# EVALUATION OF MINIMUM FLOW LINES FOR SAFETY-RELATED PUMPS AT NINE MILE POINT 2

Prepared for
Niagara Mohawk Power Corporation

September 1988

Stone & Webster Engineering Corporation
Lycoming, New York

TABLE OF CONTENTS

# SECTION 1

## SUMMARY

NRC Bulletin 88-04, requested licensees to investigate and correct, as appropriate, the potential for pump dead-heading due to pump-to-pump interactions and the adequacy of installed minimum flow capacity for safety-related systems. Specifically, a response was requested to determine the current plant status with regard to minimum flow and potential pump-to-pump interactions.

Included with this report is a copy of the BWR Owners Group (BWROG) response to the NRC dated June 29, 1988. The BWR Owner's Group authorized GE Nuclear Energy to investigate this bulletin for the BWR 2 through 6 product lines so that a consistent framework would exist for individual licensees' submittals, as well as a basis for a generic BWROG response. The BWROG report provides a generic review of the potential problems, along with responses to the different action items requested by the bulletin.

The purpose of this report is to develop a plant-specific response for NMP2 and to determine the applicability of the BWROG generic response to NMP2.

The scope of this report is limited to safety-related centrifugal pumps.

This evaluation concludes that the minimum flow capacity of the safety related pumps and arrangement of piping systems as originally specified is adequate.

Section 2

# INTRODUCTION

## 2.1 Background

NRC Bulletin No. 88-04 identified two minimum-flow design concerns. The first concern involves the potential for dead-heading one pump of a two pump combination running in parallel when they have a common minimum-flow line. The second concern is whether or not the installed minimum-flow capacity is adequate for even a single pump in operation.

Individual centrifugal pump minimum flow rates can be reduced (extreme condition would be the pump running at shut-off) if there is a common minimum flow line for a pair of pumps operating in parallel. If the pumps individual minimum flow lines, are orificed before they join into a common return line, the hydraulic resistance is controlled by the restricting orifices and the piping configuration has little, if any, affect on resistance. Therefore, there should be little adverse pump-to-pump interaction. However, if the pumps individual minimum flow lines are not orificed, but the common return is orificed, or contains no orifice, the hydraulic resistance is controlled by the piping configuration and interaction between the two pumps may occur. The severity of the interaction depends on the piping configuration, shape of the characteristic curve of the pump, and the mismatch between the pumps. In general, pump characteristic curves can be classified as; normal rising, steeply rising, drooping, or flat with the last two not normally favorable for parallel pump operation.

Some earlier centrifugal pump systems that required minimum flow lines were designed so that the capacity was sufficient to avoid overheating the pumps due to low flows. The pump manufacturer typically specified minimum flow in the range of 10-15 percent of rated flow. When pumps were operated continuously at these low flows, it was discovered that other factors besides temperature rise influenced safe continuous minimum flow operation. Centrifugal pumps may demonstrate a flow condition that has been described as "hydraulic instability" at some point below their best efficiency point (BEP) which could result in excessive vibration of the pumps and their piping systems and consequent failure of pump components. Research has been done on this subject, (Reference 3, and 4) specifically on boiler feed pumps, and it is now recognized that a distinction has to be made between normal recirculation (intermittent) and the minimum flow that is safe for extended periods of operation (continuous) which has been recommended as a minimum of 25 percent of BEP. The actual recommended continuous minimum flow is a function of pump size, capacity, speed, and horsepower.

## 2.2 Scope

The scope of this report is limited to safety-related centrifugal pumps as addressed by the NRC bulletin. Table 1 lists the systems that contain safety-related centrifugal pumps for NMP2. Though the NRC Bulletin addresses pumps with min-flow lines, this report also includes a review of safety-related pumps without min-flow lines for the potential of operating in a min-flow condition. Typically, these systems should not be a concern because the system designer would design the system to operate at their design rating (which would be greater than required min-flow) at all times. The BWROG report additionally addresses the Control Rod Drive Hydraulic System pumps and support systems such as reactor building closed cooling water system which are non-safety-related for NMP2.

## 2.3 Organization

Section 3 contains the conclusions that were reached and the recommendations made from the data presented in Section 4 along with the applicability of the BWROG generic response to NMP2:

Section 3

# CONCLUSIONS AND RECOMMENDATION

## 3.1 Potential for Dead-Heading

As discussed in Section 2, when the minimum flow discharge lines from two or more pumps join into a common line, there is a potential for interaction between the pumps. If the hydraulic resistance in the piping configuration is not controlled, a pump operating with a higher discharge pressure could reduce the flow through the pump with the lesser discharge pressure to the point where it may run dead-headed (at shut-off). This affect would be compounded if two pumps were selected to run in parallel and both pumps had drooping or flat characteristic curves.

For NMP2 there are only two safety-related systems that could have two pumps running in parallel with a common minimum flow line. These systems are the Low Pressure Core Spray System (CSL) and the Residual Heat Removal System (RHS). The CSL pump can run in parallel with pump "A" of the RHS system, while RHS "B" and "C" pumps can run in parallel with each other. The CSL pump has a 4" bypass with a hand control valve (throttleable) that connects to the 12" full flow test return line. This test return line eventually connects to an 18" return line to the suppression pool. RHS "A" pump has a 6" bypass with an individual restricting orifice that joins into the common 18" return line to the suppression pool. The RHS "B" and "C" pumps have 6" individual bypasses with individual restricting orifices joining in a 8" header and then into a common 18" return to the suppression pool. In either arrangement, the head loss due to pipe friction is insignificant compared to the restricting orifices, therefore, there should be no adverse pump-to-pump interaction. Additionally, the pumps have steeply rising curves which have good characteristics for parallel operation. Since the original design is adequate, no corrective actions are required. Table 3 provides a summary of conclusions and recommendations.

## 3.2 Adequacy of Pump Minimum Flow

As can be seen from the data in Table 2, the Emergency Core Cooling System (ECCS) pumps have design min-flows in the range of 10-17 percent of best efficiency point (BEP). The BWROG report states that for these pumps the manufacturers recommended min-flow is for intermittent operation, where intermittent operation is defined as

less than two (2) cumulative hours of minimum flow in any twenty-four (24) hour period. For a plant design life of forty (40) years this is equivalent to approximately 30,000 hours. System operation in the minimum flow mode is limited to pump start-up during surveillance testing, suppression pool cooling, and shutdown cooling, and during system start on a Loss of Coolant Accident (LOCA) signal. The total expected time in the minimum flow mode over the plant life is at most one (1) percent of the guideline recommended by the pump manufacturer. As discussed in Table 3 these pumps have the potential for operating for extended periods on minimum flow after a system start on a LOCA signal, therefore, the recommendation is to minimize the amount of time the pump is on minimum flow. For High Pressure Core Spray (CSH) and CSL the operating procedure already includes precautions against extended periods and makes provisions to divert flow from the min-flow line to the full-flow test return line. The RHS pumps are similar to the CSL pump as far as potential for extended operation, therefore, the recommendation is again to minimize the amount of time the pump is on minimum flow. It is recommended that the operating procedure for the RHS pumps (N2-OP-31) be revised to add precautions, and it should be determined if extended operating provisions can be added similar to the core sprays. The BWROG report states that BWR operating experience does not indicate any excessive wear to pumps when operating under the currently specified minimum flow conditions. It also states that recent inspection of some BWR RHS pumps indicated no pump impeller damage (due to minimum flow) that could potentially degrade pump performance over the inspection period. The report estimates that the pumps had been intermittently operated in the min-flow mode for up to 30 hours which substantiates the adequacy of the min-flows for intermittent operation.

The Reactor Core Isolation Cooling (RCIC) pump, though interlocked similar to CSH, also isolates the steam supply to the turbine trip at the same time, therefore, eliminating operation on min-flow for an extended period.

The service water pumps (2SWP*P1A-F) normally operate at their rated conditions. Due to a potential system configuration there is a steady-state condition at which the pump operates at 2698 gpm. This is acceptable since the pump manufacturer has stated that his recommended value of 2300 gpm is a continuous rating and the 2698 gpm is greater than his recommendation. In addition, there is another potential system configuration (Loss of One Division of Off-Site Power) where there is a transient condition where flow could go below the manufacturer's recommended but this is recognized by the operating procedure and as soon as possible flow has to be returned to above 3000 gpm. This also is acceptable since it is a transient condition of extremely short duration.

The condensing water pumps (2SWP*P2A,B) normally operate at their rated conditions. Due to a potential system configuration there is a steady-state condition at which the pump operates at 282 gpm. This is acceptable since the pump manufacturer has stated that his recommended value of 50 gpm is a continuous rating and the 282 gpm is greater than his recommendation.

The Reactor Coolant Recirculation Pumps (2RCS*P1A,B) are two speed pumps capable of operating continuously over a flow range of 20 to 115 percent of rated flow. The design min-flow of 11,500 gpm is when the pump is on low speed and since this value is greater than the recommended min-flow of 9440 gpm it is acceptable.

The remaining safety related pumps have essentially one operating point which is greater than the manufacturer's recommended minimum flow and is the same as their rated conditions.

All of the above pumps are included in an existing pump operability program. These pumps have had base-lines established for basic reference parameters (including vibration) during the pre-operational test program and are surveillance tested to monitor any adverse changes to these parameters, in addition to compliance to the plant safety analyses. With this in-service inspection program any deleterious effects of operating with inadequate flow would be detected in advance of significant pump performance degradation.

Since it is recognized for the ECCS pumps that the manufacturers min-flows are only for intermittent use and it has been shown that BWR operating experience does not indicate a concern with the currently specified minimum-flows, our only recommendation is to minimize the amount of time these pumps are on minimum flow. This concept is already included in the core sprays procedure and should be included in the RHS procedure.

Section 4

LIST OF TABLES

Table 1

NINE MILE POINT UNIT 2

SAFETY-RELATED CENTRIGUAL PUMP SYSTEMS

| | System | Equipment Mark No's. | No. of Pumps | Min-Flow Line (Y/N) | Min-Flow Line Common to two or more pumps (Y/N) |
|---|---|---|---|---|---|
| 1. | Low Pressure Core Spray | 2CSL*P1 | 1 | Y | Y |
| 2. | High Pressure Core Spray | 2CSH*P1 | 1 | Y | N |
| 3. | Residual Heat Removal | 2RHS*P1A,B,C | 3 | Y | Y |
| 4. | Reactor Core Isolation Cooling | 2ICS*P1 | 1 | Y | N |
| 5. | Service Water | 2SWP*P1A-F | 6 | N | N |
| 6. | Spent Fuel Pool Cooling and Cleanup | 2SFC*P1A,B | 2 | N | N |
| 7. | Control Bldg. Chilled Water | 2HVK*P1A,B | 2 | N | N |
| 8. | Condensing Water | 2SWP*P2A,B | 2 | N | N |
| 9. | Standby Diesel Generator Fuel | 2EGF*P1A-D<br>2EGF*P2A,B | 6 | N | N |
| 10. | Reactor Coolant Recirculation | 2RCS*P1A,B | 2 | N | N |
| 11. | System Pressure Pumps | 2CSL*P2<br>2CSH*P2<br>2ICS*P2<br>2RHS*P2 | 4 | Y | N |

Table 2

NINE MILE POINT UNIT 2

SAFETY-RELATED PUMPS MINIMUM-FLOW LINE DATA

| | PUMP | PUMP RATED CONDITIONS (a) FLOW(Q)-HEAD (H) | PUMP BEST EFFICIENCY POINT (b) FLOW(Qn)-HEAD (Hn) | MFG. RECOM. MIN-FLOW(c)) | PERCENT OF BEP(d) | DESIGN MIN-FLOW (e) | SHUT OFF HEAD (f) | CLASSIFICATION OF CURVE (g) | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 2CSL*P1 | 6350 gpm - 714' | 5750 gpm - 790' | 1000 gpm | 17% | 1000 gpm | 1150' | Steeply rising | 5,6,7,8, |
| 2. | 2CSH*P1 | 6435 gpm - 897' | 4800 gpm - 1950' | 500 gpm | 10% | 500 gpm | 3300' | Steeply rising | 9,10,11,12 |
| 3. | 2RHS*P1 A,B,C | 7450 gpm - 360' | 6000 gpm - 495' | 650 gpm | 11% | 1000 gpm | 755' | Steeply rising | 13,14,15,16 |
| 4. | 2ICS*P1 | 625 gpm - 2980' | 963 gpm - 2667'(h) | 148 gpm (i) | 15% | 148 gpm (i) | 3116'(h) | Flat | 17,18,19,20 |
| 5. | 2SWP*P1 A-F | 10,000 gpm-185' | 9200 gpm - 195' | 2300 gpm | 25% | 2698/ 10,000 gpm | 240' | Normal rising | 21,22,34 |
| 6. | 2SFC*P1 A,B | 2400 gpm - 500' | 3500 gpm - 450' | 900 gpm | 26% | 2400 gpm | 530' | Flat | 21,23 |
| 7. | 2HVK*P1 A,B | 349 gpm - 85' | 420 gpm - 80' | 100 gpm | 24% | 340 gpm | 95' | Flat | 21,24 |
| 8. | 2SWP*P2 A,B | 340 gpm - 60' | 450 gpm - 56' | 50 gpm | 11% | 282/340 gpm | 70' | Flat | 21,25 |
| 9. | 2EGF*P1 A-D 2EGF*P2 A,B | 10 gpm - 61' | 23 gpm - 25' | N/A | -- | 10 gpm | 78' | Steeply rising | 26,27 |
| 10. | 2RCS*P1 A,B | 47,200 gpm-805' | 45,000 gpm-850' | 9440 gpm | 21% | 11,500 gpm | 1040' | Normal rising | 28,29,30 |
| 11. | 2CSL*P2 2CSH*P2 2ICS*P2 2RHS*P2 | 50 gpm - 175' | 120 gpm - 120' | 30 gpm | 25% | 50 gpm | 175' | Flat | 21,31,32,33 |

Table 2

NINE MILE POINT UNIT 2

SAFETY-RELATED PUMPS MINIMUM-FLOW LINE DATA

Notes to Table 2

(a) The actual operating point on a pump curve specified by the system designer and guaranteed by the pump manufacturer.

(b) The point on a pump curve where the efficiency is highest.

(c) The pump manufacturers recommended minimum flow.

(d) The percentage of the mfg. recommended min-flow (c) to the pumps BEP (b).

(e) The lowest flow the system has been designed for either intermittently or on a continuous basis.

(f) The maximum head which a centrifugal pump will develop at a point where there is no flow through the pump.

(g) A general description of a pump curve as follows:

- o steeply rising - a large increase in head greater than 30%, between that developed at design capacity and that developed at shutoff. Good parallel pump operation since there will be minimum capacity changes with pressure changes.
- o normal rising - a gradual increase in head 20-30% between that developed at design capacity and that developed at shutoff. The head rises continuously as the capacity is decreased providing stable operation. Pumps with curves of this shape are used in parallel operation.
- o flat - head varies slightly (less than 20%) from that developed at design capacity and that developed at shutoff.

(h) Pump Test Data was taken at 3590 rpm. Head and flow valves were determined at 4550 rpm (rated) using the affinity laws.

(i) The pump manufacturer did not specify a minimum flow. The system designer specified a flow requirement of 75 gpm minimum in any operating mode. Flow is metered by 2ICS*R0123 which was sized for 75 gpm at 2300 rpm (turbine/pump lowest speed). Using the affinity laws this is 148 gpm at 4550 rpm.

Table 3

NINE MILE POINT UNIT 2

SAFETY-RELATED PUMPS MINIMUM FLOW EVALUATION

| PUMP | REMARKS | CONCLUSIONS | RECOMMENDATIONS |
|---|---|---|---|
| 1. 2CSL*P1 (Low Pressure Core Spray) | a) Injection valve 2CSL*MOV104 will not open unless RPV pressure decreases to within 88 psid of pump discharge pressure | a) Potential for pump tooperate on min-flow for extended period<br><br>Minimize the amount of time the pump is on minimum flow. | a) None - Operating procedure already limits operating time, and provides for extended operation of the pump by diverting flow to the test return line. |
| | b) 2CSL*P1 min-flow line combines with 2RHS*P1A min-flow line via a common 18" header. However, each individual line is orificed | b) The head loss due to pipe friction is insignificant compared to the restricting orifices, therefore, there should be no adverse pump-to-pump interaction | b) None |
| 2. 2CSH*P1 (High Pressure Core Spray) | a) Injection valve 2CSH*MOV107 automatically opens on system initiation. Initial flow rate is established by primary system pressure. Once vessel level is restored to the high level trip point (level 8) the valve closes and remains closed until reset or until level falls down to the low-low setpoint (level 2) | a) Potential for pump to operate on min-flow for extended period.<br><br>Minimize the amount of time the pump is on minimum flow. | a) None - Operating procedure already provides caution and makes provisions for extended operation of the pump by diverting flow to the test return line. |

Table 3 (con't)

NINE MILE POINT UNIT 2

SAFETY-RELATED PUMPS MINIMUM FLOW EVALUTION

| PUMP | REMARKS | CONCLUSIONS | RECOMMENDATIONS |
|---|---|---|---|
| 3. 2RHS*P1,A,B,C (Residual Heat Removal) | a) Injection valve 2RHS*MOV24(A,B,C) will not open unless RPV pressure decrease to within 130 psid of pump discharge pressure | a) Potential for pump to operate on min-flow for extended period.<br><br>Minimize the amount of time the pump is on minimum flow. | a) Revise operating procedure to include precautions.<br><br>Review operating procedure to determine if extended operating provisions can be added similar to CSL and CSH. |
| | b) 2RHS*P1A min-flow line combines with 2CSL*P1 min-flow line via a common 18" header. However, each individual line is orificed.<br><br>c) Pumps P1B, P1C have min-flow lines that are common to each other, but each bypass already has an individual restricting orifice before joining into the common line. | b,c) The head loss due to pipe friction is insignificant compared to the restricting orifices, therefore, there should be no adverse pump-to-pump interaction. | b,c) None |
| 4. 2ICS*P1 (Reactor Core Isolation Cooling) | a) Injection valve 2ICS*MOV126 automatically closes on a high level trip (level 8). Turbine steam supply valve 2ICS*MOV120 also closes on a high level trip. | a) Pump runs on min-flow intermittently during system startup and shutdown | a) None |
| 5. 2SWP*P1A-F (Service Water) | a) Pumps do not have min-flow lines. Pumps operate at 10,000 gpm but could operate below manufacturers minimum continuous flow requirements. | a) Manufacturer minimum flows are for continuous operation.<br><br>Operating procedure addresses this configuration to reestablish flow between 3,000 and 10,000 GPM. | a) None |

Table 3 (con't)

NINE MILE POINT UNIT 2

SAFETY-RELATED PUMPS MINIMUM FLOW EVALUATION

| | PUMP | REMARKS | CONCLUSIONS | RECOMMENDATIONS |
|---|---|---|---|---|
| 6. | 2SFC*P1A,B (Spend Fuel Pool Cooling and Cleaning) | a) Pumps do not have min-flow lines.<br><br>System was designed for one operating point. | a) Operating point is well above mfg. min-flow requirement. | a) None |
| 7. | 2HVK*P1A,B (Control Bldg. Chilled Water) | a) Pumps do not have min-flow lines.<br><br>System was designed for one operating point. | a) Operating point is well above mfg. min-flow requirement. | a) None |
| 8. | 2SWP*P2A,B (Condensing Water) | a) Pumps do not have min-flow lines.<br><br>Pumps operate at 340 gpm but could operate as low as 282 gpm. | a) Lowest operating point is greater than mfg. min-flow requirement. | a) None |
| 9. | 2EGF*P1A-D<br>2EGF*P2A,B (Standby Diesel Generator Fuel) | a) Pumps do not have min-flow lines.<br><br>System was designed for one operating point. | a) Mfg. recommended min-flow not available.<br><br>Design operating point and rated are the same. | a) None |
| 10. | 2RCS*P1A,B (Reactor Coolant Recirculation) | a) Pumps do not have min-flow lines.<br><br>Pumps were designed to operate continuously over a flow range of 20 to 115 percent of rated flow. | a) Lowest operating point is greater than mfg. min-flow requirement. | a) None |
| 11. | 2CSL*P2<br>2CSH*P2<br>2ICS*P2<br>2RHS*P2<br>(System Pressure Pumps) | a) Systems were designed for one operating point. | a) Operating point is greater than mfg. min-flow requirement. | a) None |

Section 5

## REFERENCES


1. Deleted

2. Deleted

3. EPRI Report CS-1445, Centrifugal Pump Hydraulic Instability dated June, 1980

4. EPRI Report CS-1512, Recommended Design Guidelines for Feedwater Pumps in Large Power Generating Units dated September 1980

5. VPF-3664-71-1 Certified CSL Pump Performance Curve

6. VPF-3664-017-2 Instruction Manual

7. PID 32A-6 Low Pressure Core Spray

8. N2-OP-32 Rev. 3 Operating Procedure

9. VPF 3666-070-1 Test Curve and Data

10. VPF 3666-020-2 Instruction Manual

11. PID 33B-8 High Pressure Core Spray

12. N2-OP-33 Rev. 3 Operating Procedure

13. VPF 3661-60-1 Test Data and Performance Curve

14. VPF 3661-20-2 Instruction Manual

15. Calculation A10.1-E-55 Rev.0 .

16. N2-OP-31 Rev. 4 Operating Procedure

17. VPF 3943-12-6 Instruction Manual

18. 761E2058 Rev. 12 Process Data

19. Calculation A10.1 - H-9 Rev. 4

20 N2-OP-35 Rev. 2 Operation Procedure

21. P222X Safety-Related Horizontal Centrifugal Pumps

22. Calculation A10.1-N113

23. Calculation A10.1-J-18 Rev. 2

24. Calculation HVK-9 Rev. 0

25. Calculation A10.1-N-17 Rev. 0

26. P225E Standby Diesel Generator Fuel Oil Transfer Pumps

27. Calculation EGF-14-1 Rev. 1

28. VPF 3726-49-3 Instruction Manual

29. 117C4534C Rev. 5 Process Data

30. N2-OP-29 Rev. 2 Operating Procedure

31. Calculation A10.1-H-22 Rev. 0

32. Calculation A10.1-E-36 Rev. 1

33. Calculation A10.1-F-10 Rev. 0

34. N2-OP-11 Rev. 2 Operating Procedure

# BWR OWNERS' GROUP

Donald N. Grace, Chairman
(201) 316-7153

c/o GPU NUCLEAR • 1 UPPER POND ROAD, BUILDING E • PARSIPPANY, NJ 07054

BWROG-8836
June 29, 1988

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

**SUBJECT: RESPONSE TO NRC BULLETIN 88-04, "POTENTIAL SAFETY-RELATED PUMP LOSS"**

Gentlemen:

The NRC issued NRC Bulletin (NRCB) 88-04, "Potential Safety-Related Pump Loss", on May 5, 1988. The purpose of the bulletin is to request all licensees to investigate potential design concerns involving safety-related pumps. The NRC concerns involve the potential for a pump to dead-head when it is operating in the minimum flow mode in parallel with another pump, and the adequacy of the minimum flow capacity.

The NRC requested that within 60 days of receipt of NRCB 88-04, licensees are to provide a written response that (a) summarized the problems and the systems affected, (b) identifies the short-term and long-term modifications to plant operating procedures or hardware that have been or are being implemented to ensure safe plant operations, (c) identifies an appropriate schedule for long-term resolution of this and/or other significant problems that are identified as a result of this bulletin, and (d) provides justification for continued operation particularly with regard to General Design Criterion (GDC) 35 of Appendix A to Title 10 of the Code of Federal Regulations (10 CFR 50), "Emergency Core Cooling" and 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling System for Light Water Nuclear Power Reactors."

Provided in the Attachment is the information requested by the NRC. Some of the information will be supplemented by plant-specific submittals, specifically that pertaining to items (b) and (c) above. The Justification for Continued Operation (JCO) provided in the Attachment is generic. The

8807010553

(WAZ2)

JCO concludes that continued operation is justified because the potential for pump damage due to minimum flow operation or dead-heading is negligible, sufficient redundancy and ECCS capacity exists to meet the requirements of 10 CFR 50.46 and GDC 35, and routine maintenance is expected to detect any pump damage before system performance is degraded.

The comments/positions provided in this letter have been endorsed by a substantial number of the members of the BWROG; however, it should not be interpreted as a commitment of any individual member to a specific course of action. Each member must formally endorse the BWROG position in order for that position to become the member's position.

If you have any questions concerning this information, please contact the undersigned or W.A. Zarbis (GE) on (408) 925-5070.

Regards,

Donald N. Grace

D.N. Grace, Chairman
BWR Owners' Group

DNG:lcv
Attachment

cc: S.D. Floyd, BWROG Vice Chairman
R.F. Janecek (CECO)
BWROG Primary Representatives
Executive Oversight Committee
S.J. Stark (GE)
NRC Regional Administrators
R. Evans (NUMARC)
H. Wyckoff (EPRI)
W.S. Green (INPO)

ATTACHMENT

# I. SUMMARY OF PROBLEM AND AFFECTED SYSTEMS

## A. Summary of Problem

The original design basis for sizing the minimum flow lines for safety-related BWR systems is to provide sufficient flow to avoid overheating the pumps due to low flow. However, current pump vendor guidelines for minimum flow are based on avoiding hydraulic instability in addition to avoiding pump overheating, leading to higher suggested minimum flow values than those used in BWR design. Hydraulic instabilities can occur at low flow rates due to flow separation across the impeller vane, which can lead to asymmetrical shaft and bearing loads in addition to pump and piping vibration. Since the pump vendor guidelines are only applicable for continuous* or intermittent** low flow operation, there are no guidelines for low flow limits for infrequent operation such as that experienced for only a limited postulated range of BWR loss-of-coolant accident (LOCA) events.

In addition, the pump minimum flow rate can be reduced (possibly leading to a condition where the pump is being run dead-headed) if there is a single minimum flow line for a pair of pumps operating in parallel. If the pumps have different pump shutoff heads, the pump with the higher shutoff head will deliver a greater flow rate; if there is a significant difference between the shutoff heads, the pump with the lower shutoff head may become dead-headed.

When the minimum flow discharge lines from two or more pumps join at some point to form a common line, there is a potential for interaction between the pumps. If the piping configuration is not controlled, the pump with the higher discharge pressure could reduce the flow through the pump with lesser discharge pressure to the point where it is inadequate for long-term integrity.

---

* Continuous operation is considered as more than two cumulative hours at minimum flow in any 24-hour period.

** Intermittent operation is less than two cumulative hours of minimum flow operation in any 24-hour period

(WAZ2)

If the pumps' minimum flow discharge lines are orificed (backloaded) in the individual pump discharge lines prior to the junction between the two pipes, and if the common line is large enough in flow area such that its resistance is a relatively small part of the overall hydraulic resistance, there should be little adverse pump-to-pump interaction. They can be expected to operate individually or in unison with no problems.

However, if the minimum flow discharge lines are not individually orificed, but the common line is orificed or provides greater flow resistance than the individual lines, interaction between the two pumps may occur. The severity of the attenuation of minimum flow through any pump depends on the shape of the head-flow curves of the pumps, and the magnitude of the mismatch between the pumps.

If the characteristic curve is such that a small change in flow results in a relatively large change in developed head, it is probable that little operational difficulty would result from an undesirable piping configuration. However, if a relatively large change in flow resulted in only a small change in developed head, some problems could occur. Further, the rate of attenuation of minimum flow through the lesser pump would be expected to accelerate with time.

B. Affected Systems

NRC Bulletin 88-04 addresses only safety-related systems; however, both safety-related and non-safety related systems are discussed below.

The BWR systems that may be affected are the Residual Heat Removal (RHR) System, including the Low Pressure Coolant Injection (LPCI), containment spray, pool cooling, and shutdown cooling functions; the core spray system (high or low pressure); the High Pressure Coolant Injection (HPCI) System; the Reactor Core Isolation Cooling (RCIC) System; and the Feedwater Coolant Injection (FWCI) System. For plants that do not have an integrated RHR system, the systems that provide the RHR system functions must be evaluated separately.

Support systems, such as service water, reactor building closed cooling water systems or keep-full systems, are diverse in design and operation. However, these systems should not be a concern since they typically do not require minimum flow lines and/or are operated at their design rating at all times.

The Control Rod Drive (CRD) hydraulic system has either an individually valved or orificed minimum flow path discharging to the condenser, and a continuous cooling water flow. During power operation, these multiple-stage, centrifugal pumps are run near their rated point. Upon plant scram, the flow rate would increase. If one of the discharge lines were to be blocked, the minimum flow path provides more than adequate minimum flow (approximately 20% of rated flow). Since only one pump is operated at a time, there is no potential for pump-to-pump interaction. However, the Emergency Procedure Guidelines (EPGs) may require running both pumps as a post-LOCA vessel water source; since this would only be after a plant scram, the pumps would not operate at low flow. Therefore, it is concluded that the current minimum flow path is adequate, and there is no potential for low flow pump-to-pump interaction.

The recirculation pumps are either variable speed pumps controlled by a motor-generator (M-G) set, or a constant speed pump controlled by a flow control valve. For M-G set plants, the pumps are prevented from running below approximately 28% rated speed by the master speed limiter. For valve control plants, the two-speed pumps are run with a minimum flow control valve position of approximately 22% at power operation above approximately 30% of rated power. Multiple interlocks prevent the recirculation pumps from running at a low flow condition. Since there are no parallel pump paths, there is no potential for pump-to-pump interaction.

C. Potential for Dead-Heading

The potential for dead-heading is addressed on a plant-specific basis.

D. Adequacy of Pump Minimum Flow

BWR operating experience does not indicate any excessive wear to pumps when operating under the currently specified minimum flow conditions. That is, no such reported wear has resulted in indicated degradation in pump performance.

System operation in the minimum flow mode is limited to pump startup during surveillance testing, pump start for suppression pool cooling and shutdown cooling, and during system start on a LOCA signal. The total expected time in the minimum flow mode over the plant

life is at most one percent of the guideline recommended by the pump vendors for intermittent operation.* Therefore, the potential for excessive wear attributable to minimum flow operation is negligible.

Recent inspection of some BWR RHR pumps have indicated no pump impeller damage (due to minimum flow) that could potentially degrade pump performance over the inspection period. It is estimated that the pumps had been intermittently operated in the minimum flow mode for up to 30 hours during this period. This further substantiates that short-term operation in the minimum flow mode has little or no impact on pump life.

Pump wear attributable to minimum flow operation is not a significant contributor to total system unavailability compared to other contributors (such as loss of emergency power, loss of cooling, etc.). This is based on BWR operating history, which indicates no occurrences of system unavailability upon demand due to pump wear incurred in minimum flow operation.

## II. SHORT-TERM AND LONG-TERM MODIFICATIONS

Operation in the minimum flow mode, which includes the potential for dead-head operation, is already minimized to the short periods of pump startup during routine testing and to system startup upon a LOCA signal. Based on pump vendor guidelines and operating experience, operation in the minimum flow mode (including dead-heading) is not expected to adversely affect pump operation. In addition, pumps have been inadvertently operated in the minimum flow and dead-headed conditions for significant periods of time. These pumps continue to operate satisfactorily with no indications of adverse consequences. Inspections of pumps that have been normally operated, including testing, indicate no significant wear from operating at the low flows.

---

Some pump vendors recommend minimum flow guidelines for intermittent operation, where intermittent operation is defined as less than 2 cumulative hours of minimum flow in any 24-hour period. For a plant design life of 40 years, this is equivalent to approximately 30,000 hours. Similar minimum flow limits have been suggested by other pump vendors.

In summary, then, experience to date indicates that minimum flow operation and dead-heading have not caused any problems. Therefore, the current inspection requirements for safety-related pumps and systems provided in the ASME Boiler and Pressure Vessel Code and also the Technical Specifications should provide adequate protection against pump performance degradation due to low flow operation.

## III. SCHEDULE

An appropriate schedule for long-term resolution of the concerns identified in NRC Bulletin 88-04 will be provided on a plant-specific basis.

## IV. JUSTIFICATION FOR CONTINUED OPERATION

The concerns stated in NRC Bulletin 88-04 are summarized as:

1. With two pumps operating in parallel in the minimum flow mode, one of the pumps may be dead-headed resulting in pump damage or failure.

2. Installed minimum pump flows may not be adequate to preclude pump damage or failure.

These concerns are addressed by the responses below which provide the basis for concluding that continued operation of BWRs is justified.

A. All Class 1, 2, and 3 centrifugal and displacement-type pumps installed in BWRs which are required to perform a specific function in shutting down the reactor or in mitigating the consequences of an accident, and provided with an emergency power source, must undergo routine in-service inspection per ASME Boiler and Pressure Vessel code Section XI, Article IWP1000. These quarterly tests are in addition to the Technical Specification surveillance requirements intended to demonstrate compliance with the plant safety analyses. The Section XI tests are intended to detect changes in pump performance; Article IWP-1500 ("Detection of Change") states:

> "The hydraulic and mechanical condition of a pump, relative to a previous condition, can be determined by attempting to duplicate, by test, a set of basic reference parameters. Deviations detected are symptoms of changes and, depending upon the degree of deviation, indicate need for further tests or corrective action."

The in-service tests measure speed (if variable speed) inlet pressure, differential pressure, flow rate, and vibration amplitude. Alert ranges and required action ranges are strictly defined, and require either increased frequency of testing or declaring the pump as inoperative, respectively. Performance outside of the required action range would place the affected system in a Limiting Condition for Operation.

Although these tests themselves would not detect pump dead-heading or inadequate minimum flow (since these are intended to be full flow tests), any deleterious effects of operating with inadequate flow would be detected in advance of significant pump performance degradation. Therefore, any changes in pump performance would be detected and corrected per routine pump testing in advance of pump degradation due to cumulative low flow effects from pump surveillance testing and normal system starts.

B. The potential for pump excessive wear attributable to minimum flow operation and/or dead-heading is negligible, since system operation in the minimum flow mode is limited to surveillance testing and during system start on a LOCA signal.

C. BWR operating experience indicates that short term operation in the minimum flow mode and/or dead-heading has little or no impact on pump life. Pumps continue to function normally after such operations.

D. Pump wear attributable to minimum flow and/or dead-heading is not a significant contributor to total system unavailability. Other factors (such as loss of emergency power, loss of cooling, etc.) are more significant. BWR operating history indicates no occurrences of system unavailability due to pump excessive wear attributable to low flow operation.

E. For the LPCI/RHR and core spray pumps, the only design basis events that would lead to pumps running in the minimum flow mode and/or dead-heading are events that result in an ECCS initiation signal while the reactor is at high pressure (above the pump shutoff head). These events are normally small break LOCAs and loss of drywell cooling isolation events. Of these, only certain small break LOCAs actually require ECCS injection from LPCI\RHR or core spray after running at low flow.

Once initiated, the maximum duration that a LPCI/RHR or core spray pump may operate in the minimum flow mode for the spectrum of hypothetical LOCAs is less than 30 minutes. This is derived from postulated small break LOCAs, wherein reactor depressurization to below the shut-off head of these pumps is delayed. For large break LOCAs, where the full complement of ECC systems is more fully utilized, the reactor inherently depressurizes through the break. The present minimum flow bypass line is expected to provide adequate protection for these pumps for the short durations postulated during both the small and large break LOCAs.

For other scenarios, there is adequate time to secure the RHR and core spray pumps, and restart them as necessary, precluding extended operation in the minimum flow mode.

F. As discussed in Item E above, only certain small break LOCAs actually require ECCS injection for LPCI or core spray where the pumps may be operated in the minimum flow mode. However, because of the excess ECCS capacity that is available, limiting LOCA scenarios do not depend on both pumps of a pair of parallel pumps to operate in order to satisfy 10 CFR 50.46 requirements and General Design Criteria 35 of 10 CFR 50 Appendix A. In fact, a realistic LOCA analysis would show that only one low pressure ECCS pump is typically necessary to satisfy core-cooling requirements during and following a LOCA.

The design basis LOCA evaluations for some plants assume that both core spray pumps are functioning. For these plants, the limiting calculated peak clad temperature would not be affected, even in the unlikely event that pump operability is affected by dead-heading.