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CAUSES OF INCORRECT SYSTEM FLOWS

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SUMMARY

LERs associated with incorrect fluid system flow rates were reviewed to identify dominant causes of the observed deficiencies other than silting or plugging of the pipes. The service water system was a major source of problems many of which occurred during the design phase of the system. Many of the flaws were not self-revealing because they reflected incorrect design assumptions, data, or calculations. Because of the subtle nature of these problems, effective and reasonable modifications of quality assurance practices associated with design control and testing are not apparent. However, the types of errors identified in this study should be considered when periodic system reviews are performed by the utility or the NRC.

1. INTRODUCTION

All fluid systems have flow requirements based on a set of scenarios that define the expected functional performance for the system. If the system is composed of physically separated branches (with no auxiliary branches) and only one function, such as high pressure safety injection, the design flows are the simple branch flows. Complicated systems, such as service water, have individual flow requirements for each component connected to the system. Such systems require careful flow balancing to insure the functional performance is met for each supported component. Some of the supported components may not achieve their design flow rates if the system is perturbed from its finely tuned configuration. This study examines some of the causes of incorrect flow rates observed in safety related plant systems.

Fluid systems can be degraded by high flows as well as low flows. Previous generic communications have dealt with excessive flows that adversely affected the net positive suction head (NPSH) of ECCS pumps during the recirculation phase following a LOCA. These include Information Notices 87-63 and 88-74. Other high flow concerns are excessive erosion in piping and excessive vibration in tube bundles in heat exchangers. There have also been generic communications on low system flow rates. These generally dealt with silting and marine growth in service water piping and were culminated by Generic Letter 89-13 that recommended maintenance activities to minimize inadequate flow rates caused by external factors. This generic letter was recently followed up by Information Notice 90-26, which highlighted low service water flows to room coolers because of incorrect pressure drop data provided by the contractor when the preoperational tests were performed.

This study was initiated by an event at Turkey Point where individual charging pumps were not able to meet the design flow requirement because of backflow through an idle pump with a broken internal valve. These types of events are a safety concern because they present degraded flow conditions that may significantly impact a safety function and may not be self-revealing or capable of being detected by existing surveillance tests. An LER search was made to identify operating conditions where off-design system flows were observed at nuclear plants since 1985. These LERs were analyzed to characterize the dominant factors affecting system flow rates.

2. EVENT DESCRIPTIONS

The following discussion summarizes several incorrect flow situations that were reported in LERs since 1985. These situations were selected because they represent a class of problems (other than pipe plugging) that cause incorrect flow in safety related systems. Additional events are presented in the appendix which includes a brief description of the cause of the incorrect flow conditions for each case.

Turkey Point, Unit 3

During power operation at Turkey Point, Unit 3, the reactor operators observed a decrease in pressurizer level and noted that the charging flow had decreased form 84 gpm to 50 gpm (Ref. 1). Initial troubleshooting focused on the charging pump relief valves, but they were not found to be leaking. After additional investigation, it was determined that none of the charging pumps could maintain pressurizer level with a 45 gpm letdown rate. Consequently, all of the pumps were declared inoperable because they couldn't meet the technical specification requirement of 60 gpm plus 9 gpm for reactor coolant pump seal leakage.

The troubleshooting revealed that the reduced flow condition was associated with one of the charging pumps. Inspection of the suspect positive displacement pump disclosed that the pump internal valves and valve guides on the discharge side of the pump were worn. Also, the center suction valve guide was found to be backed out. These degraded conditions allowed backflow from the operating pumps through the defective pump.

San Onofre, Unit 1

A review of test reports, during startup, revealed that the auxiliary feedwater system could produce excessive flow rates under certain pump operating conditions (Ref. 2) The excessive flows posed a concern because of potential water hammer in the steam generators. The LER states:

"The potential for AFW flow-rates to exceed water hammer limits was apparently caused by an error in modeling the turbine driven AFW pump and the newly installed venturis by the SCE contractor preparing the design change. The contractor did not recognize that steam pressure to the AFW pump turbine is regulated to 500 psig. As a result, the model incorrectly assumed that the AFW turbine speed would decrease as SG pressure decreased during the early and middle stages of plant cool-down. In addition, the resistance of the venturis in the non-cavitating mode were incorrectly modeled such that flow restricting capabilities were overestimated.

Due to the various possible flow combinations and configurations there are numerous and complex minimum flow requirements. This complexity resulted in the design criteria document and the start-up test criteria for maximum AFWS flow requirements being incompletely addressed and, consequently, not being properly incorporated into the start-up testing program and procedures. Since the maximum flow limitation was not properly included as a test objective in the test procedure, the initial reviewers of the test results were not aware that a design criterion had not been satisfied."

The licensee will implement appropriate design changes to insure that all the flow requirements are satisfied.

McGuire, Unit 1

In February 1989, flow tests on service water to air conditioning condensers in controlled areas revealed the flow was less than required (Ref. 3). The test was performed because the flow element had been moved in accordance with an October 1986 request. After rebalancing the system, the flow measurements were 810 gpm with the process instrumentation, 824 gpm based on a test gauge, and 1014 gpm based on an ultrasonic flow measuring instrument. The ultrasonic instrument had been used to measure flow in this leg since March 1986 when it was determined that the flow fluctuations at the flow element made it impossible to use the differential pressure instrument. The flow element was originally located downstream of a throttle valve that produced unsteady flow conditions at the flow element.

The ultrasonic flow instrument was calibrated at the plant using another flow element and a test gauge. This calibration was used throughout the three year period before the flow element was moved to a different location in the line. The ultrasonic instrument was originally calibrated at the factory and there are no approved methods for calibrating it at the station. The use of an uncalibrated instrument to verify compliance with design criteria is contrary to station administrative procedures.

Ginna

During discussions of proposed changes for a safety injection pump test procedure, it became apparent that the minimum flow recirculation valves were locked full open instead of in a throttled position (Ref. 4). The licensee performed several flow tests while readjusting the minimum flow recirculation valves. There was poor repeatability in the recirculation flow measurements for one of the pumps. Subsequent investigation indicated that the flow transmitter calibrations were in error. This error was attributed to the designer of the installed equipment.

3. DISCUSSION

A review of the events indicates 12 of the 29 events occurred in service water systems (SWS), 7 in high pressure injection systems (HPIS) or equivalent, and 3 in component cooling water systems (CCW). Because of their widespread utilization throughout the plant, one would expect that service water and component cooling water systems would be more prone to problems than other fluid systems. The fact that they account for 50% of the events is not surprising. The majority of the events occurred at pressurized water reactor plants, however, there is nothing unique at these plants that would specifically impact fluid systems.

3.1 Analysis

For purposes of discussion, the events have been sorted into four categories - design deficiencies, engineering errors, testing mistakes, and administrative errors. Design deficiencies are meant to cover problems outside of the licensee organization, while the other three categories are associated with the plant operating staff. The specific functional organization responsible for the deficiency may differ from plant to plant, but the category titles convey a sense of the associated problems. Administrative errors is a catchall for indeterminate situations.

All of the deficiencies are human errors caused by oversight, marginal decisions, or lack of knowledge. Most of the events involve a review activity in addition to the initial primary activity. Thus, in most instances, more than one person had an opportunity to catch and correct an inappropriate decision. The root causes for these events probably involve a combination of training, communication, motivation, procedures, attentiveness, sense of urgency, and other performance shaping factors. This study does not attempt to sort out these basic factors.

Design deficiencies were a major cause of these events and are reflected in the four examples summarized above. At Turkey Point, a failure of an internal valve in one of the pumps degraded the effective capacity of another pump below its design value because of backflow (Ref. 1). One would expect that the potential for reverse flow through parallel flow paths would be challenged during the design review process. Although not shown on the P&ID, there may have been some indication in the pump specifications that reverse flow through a charging pump was inhibited. Since this was the only instance of backflow found in the LERs reviewed, the problem is not very prominent. In addition, the problem was self-revealing even though the actual cause was not readily apparent.

An error in assumptions used in design calculations caused the San Onofre LER on excessive flow from AFW pumps under certain operating conditions (Ref. 2). The actual root cause whether it be poor communication to the design engineer or a poor assumption on the part of the engineer was not identified in the LER. Incorrect calculation assumptions are not readily identified during subsequent review unless they are separately flagged and the reviewer has knowledge about the specific subject. Excess flow in the AFW system could result in adverse water hammer in the spray ring and subsequent piping failure. Calculation errors that overknowledge about the specific subject. Excess flow in the AFW system could result in adverse water hammer in the spray ring and subsequent piping failure. Calculation errors that over-estimated or under-estimated hydraulic resistances were a major source of deficiencies noted in other LERs in this category.

The McGuire LER illustrates a different design deficiency - improper placement of a flow measuring element (Ref. 3). In this instance, the flow element was just down-stream of a throttled valve which produced unsteady flow conditions that resulted in non-reproducible readings. It took approximately three years before the flow element was moved to a proper location. This type of detail should have been captured during a system review or during plant shakedown when it was obvious that the measurements were inadequate. The chilled water system was affected by this deficiency and may have had low flow for about two years. The situation was self-revealing, but the corrective action was deferred for an extended period of time.

A communication problem was the apparent cause of non-reproducible flow measurements in the safety injection system at Ginna (Ref. 4). This situation was attributed to incorrect flow transmitter data obtained from the designer, however, the LER does not make clear how the transmitter data are related to non-reproducible flow measurements. This situation should have been uncovered earlier if the data were non-reproducible.

Other design related problems include incorrectly sized flow measurement elements, thermal stratification that distorted temperature measurements used in calorimetric calculations, and low flows because of underestimates of heat load requirements. Except for those situations that are self revealing, errors introduced at the design stage often elude detection by normal review and testing programs.

Another important category of deficiencies is engineering oversight which occurs under the licensee's purview. This group includes mistakes in identifying the limiting system configuration, omission of bypass flows when determining total pump flow, and errors in defining acceptance criteria for flow tests. These types of errors may not be amenable to discovery in the review process and therefore go undetected for extended periods of time. One noteworthy example occurred at Turkey Point where concern for erosion in containment coolers caused the licensee to reduce the flow to the coolers which may have violated the design criteria (Ref. 5). The mistake was discovered about four months after the system was readjusted to the lower flows.

Errors associated with flow testing centered on the accuracy or repeatability of the measuring equipment. In one instance, the instrument root valves were excessively throttled to damp out 10% pressure oscillations. The technician was forced to compensate for inadequate equipment. Wrong flow element coefficients were the cause of two LERs. These types of errors may not be captured by the review process. Two LERs dealt with ultrasonic flowmeters. In one case they were considered more accurate than the standard differential pressure meter; in the other case the accuracy was in question. If the realistic uncertainty in the testing process is too large, the tolerances on the flow rates should be loosened or the test equipment upgraded.

Other deficiencies noted in the LERs were incorrect pump impeller replacement and chronic erosion of a flow element requiring recalibration of the readout instrument. These situations reflect different types of oversights in administrative control. The use of an incorrect impeller is an obvious breakdown in the process. Tolerating a deteriorating condition such as an eroding flow element for an extended period of time represents a high threshold for adverse performance. In this instance about 18 months elapsed.

A summary of the various causes of flow errors is presented in Table 1.

All the LERs resulted in degraded flow conditions which presumably resulted in a degraded function rather than a complete loss of function. In several instances the degradation was large, approaching 50%, but in most cases it was small. The safety significance lies in the fact that the quality assurance practices were ineffective in these situations which resulted in plants operating with reduced safety margins of varying significance.

Generic Letter 89-13 on service water systems addressed functional requirements of equipment supported by the service water system. The letter included a test program to verify the heat transfer capability of coolers attached to the system. Implementation of this portion of the letter may not capture the types of design, engineering, and testing deficiencies (identified in this study) because the flaws may not be self-revealing even with testing. This type of hidden error was addressed in Information Notice 90-26, "Inadequate Flow of Essential Service Water to Room Coolers...", which noted that the vendor provided incorrect hydraulic resistance data design a water supply for the room coolers.

A recent information notice (Ref. 6) addressed orifice plates being installed backwards in several plants. This situation results in flows being underestimated which could lead to NPSH, vibration, and erosion problems.

4. CONCLUSIONS

The review of the 29 LERs identifies various ways in which errors are introduced in establishing and maintaining fluid system flow rates. These examples represent flaws in the quality assurance practices associated with fluid systems. Most of the errors in system flow rates are small and the number of events is small. Consequently, the degradation of the functional performance is not overly significant. However, many of the situations were not self-revealing, so that the errors could go undetected for extended periods of time. Although the magnitude of the problem does not appear to warrant aggressive new initiatives, these types of errors should be kept in mind when periodic system reviews are performed by the utility or the NRC.

5. REFERENCES

1. Florida Power and Light, Licensee Event Report 250/89-15, Turkey Point, Unit 3, November 16, 1989.

2. Southern California Edison, Licensee Event Report 206/89-31, San Onofre, Unit 1, December 28, 1989.

3. Duke Power, Licensee Event Report 369/89-02, Mcguire, Unit 1, April 14, 1989.

4. Rochester Gas and Electric, Licensee Event Report 244/89-07, Ginna, June 19, 1989.

5. Florida Power and Light, Licensee Event Report 250/89-14, Turkey Point, Unit 3, September 12, 1989.

6. U.S. Nuclear Regulatory Commission, Information Notice No. 90-65, "Recent Orifice Plate Problems, October 5, 1990.

TABLE 1

SUMMARY OF CAUSES OF FLOW ERRORS

- INCORRECT FLOW ORIFICE AND ORIENTATION
- INCORRECT FLOW CALCULATIONS
- INACCURATE FLOW INSTRUMENTATION
- INCORRECT SYSTEM CONFIGURATION
- INCORRECT FLOW INFORMATION FROM COMPONENT MANUFACTURER
- INCORRECT LOCATION OF FLOW INSTRUMENTATION
- INCORRECT PUMP IMPELLER
- INSUFFICIENT FLOW TEST

APPENDIX

LER Summaries

Clinton LER 461/90-02	Service water flow to numerous room coolers was low because of incorrect manufacturer data. In addition, post-modification testing of the service water system was not performed after flow restriction orifices were installed in selected lines. Throttle valve positions were changed from line-up procedure for some valves without justification.
North Anna 50.72 rpt. 20003	Service water is shared between two plants. Configuration control would allow two pumps to service both units. The system was not balanced for two pumps providing emergency flows to two units.
Salem, Unit 2 Ins. rpt. 272/90-04 Ins. rpt. 272/90-12 LER 272/90-14	The licensee discovered that the charging line flow was not added to the ECCS flow when balancing the system. Consequently, the total pump flow exceeded allowable. In addition, it was noted that the recirculation flow for the safety injection pumps was not added to the ECCS flows when balancing the system so the total pump flow exceeded allowable. The same type of calculation error was made on two different systems.
Crystal River LER 302/89-30	A service water pump was rebuilt with a new impeller in May and tested satisfactorily. A subsequent test about three months later revealed low flows. An investigation found the wrong impeller had been installed. The incorrect flow measurement in May was attributed to improper throttling of the instrument valves to damp out the 10% oscillations in the read-out equipment.
Ginna LER 244/89-07	During a discussion about a flow test procedure for a safety injection pump, it was noted that the recirculation line valve was locked open instead of being throttled. Repeated tests on the system revealed that the calibration data for the flow transmitters did not correlate accurately with the installed flow orifices.

Haddam Neck LER 213/89-14	Service water pumps were tested to verify their head at high flow rates not attainable during normal operation. The results showed the pumps did not match the manufacturer's pump curves at high flows, although they were in agreement at normal flows. High flows are required for accident conditions.
McGuire, Unit 1 LER 369/89-02	Tests revealed that the service water flow to a chilled water system was low. The original location of the flow orifice was downstream of a throttled valve in the line which produced large oscillations. An ultrasonic flow measuring device was substituted and it was calibrated against some other orifice plate. No approved procedure was used in the calibration. The sum total of this impromptu process was an under-estimation of the flow to the chiller.
North Anna, Unit 1 LER 338/89-08	A test revealed that the service water flows to recirculation spray heat exchangers were below design values. The deficiency was attributed to valves not opening fully to their throttled position and using installed flow instrumentation which was not accurate compared to more sensitive ultrasonic flow measuring devices.
Palo Verde 50.72 rpt. 16907	The licensee determined that flow orifices on the high pressure injection line to the hot legs were incorrectly sized for all three units.
San Onofre, Unit 1 LER 206/89-31	A review of start-up tests revealed that the AFW flow to the steam generators could be higher than allowed under certain conditions. The potential for excessive flows was attributed to calculation errors. The analyst did not realize that the pressure to the steam driven AFW pumps is regulated to 500 psi and does not vary. Also the hydraulic resistance of the venturis in the non-cavitating mode was incorrectly modeled.
Turkey Point, Unit 3 LER 250/89-15	The licensee discovered that backflow through an internal discharge valve (because of wear) could significantly degrade the flow of an operating charging pump.

Turkey Point, Unit 3 LER 250/89-14	The component cooling water system was originally balanced to assure minimum flow through the containment coolers. Subsequent adjustments to reduce the flow through the coolers because of concern for erosion did not consider the original design basis for the system. Lack of administrative control resulted in a degraded safety function.
Browns Ferry, Unit 1 LER 259/88-07	The licensee discovered that the indicated flow rate for the service water system was over-estimated. The deficiency was caused by an error on the flow transmitter data sheet supplied by GE which did not correspond to the actual orifice calibration sheets.
North Anna, Unit 1 LER 338/88-24	The licensee discovered the service water system could not provide adequate flow if only two pumps are operating for both units and all four component cooling water heat exchangers are in use. This was an administrative error.
Oconee, Unit 1 LER 269/88-08	The licensee discovered the service water flow to the safe shutdown facility was below design because the as-built configuration had a higher hydraulic resistance than expected and the flow measuring devices were reading high.
McGuire, Unit 1 LER 369/87-18	Licensee discovered that service water flow was incorrect. The original flow element eroded and needed frequent calibration. A new element was installed, but new calibration data were never entered into the procedures after completion of the modification.
Sequoyah, Unit 1 LER 327/87-50	The licensee discovered the flow in the containment spray system was low. This deficiency was attributed to incorrect flow restriction in the lines and incorrect acceptance criterion for pump discharge pressure.
Sequoyah, Unit 1 LER 327/87-37	Licensee discovered the service water flow to room coolers was low because the heat loads were incorrectly estimated.
Trojan LER 344/87-30	The component coolant water flow to the RHR heat exchangers was found to be low. The system had been balanced in a configuration other than the limiting accident situation.

Grand Gulf LER 416/86-29	Service water flow to several room coolers was incorrect because the wrong flow coefficient was used for the flow measuring device.
Haddam Neck LER 213/86-34	Stratification of reactor coolant leaving the steam generator caused temperature variations in the cold leg measurements that affected calorimetric calculations. Temperature detectors were relocated to pump discharge to eliminate temperature measurement anomalies.
Palisades LER 255/86-33	Use of an unmodified pump impeller resulted in LPSI pump performance below FSAR requirements.
Palisades LER 255/86-32	Undersized RHR heat exchangers were installed in plant. The flow through the heat exchangers was throttled to limit total pressure drop across the unit.
Trojan LER 327/86-44	Licensee determined the controlled leakage to the RCP seals would be larger than estimated because the pump head was higher. This higher seal flow would reduce available ECCS flow.
Calvert Cliffs, Unit 1 LER 317/85-07	HPSI flows were outside of the acceptable range. Extensive testing and corrective actions were ineffective in achieving consistent results.
Cook, Unit 1 LER 315/85-31	Low pressure injection flow was discovered. Deficiencies attributed to errors in scale gradations and erroneous transmitter calibrations. Alternate flow path used during RHR operation, because of vibrations, circumvented low flow alarm.
Palo Verde LER 528/85-08	AFW flow could exceed maximum design value for events having low SG pressure.
Sequoyah, Unit 1 LER 327/85-44	Total safety injection flow exceeded design value. Sum of the injection line flows did not equal header flow measurement because of accumulation of inaccuracies.
North Anna, Unit 2 LER 339/90-08	Licensee discovered that in line flow measurement inaccurate. Flow based on pressure drop along 2 feet of straight pipe. Error estimate 10%.

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