurate, but serve to indicate possible areas where further efforts should be concentrated to better understand structural failure of components and systems due to time-related degradation.

References

1. G. A. Murphy, R. B. Gallaher, M. L. Casada, and H. C. Hoy, "Survey of Operating Experience from LERs to Identify Aging Trends," NUREG/CR-3543 (January 1984).