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Office for Analysis and Evaluation
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SUBJECT: RECENT SOLENOID-OPERATED VALVE EXPERIENCES INVOLVING MAINTENANCE AND TESTING DEFICIENCIES

Enclosed is a Technical Review Report on "Recent Solenoid-Operated Valve Experiences Involving Maintenance and Testing Deficiencies." It describes common-mode SOV failures at Salem 2 and Peach Bottom Units 2 and 3. The common-mode SOV failures at Salem resulted in a catastrophic failure of turbine equipment that resulted in an outage of about 6 months. The Peach Bottom event involved repetitive failures of safety systems with a shorter duration outage.

The Technical Review Report concludes that the events at Salem Unit 2 and Peach Bottom Units 2 and 3, are exemplary of situations where less than adequate surveillance testing and maintenance of SOVs resulted in the reduction of plant safety margins and/or significant financial burden. In recognition of the fact that highly reliable, nonobtrusive SOV diagnostic monitoring equipment is not available, prudent preventive maintenance and surveillance testing should be utilized to minimize the likelihood for common-mode SOV failures thereby enhancing reactor safety and possibly avoiding major downtimes.

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AEOD Technical Review Report

Unit Nos:	Salem Unit 2; Peach Bottom Units 2 and 3	TR Report No.:	AEOD/T92-04
Docket No.:	50-311; 50-277; 50-278	Date:	June 1992
Licensee:	Public Service Electric and Gas; Philadelphia Electric Company	Evaluator/Contact:	H.L. Ornstein

SUBJECT: RECENT SOLENOID-OPERATED VALVE EXPERIENCES INVOLVING MAINTENANCE AND TESTING DEFICIENCIES

In February 1991, the NRC issued an AEOD Case Study, "Solenoid-Operated Valve Problems at U.S. Light Water Reactors," NUREG-1275, Volume 6 (Reference 1). That report presented information on about four dozen events in which solenoid-operated valves (SOVs) had failed or were degraded so that the safety margins of plants were reduced below the levels assumed in plant safety analyses.

This technical review report presents recent SOV operating experience. It describes common-mode failures at the Salem Unit 2 and Peach Bottom Units 2 and 3 plants. At the Salem plant, there was a catastrophic failure of turbine and generator equipment that resulted in an outage of about six months. The Peach Bottom event involved repetitive failures of safety systems with a shorter duration outage. The events described in the report demonstrate the need for prudent preventive maintenance and surveillance testing.

DISCUSSION

It is the author's view that prudent maintenance and surveillance testing can help minimize the likelihood for common-mode SOV failures. However, maintenance and surveillance testing are not substitutes for good engineering and should not be relied upon to overcome all design and application errors.

Although it did not involve any "safety-related" systems, one of the most costly common-mode SOV events in the United States was the turbine overspeed event which occurred at Salem Unit 2 on November 9, 1991. That event involved the failure on demand of three solenoid-operated valves in the turbogenerator's overspeed protection control system. Those three SOV failures resulted in major damage to the turbine and generator; condenser failures; lube oil and hydrogen fires; and a hydrogen explosion. The turbine speed was estimated to be 2900 rpm (vs. 1800 rpm rated speed). Turbine missiles penetrated the turbine casing, and some missiles traveled over 100 yards. Figures 1 and 2 show some of the damage. The event resulted in an extended outage expected to be about six months with a cost estimated at over 100 million dollars.

About three weeks before that event, the licensee was performing a test of two SOVs in the main turbine's overspeed trip system (References 2 and 3). The surveillance test

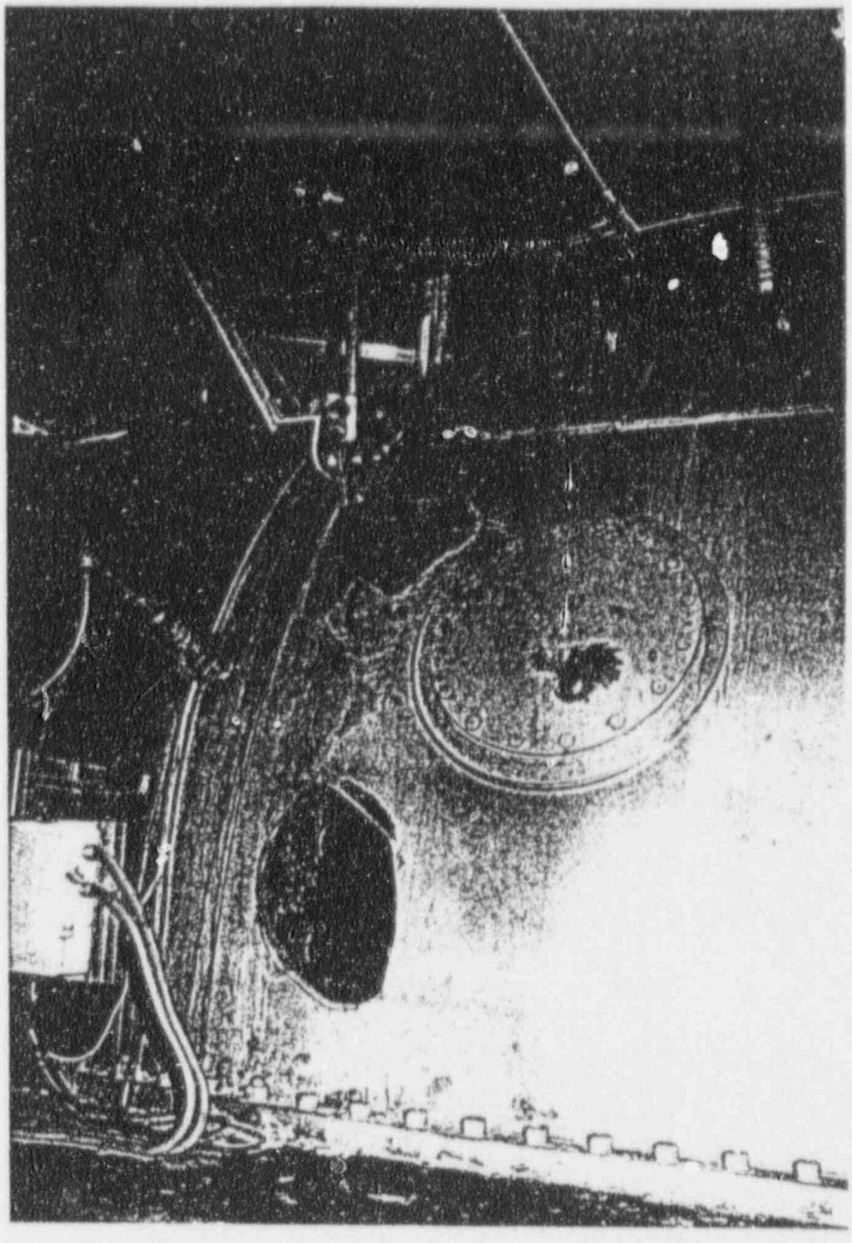

Figure 1 Turbine Casing
Salem Unit 2

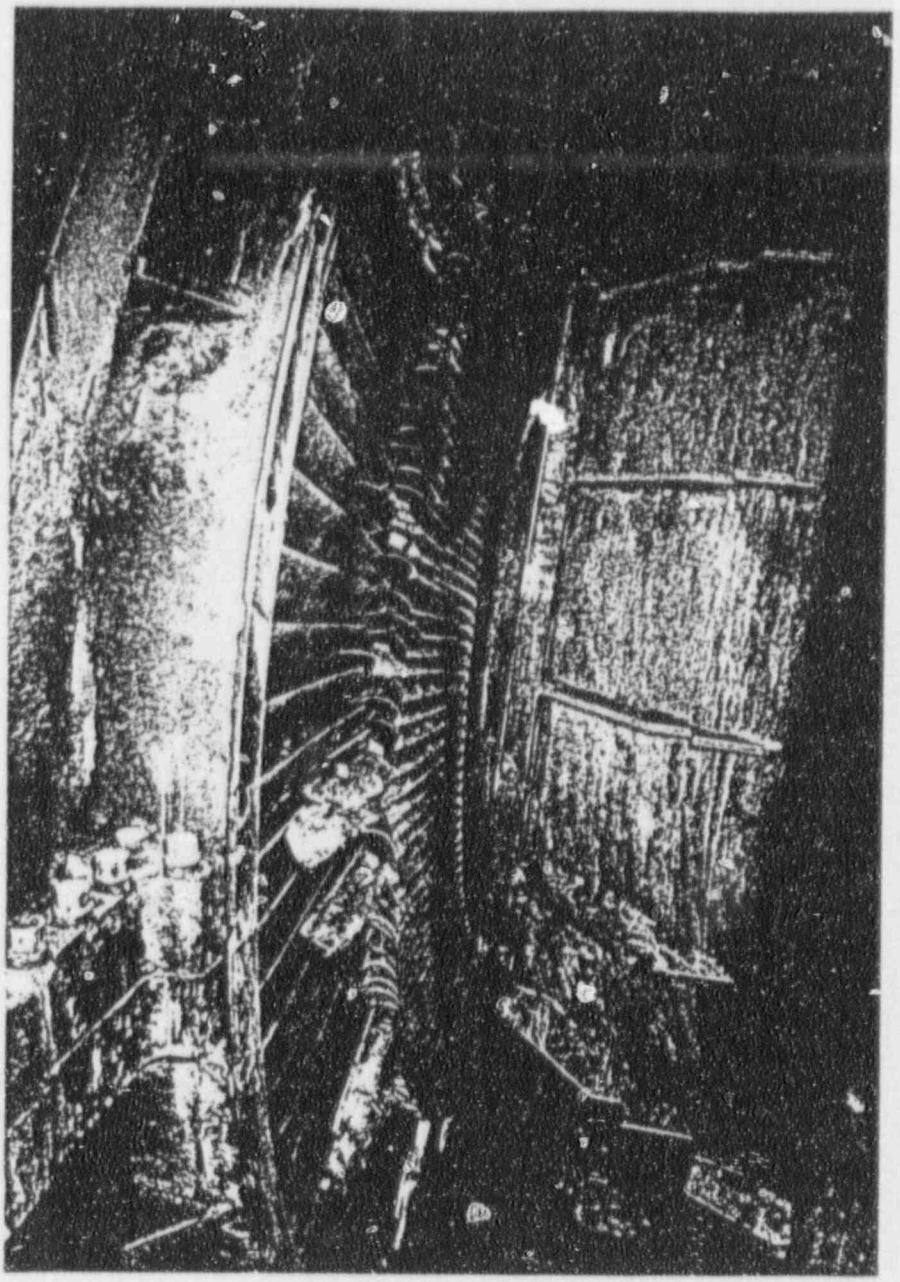

Figure 2 Low Pressure Turbine
Salem Unit 2

being conducted was not capable of revealing the malfunction or degradation of one of two parallel overspeed protection controller SOVs (OPC 20-1 or OPC 20-2 shown in Figure 3). A successful test would confirm that at least one of those two SOVs was operating properly. An unsuccessful test would indicate failures of both SOVs. The operators performing the test in October were puzzled when the surveillance test showed that both SOVs were inoperable. They repeated the test a second time and had the same results. The operators discussed the test failures with other station personnel and they collectively concluded that the SOVs could not both have failed, and that something must have been wrong with the test procedure. It is highly probable that both SOVs did not fail at once in October 1991. It is quite likely that one SOV had failed earlier (and had been undetected), and that the second SOV had undetected degradation, and it failed at the time of the surveillance test. Three weeks later, on November 9, 1991, the main turbine overspeed protection system was tested. However, in addition to the two undetected failed SOVs, a third SOV which was being tested also failed (SOV ET-20 shown in Figure 3). Had either of the first two SOVs been operable (OPC 20-1 or OPC 20-2), one of them would have actuated upon failure of the third SOV (ET-20), and a simple turbine trip would have occurred without any damage.

Reference 1 noted many other previous events in which inadequate surveillance testing was responsible for not detecting common-mode SOV failures or degradations which compromised safety systems at other plants. An example of inadequate surveillance testing which did not detect individually failed SOVs in a similar parallel arrangement was observed in Liebstadt's emergency diesel generators (EDGs) (Reference 1). On a visit to the Waterford Unit 3 nuclear power plant in March 1992, the author learned that after the Salem 2 event, the Waterford licensee conducted a test of its turbine overspeed system, using a revised testing procedure in order to determine the operability of each of the two parallel SOVs, OPC 20-1 and OPC 20-2. Previous testing at Waterford like the testing at Salem was incapable of detecting a single failed SOV. Waterford's first test (Reference 4), which was performed on February 21, 1991, revealed a failed SOV (Parker Hannefin Model No. MRFN16MX0834 – the same model valve as the ones which had failed at Salem). The Waterford staff proceeded to test the second Parker Hannefin MRFN16MX0834 SOV with great hopes that it would work satisfactorily – otherwise, they feared that they would have been in a situation similar to that at Salem Unit 2 (i.e., performing a new test, finding both SOVs failed, and suspecting that the SOVs were really operable and assuming that the surveillance testing procedure was flawed). Fortunately, the surveillance test of the second SOV at Waterford found that it did operate satisfactorily, thereby confirming that the new surveillance testing procedure was not flawed, and that the first SOV which had been tested had truly failed.

A less dramatic, but more safety significant example of inadequate SOV surveillance testing occurred at the Peach Bottom Unit 3 facility in August 1991. At that time, the Peach Bottom station experienced widespread degradation and multiple failures of SOVs affecting many safety-related systems. As noted in References 5 and 6, SOVs piloting air-operated valves (AOVs) controlling emergency service water (ESW) for the HPCI and RCIC room coolers had been sticking during surveillance tests. Similar events involving valves controlling ESW to other safety-related equipment was reported in an initial notification report to the NRC Operations Center (Reference 5). That report

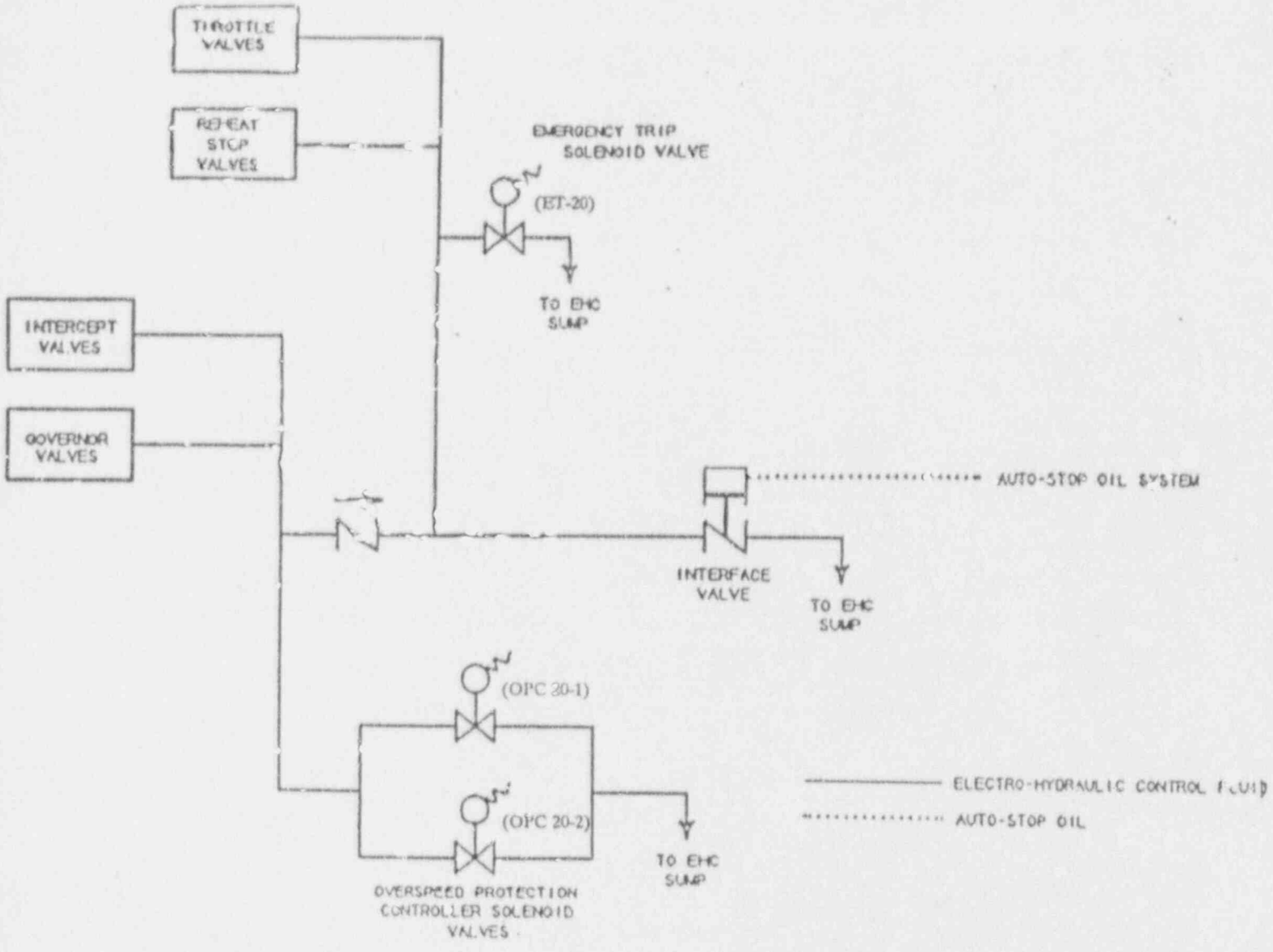

Figure 3 Turbine Electro-Hydraulic Control System
Salem Unit 2

noted that on August 25, 1991, two SOVs controlling ESW to HPCI and RCIC room coolers were found to be mechanically bound. With regard to RCIC room coolers, the licensee "immediately agitated the valve enough so it would operate properly." As a result, the licensee considered the room cooler "fully operable." In addition, the licensee said that the plant had several problems with air-operated valves failing to operate in the past on other systems. However, the licensee noted that the station had "always been able to mechanically agitate these valves so they became operational again." Reference 5 noted that the licensee also said that for the August 25, 1991, event, "they never declared HPCI or RCIC inoperable because the room cooler problems were corrected immediately upon discovery." Subsequently, since redundant HPCI and RCIC room coolers were already isolated, Peach Bottom management declared the HPCI and RCIC systems inoperable, and the unit was shutdown. A subsequent NRC inspection (Reference 6) concluded that the issue of unreported SOV failures noted on August 25, 1991, appeared to have been an isolated case.

Subsequently a review of SOV applications found that each Peach Bottom unit utilized 44 of the same model (ASCO 206-832) SOVs as the ones that had failed on August 25, 1991. Forty of those SOVs controlled room cooling for all the RHR and core spray pumps as well as room cooling for the HPCI and RCIC systems at each Peach Bottom unit. The other four SOVs were located in the ESW return lines from each of the station's four EDGs. Reference 6 indicates that there had been 22 reported failures of those SOVs prior to the August 25, 1991, event.

In response to some of the previous SOV failures, the licensee did extensive root cause failure analysis. Contaminants from the instrument air system and valve lubricants were believed to have caused some of those failures. However, prior to the August 25, 1991, event, the licensee had not taken any systematic steps to preclude common-mode failures of the SOVs in multiple safety systems at both units. (It is interesting to note that prior to installing these SOVs in the late 1980's, the licensee conducted NPRDS searches on ASCO 206-832 valves and only found two entries, both of which involved installation errors with no operating failures reported). None of Peach Bottom's 22 "internally" reported failures were reported to NPRDS or the NRC's LER system prior to August 1991.

After the August 25, 1991, event the licensee embarked on an aggressive program to prevent similar common-mode SOV failures. In addition to performing detailed plant walkdowns with verification of SOV applications (temperature, orientation, MOPD, voltage life cycle, etc.), the licensee has implemented frequent stroke testing of the SOVs of concern (weekly and in some cases, semi-weekly testing). For the longer term, the licensee is planning to implement staggered maintenance, staggered surveillance testing, and SOV diversity (the use of different SOV models in alternate ECCS trains).

CONCLUSIONS

The events described above at Salem Unit 2 and Peach Bottom Units 2 and 3, are exemplary of situations where less than adequate surveillance testing and maintenance of

SOVs resulted in the reduction of plant safety margins and/or significant financial burden. In recognition of the fact that highly reliable, nonobtrusive SOV diagnostic/monitoring equipment is not available, prudent preventive maintenance and surveillance testing should be utilized to minimize the likelihood for common-mode SOV failures thereby enhancing reactor safety and possibly avoiding major downtimes.

REFERENCES

1. U.S. Nuclear Regulatory Commission, Office for Analysis and Evaluation of Operational Data, Case Study AEOD/C90-01, "Operating Experience Feedback Report—Solenoid-Operated Valve Problems," H.L. Ornstein, NUREG-1275, Volume 6, February 1991.

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3. U.S. Nuclear Regulatory Commission, Inspection Report 50-311/91-81, Salem Nuclear Generating Station Unit 2, January 27, 1992.

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6. U.S. Nuclear Regulatory Commission, Inspection Report 50-277/91-27; 50-278/91-27, Peach Bottom Atomic Power Station Units 2 and 3, October 17, 1991.