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ACCIDENT SEQUENCE PRECURSOR EVENTS WITH AGE-RELATED CONTRIBUTORS

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ABSTRACT

The Accident Sequence Precursor (ASP) Program at ORNL analyzed about 14,000 Licensee Event Reports (LERs) filed by U.S. nuclear power plants 1987–1993. There were 193 events identified as precursors to potential severe core accident sequences. These are reported in NUREG/CR-4674, Volumes 7 through 20.[1] Under the NRC Nuclear Plant Aging Research program, the authors evaluated these events to determine the extent to which component aging played a role.

Events were selected that involved age-related equipment degradation that initiated an event or contributed to an event sequence. For the 7-year period, ORNL identified 36 events that involved aging degradation as a contributor to an ASP event. Except for 1992, the percentage of age-related events within the total number of ASP events over the 7-year period (~19%) appears fairly consistent up to 1991. No correlation between plant age and number of precursor events was found. A summary list of the age-related events is presented in the report.

INTRODUCTION

The Nuclear Plant Aging Research Program identifies aging as the cumulative, time-dependent degradation of a system, structure, or component in a nuclear power plant that, if unmitigated, could compromise continued safe operation. Necessary measures must, therefore, be taken to ensure that aging does not reduce the operational readiness of plant safety systems and does not result in common-mode failures of redundant, safety-related equipment, thus reducing defense-in-depth. It is also necessary to ensure that aging does not lead to equipment failure that could cause an accident.

In September 1994, there were 109 licensed commercial light-water reactor (LWR) power plants in operation in the United States. The age distribution of the plants is as follows:

Operating lifetime (years since operating license)	*Number of plants*
>20	38
15–20	21
10–14	14
5–9	33
<5	4

As U.S. LWRs have aged, some problems have occurred as a result of time-dependent degradation mechanisms such as stress corrosion, thermal aging, radiation embrittlement, fatigue, and erosion. Typical problems have included failures in pumps, valves, and relays; embrittlement of cable insulation; and cracking in steam generator tubes. Although progress is being made to mitigate the degradation that has already been identified, significant questions concerning age-related degradation of systems, structures, and components remain because of the variety of components in a commercial power reactor, the complexity of the aging process, and the increasing age of these power plants.

DESCRIPTION OF ASP STUDY

The ASP Program owes its genesis to the Risk Assessment Review Group,[2] which concluded that "unidentified event sequences significant to risk might contribute... a small increment... [to the overall risk]." The report continues, "It is important, in our view, that potentially significant [accident] sequences, and precursors, as they occur, be subjected to the kind of analysis contained in WASH-1400."[3] Evaluations done for the 1969–1981 period were the first efforts in this type of analysis.

Accident sequences of interest in the ASP study are those that, if additional failures had occurred, inadequate core cooling would have resulted and, as a consequence, could have caused severe core damage. For example, a postulated loss-of-coolant accident with a failure of a high-pressure injection (HPI) system may be examined or studied. In this simple example, the precursor would be the HPI failure. Accident sequence precursors are events that are important elements in such accident sequences. Such precursors could be infrequent initiating events or equipment failures that, when coupled with one or more postulated events, could result in a plant condition leading to severe core damage.

Events considered to be potential precursors are analyzed, and a conditional probability for subsequent core damage is calculated. This is done by mapping failures observed during the event onto ASP event trees. Those events with conditional probabilities of subsequent severe core damage greater than 1.0×10^{-6} are identified and documented as precursors. For more information on event selection and analysis see Chapter 2 of the 1993 ASP report.[1]

It should be noted that the ASP selection methodology is continually evolving and each year's precursors should not be compared to previous yearly selections and assessments.

In addition to the events selected as accident sequence precursors, events involving loss of containment function and other events that are considered serious but that are not modeled are identified in the ASP Program. These events are also documented in the ASP reports.

The ASP study is subject to certain inherent limitations. The results were based on limited data, and the study may be biased by many of the decisions inherent in the process as well as in the methodology itself. A determined effort is being made in the ASP program to address these limitations. Although uncertainties exist in the numeric probability estimates associated with each event addressed in the reports, the identification of the more serious events from a core damage standpoint is considered reasonably certain.

Direct comparison of results with those of earlier years is not possible without substantial effort to reconcile analysis differences. Additional equipment and procedures were incorporated into the analysis of 1992 and 1993 events. The models used in the analysis of 1988–1993 events differ from those used in 1984–1987 analyses. Starting in 1988, the project team evaluated only a portion of the licensee event reports (LERs). Before 1988, all LERs were reviewed by members of the project team. Because of the differences in analysis methods, only limited observations are provided here. Refer to the 1986 precursor report for a discussion of observations for 1984–1986 results and to the 1987–1991 reports for the results of those years.

AGE-RELATED ASP EVENTS

This report presents the results of an evaluation of nuclear power plant operating events identified by the ASP Program for 1987–1993 to determine the extent to which aging has played a role in the ASP events for that period. The ASP Program examined approximately 14,000 Licensee Event Reports (LERs) filed during the period 1987–1993. Of these, 193 events were identified as precursors to potential severe core accident sequences and reported in Reference 1. The authors' review of those 193 events identified 36 that involved aging degradation as a contributor to the event.

Only events involving equipment degradation were selected for further study. The appendices of the ASP Reports contain an event analysis and a copy of the LER for each event identified as a precursor event. On the basis of the event description in the analysis and the accompanying LER, the authors determined whether the event had an age-related contributor. In some cases, discussions with ASP Program personnel helped to conclude whether the event was age-related. A summary list of the age-related events is presented in Table 3.

TABLE 1. NUMBER OF ASP AND AGE-RELATED ASP EVENTS

Year	No. of ASP events	No. of events with age-related causes (% of all ASP events)
1987	33	7 (21%)
1988	32	6 (19%)
1989	30	6 (20%)
1990	28	6 (21%)
1991	27	6 (22%)
1992	27	1 (4%)
1993	16	4 (25%)
All years	193	36

A review of the 193 ASP events identified 36 involving aging degradation that could be considered contributors to the ASPs. Except for 1992, the percentage of age-related events within the total number of ASP events (~21%) appears fairly consistent up to 1991 (Table 1). Only one age-related event could be found in the 1992 ASP events. The lower number of ASP events for 1993 reflects the changes to the selection methodology of the ASP program.

Although aging processes affect all components to some degree, there generally is not a coordinating mechanism to cause failure to occur simultaneously in multiple components. For standby components, surveillance testing can and does detect potential age-related failures. This is illustrated in event numbers 9, 16, 23, and 24–27 in Table 3.

The discussion above emphasizes the importance of a point illustrated by NUREG/CR-3543, *Survey of Operating Experience from LERs to Identify Aging Trends*, and by the ASP status reports (NUREG/CR-4674), that routine monitoring and surveillance testing is the most important defense against safety function degradation. Monitoring of operating equipment and periodic surveillance testing of standby equipment can and does identify age-related failures. With effective surveillance and monitoring programs, aging problems can be handled even though component design and equipment qualification testing can never completely eliminate individual aging failures.

NONAGE-RELATED ASP EVENTS 1987–1993

To provide comparison with age-related ASP events, LERs for the ASP events determined to be nonage-related were also reviewed to determine other causes for the event. Each event was reviewed for a root cause identified from the LER narrative along with any contributory cause(s). Table 2 illustrates the distribution of event causes among various categories. (The root cause categories are not taken from the ASP program.) It can be seen that about one-third of the nonaging events are attributable to personnel errors by operators or other plant personnel. Design and engineering errors make up about one-fifth of the root causes. Errors induced by procedure deficiencies and miscellaneous causes were each responsible for less than 20% of the events.

CONCLUSIONS

Detailed review of the 36 age-related ASP events shows no correlation between plant age and frequency of precursor events caused by aging factors—either component aging or structural aging. For example, Byron 2, in commercial operation for only four months, experienced a possible aging failure of a capacitor in an instrument power supply inverter. Eleven months after beginning commercial operation, Salem 2 entered a Limiting Condition for Operation when a corrosion-induced leak was found in a room cooler for safety-related equipment.

On the other hand, ASP events at older units—Oconee 3, Zion 1 and 2, Dresden 2 and 3, and Pilgrim—resulted from aging of components that may or may not have been in service for the entire time of commercial operation for these units.

Investigation into the details of each of the 36 ASP aging events reveals that, in most cases, more rigorous surveillance and maintenance would have prevented or mitigated the events.

TABLE 2. DISTRIBUTION OF NONAGING ASP EVENTS 1987 TO 1993

Identified Root Cause	No. of Events	Percent
Personnel—operators, maintenance, training, etc.	52	33
Design, engineering error	30	19
Procedure deficiencies	21	13
Spurious or unknown	11	7
Weather, external environment	11	7
Manufacture error, defective part	10	6
Construction error	3	2
Maintenance error	3	2
Other	16	10
Total nonaging ASP events	157	~100%

REFERENCES

1. 1994, *Precursors to Potential Severe Core Damage Accidents: 1993—A Status Report, NUREG/CR-4674, Vol. 19*, U.S. Nuclear Regulatory Commission, Washington, DC.

2. 1978, *Risk Assessment Review Group, NUREG/CR-0400*, U.S. Nuclear Regulatory Commission, Washington, DC.

3. 1975, *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400 (NUREG-75/014)*, U.S. Nuclear Regulatory Commission, Washington, DC.

TABLE 3. SUMMARY OF AGE-RELATED ASP EVENTS 1987–1993

Event No.	Event date	LER No.	Plant name	Event description	Age-related cause		Conditional core damage probability
					Direct	Contributory	
1	01/87	387/87-003	Susquehanna 1	Both diesel generators are unavailable	Capacitor failed in EDG controls due to aging		7.5×10^{-6}
2	05/87	455/87-007	Byron 2	Trip with feedwater isolation and one AFW train unavailable	Possible aging failure of capacitor		3.7×10^{-5}
3	07/87	255/87-024	Palisades	7½-hour LOOP when main transformer deluge system actuated	Contaminant/corrosion buildup in main transformer deluge system		4.3×10^{-4}
4	07/87	338/87-017	North Anna 1	SG tube rupture and plant trip	No identified root cause of SG tube failure		7.7×10^{-4}
5	09/87	346/87-011	Davis-Besse	Scram; 13.8-kV failure; secondary side RV failed open; service water inoperable; decay heat train failure		MSSV failed to reseat; valve disc collar galled	7.6×10^{-7}
6	09/87	370/87-016 370/87-017	McGuire 2	Loss of power to DEH caused TG trip and scram; SW train and PORVs unavailable	MCC tripped; worn insulation on IA compressor motor caused ground		7.0×10^{-6}
7	12/87	344/87-037	Trojan	Reactor trip and one AFW pump fails to start	Aging failure of microswitch in EHC pushbutton	Loose electrical connections; loose valve seat in MOV	4.8×10^{-5}
8	02/88	400/88-006	Harris	Seal water unavailable to SW system pumps	Debris in SW check valves prevented isolation of nonsafety-related portion of SW system		4.8×10^{-4}
9	03/88	414/88-012 414/88-015 Rev. 1	Catawba 2	Degraded AFW system		Valves in AFW and nuclear SW system obstructed by Asiatic clams	2.7×10^{-4}
10	04/88	369/88-007 Rev. 1	McGuire 1	Scram; TDAFW train failed to start		Valve packing leakage caused failure of limit switch on TDAFW steam supply valve	1.0×10^{-6}
11	05/88	275/88-014	Diablo Canyon 1	Degraded diesel generators due to clogged filters	Biofouling in EDG fuel filters		4.1×10^{-4}
12	06/88	424/88-016 Rev. 1	Vogtle 1	Water leakage into control room panel caused spurious PORV actuation		Dust accumulation on heaters in room above CR caused spurious fire system actuation	8.0×10^{-5}
13	09/88	344/88-029	Trojan	Both trains of SI and one EDG inoperable for 16 min	Clam debris in SI pump lube oil cooler		8.6×10^{-5}
14	02/89	338/89-005	North Anna 1	Scram from MFW regulating valve closure; SGTR; RHR suction valve failure to open	Fatigue failure of IA line for MFW regulating valve	Steam generator tube rupture	1.9×10^{-4}

Event No.	Event date	LER No.	Plant name	Event description	Age-related cause		Conditional core damage probability
					Direct	Contributory	
15	03/89	249/89-001	Dresden 3	LOOP while LPCI unavailable; degraded HPCI, CCSW, and IA systems	Grounded capacitor in power circuit breaker; dirty contacts on another breaker caused LOOP	LPCI: breaker did not close due to sticking linkage; breakers not included in maintenance program	1.3×10^{-5}
16	03/89	317/89-005	Calvert Cliffs 1	Failure of IA boundary check valve; could have resulted in saltwater pump runout in case of containment pump recirculation and LOOP	Worn valve seat (over 10 years in service)	Valve type inappropriate	1.4×10^{-6}
17	03/89	369/89-004	McGuire 1	Steam generator tube rupture	Corrosion assisted cracking of SG tube		7.7×10^{-4}
18	04/89	368/89-006	Arkansas Nuclear One Unit 2	Scram; HP turbine extraction steam line ruptured; one train of AFW unavailable	Pipe rupture due to erosion/corrosion of extraction steam line	AFW suffered overspeed trip due to drift in governor ramp setting	1.2×10^{-4}
19	11/89	289/89-002	TMI 1	Oil sludge rendered EDGs inoperable	Sludge formation from overheating and infrequent oil changes		2.4×10^{-4}
20	01/90	237/90-002	Dresden 2	Reactor scram followed by a loss of offsite power	Fault in condensate booster pump motor	Insulation degraded in auxiliary transformer	3.1×10^{-6}
21	01/90	366/90-001	Hatch 2	Scram while HPCI inoperable; MSIV closed on false low condenser vacuum signal	Excessive wear from sensing line vibration caused instrument isolation valve to close	Design deficiency allowed single failure to cause MSIV closure	6.0×10^{-5}
22	09/90	293/90-013	Pilgrim	Scram; RCIC failed; FW, HPCI, and RHR problems occurred during shutdown cooling	Short in junction box from degraded seal on nearby leaking RV allowed moisture intrusion		8.4×10^{-5}
23	11/90	295/90-023	Zion 1	Two of three EDGs inoperable	Swing EDG: O-rings in manual air start valve degraded from contamination and high ambient temperatures in IA system; 1A EDG: corrosion on control room switch contacts		1.4×10^{-5}
24	12/90	311/90-042	Salem 2	SI and one train of emergency power unavailable	Charging pump unavailable; external corrosion caused leak in pump room cooler for component cooling water pump		1.3×10^{-6}
25	12/90	482/90-025	Wolf Creek	SI pumps inoperable – common minimum flow return line to RWST frozen	Heat tracing did not automatically energize because internal corrosion caused temperature switch failure		4.7×10^{-5}
26	03/91	440/91-009	Perry	Div 1 and Div 2 EDGs inoperable	Div 2: field contactor failed to close due to wear in linkage (possible vibration)	Div 1: limit switch on motor-operated potentiometer malfunctioned	5.3×10^{-4}

Event No.	Event date	LER No.	Plant name	Event description	Age-related cause		Conditional core damage probability
					Direct	Contributory	
27	05/91	333/91-006	Fitzpatrick	Plant shut down to repair both trains of LPCI	LPCI A: O/B containment isolation valve stem fractured; severe damage to disc and seat LPCI B: I/B containment isolation valve failed in mid-position because of worn stem thread		2.0×10^{-5}
28	06/91	304/91-004	Zion 2	Scram from MFW pump trip; one AFW pump failed to start	LOFW when capacitor failed in SG water level control power supply		1.0×10^{-5}
29	07/91	287/91-007	Oconee 3	Scram due to LOFW with degraded EFW	LOFW: particles from degraded seal clogged IA line to controller for CD system: all CD flow isolated		1.8×10^{-5}
30	08/91	336/91-009	Millstone 2	Both diesel generators unavailable and unit shut down	Potentiometer in EDG controls degraded	Possible contamination of EDG hydraulic control oil system	2.1×10^{-4}
31	08/91	410/91-017	Nine Mile Point 2	Loss of five nonsafety uninterruptible power supplies	Transformer failed from undetermined cause	Degraded batteries in UPS logic power supply	3.8×10^{-4}
32	02/92	254/92-004	Quad Cities 1	Reactor trip with HPCI with one SRV unavailable	Unknown	Wear debris in solenoid contacts due to aging	6.9×10^{-6}
33	3/93	529/93-001	Palo Verde 2	SG tube rupture	IGA/IGSCC of SG tube	Aging of radiation monitor	4.7×10^{-5}
34	4/93	339/93-002	North Anna 2	Auxiliary feedwater disabled after reactor trip	Potentiometer corroded in main generator controls		1.1×10^{-6}
35	6/93	213/93-006 213/93-007	Haddam Neck	Degraded MCC, PORV, and EDG	Aging, dust buildup, heat on generator controls		6.5×10^{-5}
36	12/93	370/93-008	McGuire 2	LOOP and failure of an MSIV to close	Possible aging failure of high voltage insulator		9.3×10^{-5}