UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUL 16 1985

MEMORANDUM FOR: James M. Taylor, Director
Office of Inspection and Enforcement

FROM: Edward L. Jordan, Director
Division of Emergency Preparedness
and Engineering Response
Office of Inspection and Enforcement

SUBJECT: STEAM BINDING IN AUXILIARY FEEDWATER SYSTEMS

Temporary Instruction 2515/67 directed the regional offices to conduct surveys of licensee responses to two identified safety issues: Steam Binding in Auxiliary Feedwater Systems and Mispositioned Control Rods. These issues were addressed more than a year ago by IE Information Notices (IN) and by Institute of Nuclear Power (INPO) Significant Event Reports (SERs) and INPO Significant Operating Experience Reports (SOERs). The SOERs contained specific recommended actions to alleviate the safety concern.

The primary purpose of our survey is to determine the actions that licensees are taking in response to the two selected safety issues. The secondary purpose is to determine the actions that licensees are taking in response to the recommendations in INPO's SOERs.

For the first issue, Steam Binding in Auxiliary Feedwater Systems, the responses have been received and an initial review has been performed. The results are provided in the enclosure and can be summarized as follows:

1) No immediate safety problems were found; that is, no hot pipes or disabled pumps were found by the inspectors.

2). The INPO recommendation of primary safety importance concerned monitoring auxiliary feedwater system temperature each shift. Of the 58 units surveyed, 39 had such monitoring to detect any back leakage of hot water into the system. At most of the units, this is done by touching the pipe. Seventeen units had some degree of justification for not monitoring, such as a normally closed globe valve in addition to check valves in the system. Two units did not have what we considered to be reasonable justification for the lack of monitoring. These two units are TMI-1 and Trojan. Based on followup discussions with Regions I and V, we understand that both facilities have now begun monitoring.

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XA

3) The INPO recommendations next in safety importance concerned procedures and training for detecting and correcting back leakage. Of the 58 units surveyed, 25 had both procedures and training, 20 lacked either procedures or training, and 13 had neither. Procedures are quite important to ensure that monitoring is consistently performed, both now and in the future. For example, simply telling the auxiliary operators to check the pipe temperatures each shift, without explaining why or providing any guidance on recovery, will not provide a lasting solution of reasonable quality. Therefore, we will propose an IE bulletin to request that all licensees develop and implement procedures. (Training and awareness will follow as a matter of course from implementation of procedures.) We plan to meet with INPO to review results of their review of licensee actions to the SOER and discuss our findings and planned actions.

4) Other INPO recommendations of lesser safety significance had a lesser degree of implementation. We do not plan any short-term action regarding these other recommendations.

5) In the longer run, all of the responses will be reviewed by NRR in the process of resolving Generic Issue 93, "Steam Binding of Auxiliary Feedwater Pumps."

In summary, for the steam binding issue, all but two units had alleviated the safety problem to some degree, but many licensees lacked the procedures or training needed for a lasting solution of reasonable quality.

Responses for the second issue, Mispositioned Control Rods, are expected later this month. We will inform you of the results when a preliminary review has been completed.

Edward L. Jordan, Director
Division of Emergency Preparedness
and Engineering Response
Office of Inspection and Enforcement

Enclosure: Summary of the Responses to TI 2515/67
Related to Steam Binding of Auxiliary Feedwater

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*See previous concurrences

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Summary of the Responses to TI 2515/67 Related to
Steam Binding of Auxiliary Feedwater

Temporary Instruction 2515/67 directed the regional offices to conduct surveys of licensee responses to two identified safety issues, steam binding in auxiliary feedwater systems, and mispositioned control rods. For the first issue, steam binding in auxiliary feedwater systems, the responses have been received and an initial review has been performed. Tabulation of those responses are given in the attachments.

No immediate safety problems were found: that is, no hot pipes or disabled pumps were found by the inspectors.

Of the 58 units surveyed, 39 units monitor AFW piping temperature at least once every 12 hours (INPO recommendation 1). The principal method used to monitor the AFW piping temperature is touch. Only four units have control room readout.

Of the remainder, 17 units had some degree of justification. These units are listed below and their justifications are summarized.

Calvert Cliffs 1 & 2 - monitoring is accomplished weekly. No recent history of steam binding. Appropriate check valve design.

Indian Point 3 - closed MOV in discharge line.

Millstone 2 - normally closed regulating (globe) valve.

Salem 1 & 2 - closed isolation valve.

Yankee Rowe - complete separation of AFW trains makes multiple failures unlikely. Licensee also claims credit for watch-standers' ability to detect but resident disagrees.

Crystal River 3 - has ultrasonic flow detectors that also detect back-leakage. (Monitoring has begun since the survey.)

Oconee 1, 2, & 3 - a closed gate valve, no history of steam binding, and a long uninsulated discharge line.

Turkey Point 3 & 4 - closed globe valves and self-venting pumps.

Palisades - closed flow control (globe) valves.

Davis-Besse 1 - normally closed MOVs.

Byron 1 - pump casing vented daily. Licensee also claims credit for water hammer prevention instrumentation but resident disagrees.

Waterford 3 - closed isolation valves.

Two units that did not monitor had little justification. They are:

TMI 1 - no previous problems. Check for leakage during plant startup. The licensee planned to provide general awareness training. (Since the survey, the licensee has ag ed to monitor once per shift.)

Trojan - considering monitoring. (Monitoring has begun since the survey.)

Seventeen units monitor the temperature of AFW piping after each operation in addition to the routine checks (INPO recommendation 2). Note that for plants already monitoring once a shift, this does not carry a great deal of safety significance.

Twenty-five units had procedural guidance and training on identifying and correcting backleakage (INPO recommendation 4), 13 had neither, and the remaining 20 had less than full implementation of the recommendation. Details are provided in Table 1.

Procedural corrective actions include: vent and flush, close isolation valves and slowly reopen, use AFW booster pump to cool, and stroke MOV to reseat check valve.

Nine units leak test the valves or verify that they shut (INPO recommendation 5). In-service testing (IST) required by ASME Section XI Part IWV depends upon the licensee's classification of the valve. It usually entails operability testing only, when any testing is required. The answers to question 7b left doubt about the respondent's definition of "inspection," but the 13 "yes" answers probably refer to the ASME in-service inspection.

We did not determine how many units had reviewed their check valve design for suitability; that is, ability to seat with low ΔP (INPO recommendation 3). We did note that 13 units determined that procedural changes were needed to assure check valve seating and implemented them.

We did not determine whether or not unnecessary thermal insulation had been removed (INPO recommendation 6).

Attachments:
1. Table 1 - Tabular Summary
2. Table 2 - Follow Up Commitments
   Mentioned in Response to TI 2515/67

TABLE 1

TABULAR SUMMARY

PLANT	ACTION (JUSTIFY/ MONITOR)	PROCEDURES FOR IDENTIFICATION/ CORRECTION	TRAINING FOR IDENTIFICATION/ CORRECTION
** JUSTIFY			
SALEM 1	JUSTIFY	BOTH	BOTH
SALEM 2	JUSTIFY	BOTH	BOTH
OCONEE 1	JUSTIFY	BOTH	BOTH
OCONEE 2	JUSTIFY	BOTH	BOTH
OCONEE 3	JUSTIFY	BOTH	BOTH
CALVERT CLIFFS 1	JUSTIFY	BOTH	NEITHER
CALVERT CLIFFS 2	JUSTIFY	BOTH	NEITHER
YANKEE-ROWE	JUSTIFY	CORRECT	CORRECT
BYRON 1	JUSTIFY	CORRECT	NEITHER
CRYSTAL RIVER 3	JUSTIFY	NEITHER	BOTH
INDIAN POINT 3	JUSTIFY	NEITHER	NEITHER
MILLSTONE 2	JUSTIFY	NEITHER	NEITHER
TURKEY POINT 3	JUSTIFY	NEITHER	NEITHER
TURKEY POINT 4	JUSTIFY	NEITHER	NEITHER
PALISADES	JUSTIFY	NEITHER	NEITHER
DAVIS-BESSE	JUSTIFY	NEITHER	NEITHER
WATERFORD 3	JUSTIFY	NEITHER	NEITHER
** MONITOR			
BEAVER VALLEY 1	MONITOR	BOTH	BOTH
INDIAN POINT 2	MONITOR	BOTH	BOTH
CATAWBA 1	MONITOR	BOTH	BOTH
FARLEY 1	MONITOR	BOTH	BOTH
FARLEY 2	MONITOR	BOTH	BOTH
MCGUIRE 1	MONITOR	BOTH	BOTH
MCGUIRE 2	MONITOR	BOTH	BOTH
ROBINSON 2	MONITOR	BOTH	BOTH
SEQUOYAH 1	MONITOR	BOTH	BOTH
SEQUOYAH 2	MONITOR	BOTH	BOTH
SURRY 1	MONITOR	BOTH	BOTH
SURRY 2	MONITOR	BOTH	BOTH
ZION 1	MONITOR	BOTH	BOTH
ZION 2	MONITOR	BOTH	BOTH
FT CALHOUN	MONITOR	BOTH	BOTH
ANO 1	MONITOR	BOTH	BOTH
ANO 2	MONITOR	BOTH	BOTH
SAN ONOFRE 2	MONITOR	BOTH	BOTH
SAN ONOFRE 3	MONITOR	BOTH	BOTH
PALO VERDE 1	MONITOR	BOTH	BOTH

TABLE 1

TABULAR SUMMARY

PLANT	ACTION (JUSTIFY/ MONITOR)	PROCEDURES FOR IDENTIFICATION/ CORRECTION	TRAINING FOR IDENTIFICATION/ CORRECTION
HADDAM NECK	MONITOR	BOTH	NEITHER
D C COOK 1	MONITOR	BOTH	NEITHER
D C COOK 2	MONITOR	BOTH	NEITHER
NORTH ANNA 1	MONITOR	IDENTIFY	IDENTIFY
NORTH ANNA 2	MONITOR	IDENTIFY	IDENTIFY
SAN ONOFRE 1	MONITOR	IDENTIFY	IDENTIFY
ST LUCIE 1	MONITOR	NEITHER	BOTH
ST LUCIE 2	MONITOR	NEITHER	BOTH
SUMMER	MONITOR	NEITHER	BOTH
DIABLO CANYON 1	MONITOR	NEITHER	BOTH
PRAIRIE ISLAND 1	MONITOR	NEITHER	IDENTIFY
PRAIRIE ISLAND 2	MONITOR	NEITHER	IDENTIFY
KEWAUNEE	MONITOR	NEITHER	IDENTIFY
POINT BEACH 1	MONITOR	NEITHER	IDENTIFY
POINT BEACH 2	MONITOR	NEITHER	IDENTIFY
GINNA	MONITOR	NEITHER	NEITHER
MAINE YANKEE	MONITOR	NEITHER	NEITHER
WOLF CREEK 1	MONITOR	NEITHER	NEITHER
RANCHO SECO	MONITOR	NEITHER	NEITHER
-- NEITHER			
TMI 1	NEITHER	NEITHER	NEITHER
TROJAN	NEITHER	NEITHER	NEITHER

TABLE 2

FOLLOW UP COMMITMENTS MENTIONED IN RESPONSE TO TI 2515/67
* Items that Resident has reported complete following survey

LVERT CLIFFS 1	ESTABLISH LEAK CHECKS IN FUTURE.
LVERT CLIFFS 2	ESTABLISH LEAK CHECKS IN FUTURE.
RUN 1	ADDITIONAL REVIEW OF APPROPRIATENESS OF WATER HAMMER INSTRUMENTS FOR STM BINDING
STAL RIVER 3	REPLACE ULTRASONIC FLOW DET. BEGIN MONITORING.* INSTALL ALARMS.
RLEY POINT 3	BEGIN MONITORING BY 6/1/85. TRAINING AND PROCEDURAL GUIDANCE BY 6/1/85.
RLEY POINT 4	BEGIN MONITORING BY 6/1/85. TRAINING AND PROCEDURAL GUIDANCE BY 6/1/85.
LISADES	ACTION ON LEAK CHECK BY 9/1/85.
AVER VALLEY 1	CONSIDERING INSTALLING TEMPERATURE INDICATORS.
GUIRE 1	CONTROL ROOM COMPUTER PT FOR TEMP READOUT.
RRY 1	DESIGN CHANGE CONCERNING TEMP READOUT IN CONTROL ROOM.
RRY 2	DESIGN CHANGE CONCERNING TEMP READOUT IN CONTROL ROOM.
CALHOUN	PERMANENT TEMP MONITORS TO BE INSTALLED FALL 85.
MMER	INSTALL CONTROL ROOM ANNUNCIATOR.
ABLO CANYON 1	DESIGN CHANGE TO INSTALL CONTROL ROOM ANNUNCIATOR.
AIRIE ISLAND 1	EVALUATE LEAK TEST, INSPECTION.
AIRIE ISLAND 2	EVALUATE LEAK TEST, INSPECTION.
INT BEACH 1	REPLACE LEAKING CHECK VALVE.*
NNA	INSTALL TEMP DETECTORS IN AFWP DISCH LINE W/REMOTE COMPUTER MONITORING AND ALARM
1	CHECK FOR LEAKAGE AFTER EACH OPERATION. TRAIN WATCH-STANDER. CONSIDER INSTRUMENT
OJAN	MONITOR, INSTALL PYROMETERS, PROVIDE PROCEDURAL GUIDANCE AND TRAINING, INSPECT.

Information for CRGR Review
on Proposed IE Bulletin 85-XX
"Steam Binding of Auxiliary Feedwater Pumps"

The following information is intended to assist the examination of the regulatory [illegible] of the proposed Bulletin:

1. The proposed generic requirement is spelled out in the attached bulletin. In sum, licensees for [illegible] pressurized water reactor (PWR) units with operating licenses (OLs) and [illegible] PWR units with construction permits (CPs) [illegible] to develop and implement procedures:

(A) to monitor temperature of auxiliary feedwater (AFW) system [illegible] [illegible] [illegible] binding
(B) to [illegible] steam binding if it occurs
(C) to [illegible] steam binding if it occurs

Licensees are further asked to report their actions to the NRC.

[illegible] licensees that followed the recommendations made by [illegible] 1980 [illegible] addressed for action to those licensees [illegible] [illegible] [illegible] [illegible] survey [illegible] [illegible] do not have [illegible] [illegible]

2. Documents referenced in the proposed [illegible] [illegible] [illegible] that [illegible] the bulletin are listed below:

[illegible]

[illegible]

[illegible]

[illegible]

1. [illegible] Steam Binding of [illegible] Feedwater Pumps [illegible] Revision 2, December [illegible], 198[illegible]

2. [illegible] gives results of [illegible] [illegible] [illegible]

[illegible] Section IV.B [illegible]

3. The steps anticipated that licensees must carry out to complete the requirements are briefly described below:

a. Are there any short-term and long-term requirements? Is the proposed bulletin the definitive, comprehensive position on the subject or does it represent the first of a series of requirements to be issued in the future?

The proposed bulletin discusses both these aspects. Developing and implementing procedures for monitoring, detecting, and correcting AFW steam binding will satisfy the short-term requirements imposed by this proposed bulletin. However, NRR also is reviewing this subject under Generic Issue 93 and may impose additional requirements in the future.

b. How does this requirement affect other requirements? Does this requirement mean that other items or systems or prior analyses need to be reassessed?

We do not believe that the requirements of the proposed bulletin will affect any other requirements. Neither will they change other assessments.

c. Is it only computation? Or does it require or may it entail engineering design of a new system or modification of any existing systems?

The proposed bulletin states that the requirements can be satisfied by simple means, such as an operator touching the pipe to make sure it is not hot. Some licensees may wish to make system modifications, such as adding a resistance temperature detector with alarm and readout in the control room.

d. What plant conditions are needed to install and conduct preoperational tests and to declare the plant operable?

The requirements of the proposed bulletin can be implemented independent of plant conditions.

e. Is plant shutdown necessary?

No.

f. Does design need NRC approval?

The requirements of the proposed bulletin do not impose design changes. If designs are changed, however, 10 CFR 50.59 applies. The most likely design changes are the additions of-temperature monitors, which would not require NRC approval under 10 CFR 50.59.

g. Does it require new equipment? Is it available for purchase in a sufficient quantity by all affected licensees or must such equipment be designed? What is the lead time for availability?

No new equipment is required. If some licensees choose to install temperature monitors, this can be done with readily available equipment.

h. May equipment be used when it is installed or does it need staff approval before use? Does it need Tech Spec changes before use?

   If temperature monitors are installed, they may be used once installed without staff approval. No Tech Spec changes are required.

4. The requirements of the proposed bulletin would apply to the addressees for action given in Attachment 1 of the proposed bulletin. This consists of 28 of the PWR units having an OL and all 26 PWR units having a CP. These PWRs have been determined to need procedures concerning this subject.

5. For each applicable reactor category, additional information is supplied below.

   Note that the action addressees are 28 operating units and 26 units under construction. This amounts to 36 sites when we count multiple units, such as Byron Units 1 and 2, as a single site. For the purpose of the analysis described below, there is no real difference between the operating units and the units under construction.

   a. A risk reduction assessment performed using a data base and methodology commonly accepted within NRC.

      The risk of core melt because of unavailable AFW is estimated in the AEOD case study, Section 3.2, and in the NRR prioritization for Generic Issue 93.

      In the AEOD study, the results of the Reactor Safety Study Methodology Applications Program (NUREG/CR-1659) for Sequoyah were used. There, the accident sequence (labeled TML) for the loss of the steam conversion system after a transient event other than loss of offsite power was a dominant contributor to risk of core melt. The unavailability of the AFW system increased by a factor of 4 above previous estimates because of steam binding. This increase doubled the contribution of the TML sequence to the probability of a category PWR-3 release and added at least $1x10^{-5}$/RY to the overall probability of core melt. This increased the risk by about 60,000 man-rem for the remaining lifetime of all operating PWRs (47 units with an average remaining life of 27 years when the AEOD study was published in July 1984).

      In the NRR prioritization, the results of the Reactor Safety Study (WASH-1400) for Surry were used. There, the accident sequence (labeled TMLB') for the loss of the steam conversion system after a transient event with loss of offsite power was a dominant contributor to risk of core melt. Because of uncertainty, NRR considered a range of values for AFW pump failure probability. For the lower value (basic case), the steam binding would result in the doubling of AFW system unavailability; the contribution of the TMLB' sequence then also would be nearly doubled. The difference from the Sequoyah case is represented by the higher starting unavailability for AFW resulting from loss of offsite power in the Surry case. The weighted sum of increased public dose resulting from consideration only of the TMLB' sequence for the 90 PWRs expected to be operating having an average life of 28.8 years is about 30,000 man-rem. It is possible that the pump failure probabilities used in the basic case are overly optimistic. Accordingly, NRR also made a more conservative estimate which yielded a dose increase of about 96,000 man-rem.

The requirements of the proposed bulletin are intended to ensure this risk is not realized. Monitoring once per shift is expected to decrease the likelihood of steam binding substantially. As discussed previously, the monitoring already is being conducted at many operating PWRs and the other operating PWRs have some justification for not monitoring once per shift. However, many of the operating PWRs as well as PWRs under construction do not have procedures. Without procedures, the gains in risk reduction are expected to dissipate over time. For instance, simply telling operators to feel the pipes once per shift without any further explanation or guidance will not provide a lasting solution of reasonable quality. The bulletin seeks to require such procedures be prepared by those licensees that have not already done so. The needed training and awareness should follow as a matter of course from implementation of the procedures and the solution should be lasting.

b. An assessment of costs.

(1) To NRC:

We estimate a man-week is required for inspection and inspection reporting and review for each site. At $2000 per man week, this translates to a total cost of about $70,000. After a year or two has passed, an additional $30,000 will be needed to review licensee responses, close the bulletin, and print the NUREG report. Thus, the total NRC costs are estimated to be about $100,000.

(2) To licensees:

(a) Occupational dose.

No additional occupational radiation exposure is expected from the requirements of the proposed bulletin. The procedures deal with a secondary system that handles nonradioactive water.

(b) Complexity of plant and operations.

The requirements of the proposed bulletin do not add any foreseeable complexity to either plant or operations. The monitoring already is being performed, where needed. If, as a result of the bulletin, additional licensees decide to perform monitoring, this can be readily accomplished in conjunction with routine tours already conducted by operators.

(c) Total financial costs.

We estimate the one-time effort would require about 11.5 man-weeks per site or about 400 man-weeks in all. This includes writing, testing, and promulgating the procedures and writing the response to the bulletin. The cost of one-time effort for 36 sites is then about $800,000. We estimate continuing effort to require about 45 man-weeks per year for monitoring the system temperature and about 140 man-weeks per year for retraining and maintaining the procedures. This amounts to about $300,000 per year in all.

These estimates assume that, at each of the 36 sites addressed for action, procedures are written and implemented. With regard to the actual cost of monitoring, most plants that need monitoring are already conducting it. It was assumed that 10 additional construction sites would perform monitoring as a result of the bulletin.

c. The basis for requiring or permitting implementation by a given date or on a particular schedule.

Requiring the response to the proposed bulletin within 120 days for operating reactors allows a reasonable time period for licensees to develop and implement the procedures, which essentially only document present practice. The time period is not so long that licensees would tend to neglect the work. The limit of 1 year for plants under construction is to allow for orderly closeout of the bulletin within a reasonable time.

d. Other acceptable implementation schedules and the basis therefor.

We currently foresee no real need for requesting a different schedule, but would consider any licensee's request for additional time on its own merits. Since the monitoring is already being conducted, where needed, different schedules for implementing the procedures would not present problems.

e. Schedule for staff actions involved in completion of requirement (based on hypothesized effective date of approval).

The staff will issue the proposed bulletin upon approval. Depending on region and resident inspector schedules, the staff plans to close the bulletin in 2 years.

f. Prioritization of the proposed requirement considered in light of all other safety-related activities under way at all affected facilities.

The problem, which this proposed bulletin addresses in the near-term, has been assigned high priority by NRR in its Generic Issue No. 93, which addresses the problem in the longer term. Thus, we consider this proposed bulletin to be of high priority.

g. Does this proposed requirement involve recordkeeping?

Not explicitly. However, log entries will probably be made to record the results of monitoring once per shift.

6. IE position as to whether the requirement implements existing regulations or goes beyond them.

   Because plant technical specifications require the AFW system to be operable in modes 1, 2, and 3, the requirements of the proposed bulletin for detecting and correcting steam binding implement existing regulations and do not go beyond them. The requirement for procedures on monitoring temperature of the pump casing or the discharge pipe amounts to formalizing an existing good surveillance practice. This ensures the continuation of the practice and, thus, the availability of the system. Accordingly, we conclude that all the requirements of the proposed bulletin implement regulations and do not exceed them.

7. The proposed method of implementation along with the concurrence (and any comments) of OELD on the method proposed.

   The proposed bulletin has been concurred in by OELD with no comments.

8. Regulatory analysis sufficient to address the

   a. Paperwork Reduction Act
   b. Regulatory Flexibility Act
   c. Executive Order 12291

   This request for information was approved by the Office of Management and Budget under blanket clearance number 3150-0011 as meeting requirements of the Paperwork Reduction Act and Executive Order 12291. Sufficient hours are included in the NRC budget for this request. Since this is not a rulemaking action, the Regulatory Flexibility Act does not apply.

Marlene → File

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF INSPECTION AND ENFORCEMENT
WASHINGTON, D.C. 20555

January 25, 1984

IE INFORMATION NOTICE NO. 84-06: STEAM BINDING OF AUXILIARY FEEDWATER PUMPS

Addressees:

All pressurized water reactor (PWR) facilities holding an operating license (OL) or construction permit (CP).

Purpose:

This information notice provides notification of a problem pertaining to steam binding in the auxiliary feedwater (AFW) pumps due to leakage from the main feedwater system. It is expected that addressees will review the information provided for applicability to their facilities. No specific action or response is required.

Description of Circumstances:

On April 19, 1983, Carolina Power and Light reported that the two motor-driven AFW pumps started automatically on low steam generator level following a manual scram at the H. B. Robinson nuclear plant. After two minutes, the B train AFW pump tripped. The trip was attributed to a signal from low discharge pressure.

The discharge piping from the motor-driven AFW train is connected to the main feedwater piping near the steam generator. (See Figure 1.) Hot water, about 425°F, from the main feedwater system leaked back through the first check valve, the motor-operated valve, and the second check valve to the pump and flashed to steam because of the lower pressure in the AFW system. (A significant amount of steam was vented from the pump casing during the testing to determine the cause of the trip.) When the motor-driven pumps started, the instrumentation sensed a low discharge pressure. The steam binding reduced flow and prevented discharge pressure from increasing above the low pressure setpoint in the 30 seconds before the instrumentation tripped the pump. Condensation could have further lowered the pressure to the sensors.

Robinson had experienced leakage through valves in the discharge piping and consequent trips of the A train AFW pump on June 11 and 16, 1981. On July 21, 1983 the steam-driven pump was declared inoperable because of potential steam binding caused by leakage from the feedwater system. Crystal River 3 reported two steam-voiding events which caused the emergency feedwater system train B to be declared inoperable. Two similar events were reported at D.C. Cook Unit 2

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in 1981. (Reference LERs 50-261/83-044, 83-016, and 81-016; 50-301/82-076, and 83-045; and 50-316/81-032 and 81-063.)

A special interim procedure at Robinson calls for the venting of all three pumps once each shift, monitoring of the casing temperatures, and operating the pumps as required to prevent saturation conditions in the system. Cook also monitors the AFW system temperature. Robinson is exploring a design change or replacement of the check valves as a long-term solution.

The safety implication of these events is that leakage into the AFW from the feedwater system constitutes a common mode failure that can lead to the loss of all AFW capability. Further, there is the potential for water hammer damage if an AFW pump discharges relatively cold water into a region of the piping system that contains steam. Since the design of the AFW at Robinson is typical of other PWRs, the potential for backleakage exists in other operating plants. Routine monitoring of the AFW system temperature would detect backleakage so that the system could be periodically vented to prevent steam binding until an appropriate long-term solution is developed.

No written response to this notice is required. If you have any questions regarding this matter, please contact the Regional Administrator of the appropriate NRC Regional Office, or this office.

E. L. Jordan

Edward L. Jordan, Director
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Attachments:
1. Figure 1, "Simplified Schematic of Feedwater and Auxiliary Feedwater Systems"
2. List of Recently Issued IE Information Notices

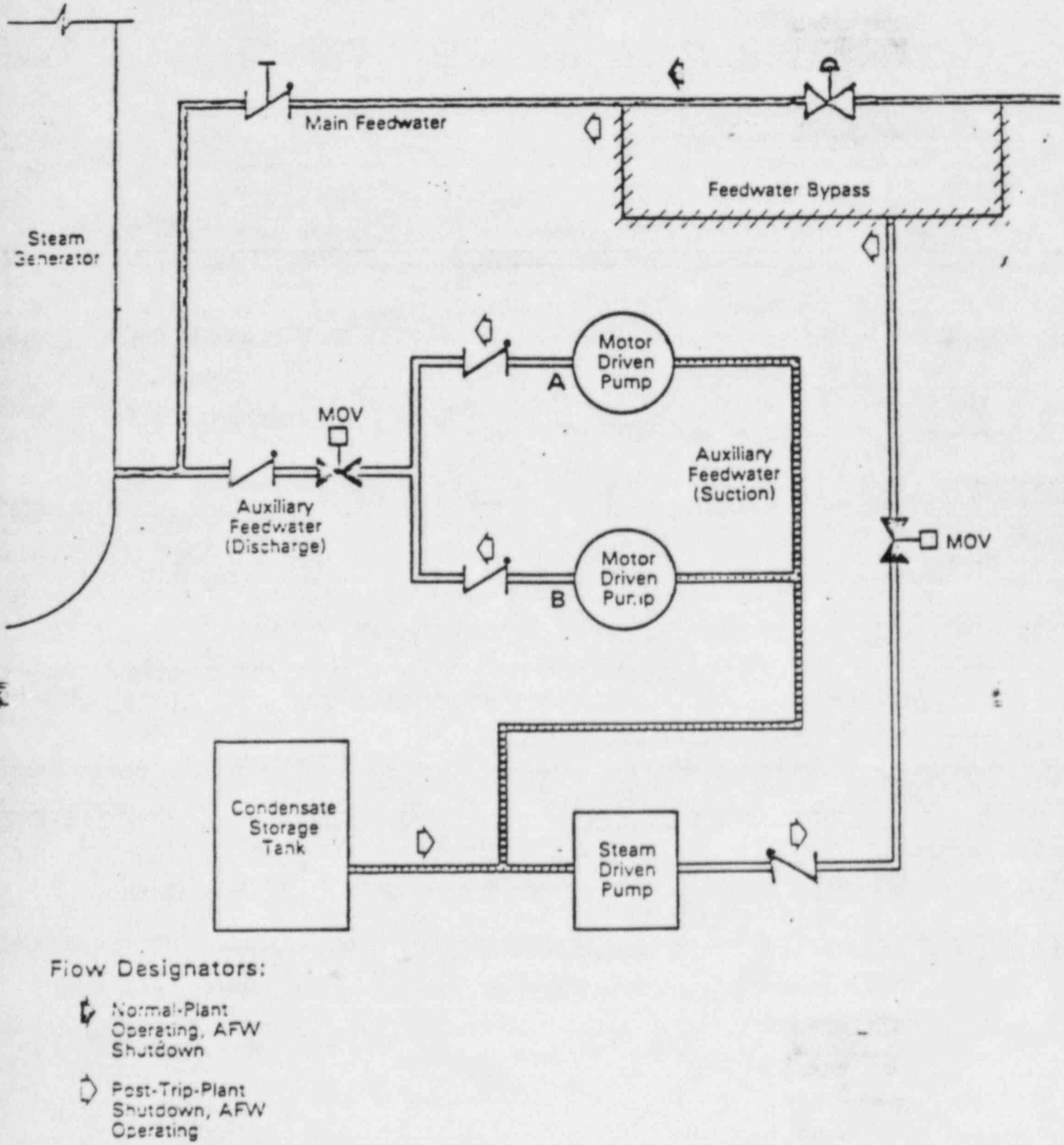

Figure 1. Simplified Schematic of Feedwater and Auxiliary Feedwater Systems

AEOD/C404

STEAM BINDING OF AUXILIARY FEEDWATER PUMPS

Reactor Operations Analysis Branch

Office for Analysis and Evaluation

of Operational Data

JULY 1984

Prepared by: Wayne D. Lanning

NOTE: This report documents the results of study completed to date by the Office for Analysis and Evaluation of Operational Data with regard to a particular operational situation. The findings and recommendations do not necessarily represent the position or requirements of the responsible program office nor the Nuclear Regulatory Commission.

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APPENDIX

EXECUTIVE SUMMARY

A case study was completed to evaluate the generic safety implications of backleakage to the auxiliary feedwater (AFW) system. Backleakage is defined as the leakage of hot main feedwater or steam from the steam conversion system to the AFW system. The AFW system is a safety system on a pressurized water reactor (PWR) whose safety function is to provide a source of water for the steam generators when the main feedwater system is not available and to mitigate design basis accidents.

Operational experience has shown that on numerous occasions an AFW pump was rendered inoperable due to steam binding resulting from the leakage of hot feedwater to the AFW system. Multiple valves in series between the steam conversion system and the AFW system leaked and failed to provide isolation between the interfacing systems. The safety implication of these operating events was that backleakage represents a potential common cause failure for the AFW system that can cause the loss of its safety function.

Operating experience involving backleakage to the AFW system since 1981 included twenty-two events at six operating PWRs in the United States and one foreign plant. These events involved the misoperation or failure of about 60 check valves and five motor-operated valves installed to prevent reverse leakage. Other plants were known to have experienced backleakage, but the events were not considered as reportable occurrences. The events at Surry Power Station Unit 2, H. B. Robinson Unit 2, and Joseph M. Farley Units 1 and 2, provided evidence that more than one AFW pump can be simultaneously adversely affected by backleakage. The recent Surry event is the most significant event analyzed and is considered a precursor to a potentially

serious accident scenario involving the loss of all feedwater. At Surry, the simultaneous steam binding of a pump in each train of the AFW system rendered the system incapable of performing its design function. The major findings of the study are:

1. The trend of the operating events involving backleakage to the AFW system increased sharply in 1983 when 13 of the 22 events occurred at five Westinghouse-designed plants.

2. AEOD's assessment of the safety significance of the events showed that (a) the loss of a single train due to steam binding is significant because it is presently an undetectable failure that jeopordizes the capability of the AFW system to meet single failure criterion, i.e., potential common mode failure, and (b) the unavailability of the AFW system due to steam binding contributes significantly to risk of core melt in PWRs.

3. The potential for backleakage into the AFW system is generic to all operating PWRs. The review of the AFW designs for the three PWR vendors found that check valves and remotely-operated valves in some designs isolate the AFW system from the steam conversion system. The AFW designs at Westinghouse-designed plants appeared more susceptible to backleakage and steam binding of the pumps because the remotely-operated valve is often normally open. Operating experience showed that backleakage occurred primarily at Westinghouse-designed plants.

4. The potential for common mode failure of the AFW system is present whenever one pump is steam bound because the pumps are connected by common piping (discharge header and/or recirculation piping) with only a single check valve to prevent backleakage of hot water to a second or third pump.
5. While a potential exists for backleakage to other safety systems in both PWRs and boiling water reactors (BWRs), there is no known report of steam binding of a pump in other safety systems. The standby safety systems are isolated from operating systems at higher pressures and temperatures by check valves and motor-operated valves similar to the AFW systems. The potential for steam binding is minimized because the remotely operated valve is normally closed and is leak tested (the AFW valves are not). However, leakage through an upstream check valve has caused the remotely-operated valve to fail to open due to thermal binding and other reasons--a separate concern from steam binding. A previous AEOD study recommended measures to ensure the function of the valves which should address this concern. Since some BWR systems employ a smaller number of valves than were available in the AFW systems that experienced backleakage and steam binding of the pumps; a separate AEOD effort will further evaluate the safety significance of backleakage in BWR systems.

6. The analyses of the causes for check valve leakage did not identify any pattern or single major cause of the failures of the check valves. The causes differed between plants and involved different valve designs.

7. The study did not identify any regulatory requirements or uniform plant practices to reduce the likelihood of steam binding of the AFW pumps and common mode failure of the AFW system.

AEOD recommends that the Office of Nuclear Reactor Regulation require PWR licensees to monitor the AFW system to detect backleakage and ensure that the fluid conditions within the AFW system are well below saturation conditions to prevent steam binding of the AFW pumps.

AEOD suggested a possible method for further consideration that could reduce the likelihood of steam binding the AFW pumps and common mode failure of the AFW system. The method contains two basic elements: first, preventive measures to ensure that the isolation valves can perform their intended function; and second, surveillances to ensure that the isolation function does not experience undetected degradation during operations.

1.0 INTRODUCTION

Recurrent operational events at the H. B. Robinson Nuclear Power Plant involving automatic trips of the auxiliary feedwater (AFW) pumps prompted AEOD to perform an engineering evaluation of the events. The pumps tripped due to a low pressure sensed in the discharge piping after the pumps were started automatically. The cause of the low pressure was attributed to steam binding of the pumps from leakage of main feedwater (MFW) into the AFW system (backleakage). The hot MFW (about 425°F) leaked past two check valves and a closed motor-operated valve and flashed to steam in the lower pressure AFW system. Although the events involved only a single pump, the same phenomena had occurred in different AFW pumps at different times. Thus, a safety concern was raised that both trains could become steam bound simultaneously.

The Engineering Evaluation (Ref. 1) concluded that an Information Notice should be issued promptly to inform other licensees of the potential for the loss of AFW capability due to backleakage and steam formation in the AFW system. The Office of Inspection and Enforcement issued the Information Notice on January 25, 1984. In the meantime, AEOD proceeded with a case study to evaluate the generic safety implications and to identify potential changes to technical specifications and inservice testing programs to detect leakage into the AFW system and prevent steam binding.

This case study report documents the results of AEOD's activities with regard to steam binding of the AFW pumps. Representative designs of AFW systems at operating PWRs are evaluated in Section 2. An evaluation of the operational experience dealing with reported backleakage events is contained in Section 3 followed by a discussion of the causes for valve leakage in Section 4. Requirements for leakage detection are addressed in Section 5. Section 6 presents the findings and conclusions developed from the analysis and evaluation of AFW steam binding phenomena which form the bases for the recommendations contained in Section 7.

2.0 AUXILIARY FEEDWATER SYSTEM DESCRIPTIONS

This section summarizes the AFW system designs for operating Westinghouse, Babcock and Wilcox, and Combustion Engineering plants based on the AFW system descriptions compiled by the NRC Bulletins and Orders Task Force in NUREG-0560, NUREG-0611, and NUREG-0635, respectively. (Note that as a result of this and other post-TMI activities the designs of some AFW systems were changed or are undergoing changes. The descriptions contained in this section reflect the configuration of the AFW system at the time of this study.) The designs are reviewed to determine (1) whether the potential for backleakage exists during normal plant operation when the AFW system is not operating and (2) whether multiple pumps could be simultaneously affected. Thus, the focus of the review is to first highlight the number and kinds of valves that are used to isolate the AFW system from the steam conversion system (main feedwater and steam generators) and then identify common piping between the AFW trains which could provide a flow path for MFW or steam that could lead to simultaneous steam binding of the AFW pumps.

2.1 Westinghouse Plants

The review of the AFW designs at Westinghouse operating plants found that the AFW and MFW systems are isolated either by multiple check valves in series because the remotely operated valve is normally open, or by multiple check valves and a normally closed remotely-operated valve. Thirty of the operating plants use only check valves while only three plants (Robinson, Sequoyah, and Turkey Point) employ the latter configuration for isolating the interfacing systems. Since Robinson experienced more backleakage events than other plants, its AFW system is described in this section.

The primary differences among the plants that use only check valves to isolate the interfacing systems is that in two plants the AFW system is connected directly to the steam generators via the MFW bypass piping rather than to the MFW piping as for the other 28 designs. These two plants (McGuire and Summer) employ the Model D preheat steam generator design. A small feedwater flow rate is maintained in the bypass piping to prevent backleakage from the steam generator. However, even in these two designs the AFW and MFW systems also interface at another location that provides the same potential for backleakage as for other Westinghouse steam generator designs.

A schematic of the AFW system for the H. B. Robinson Unit 2 plant is shown in Figure 1. The two motor- and one turbine-driven pumps share a common suction from the condensate storage tank. The two motor-driven pumps discharge to a common header before the flow is piped to each of the three steam generators. A single check valve exists between each pump and the header. A check valve and a normally closed motor-operated valve exist in the piping between each steam generator and the common header. Thus, if the check valve and motor-operated valve leak in the pipe to either steam generator, only a single check is available to protect the pump from backleakage.

The turbine-driven AFW pump is connected to the MFW piping by a separate flow path via the MFW bypass piping. This piping contains only one check valve and a normally closed motor-operated valve for isolation.

The discharge of all three pumps is connected by a common recirculation pipe to the condensate storage tank (see Figure 1). When the MFW leaks into the AFW system, the water in the normally filled pipes is transferred to the condensate storage tank through the recirculation piping.

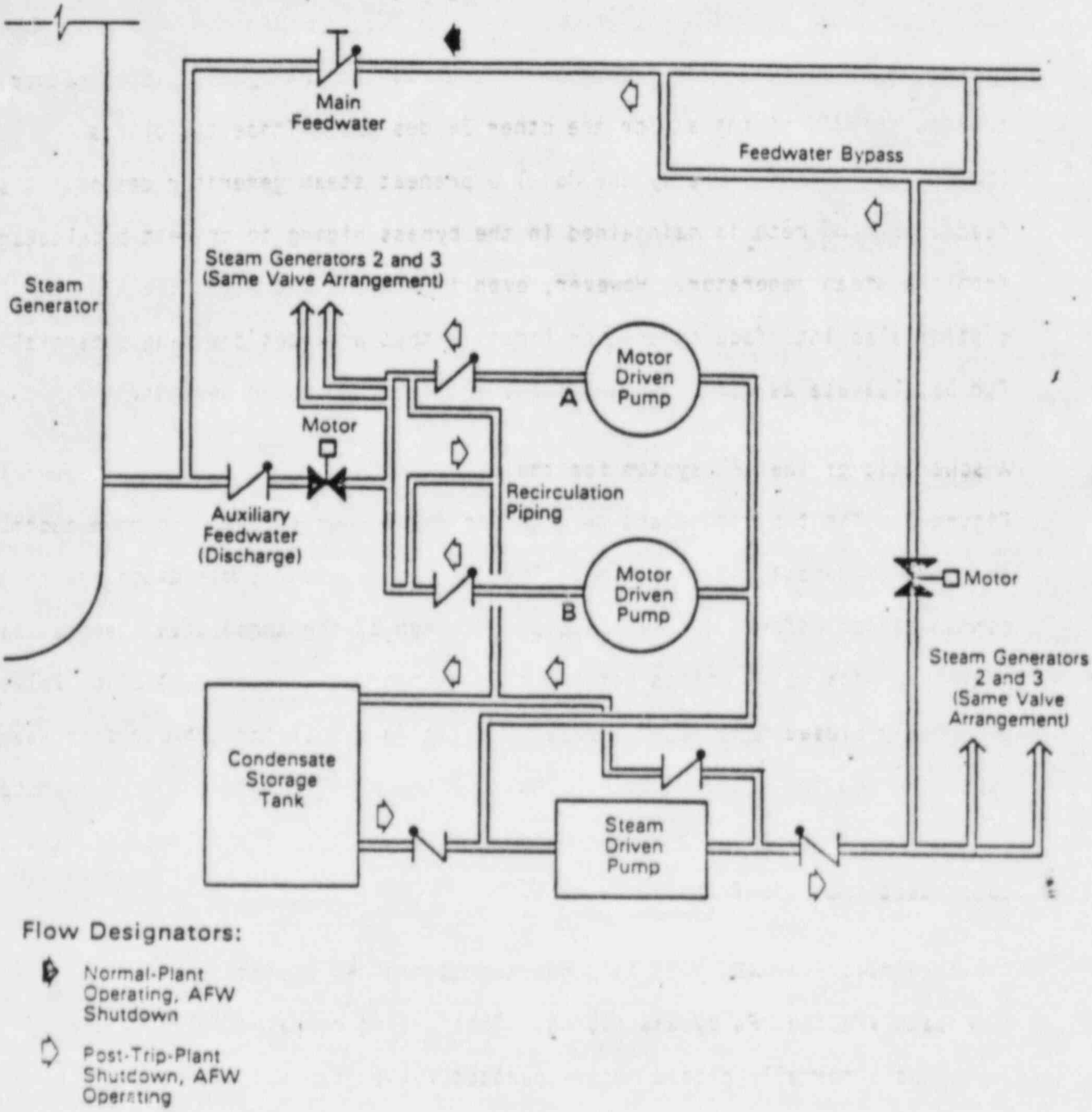

Figure 1 Schematic of H. B. Robinson Auxiliary Feedwater System

A single check valve in the recirculation piping separates each of the pumps in the AFW system. Hence, in the event that a pump becomes steam bound, the recirculation piping provides a flow path for the hot water to the other pumps if the single check valve in the piping to each of the other pumps leaks. The seating force for the check valve is provided by the column of water from the valves to the condensate storage tank, which may not be effective in properly seating the valve to prevent backleakage because both sides of the check valve communicate with the condensate storage tank. The valve in the recirculation piping near the pump discharge opens each time the AFW pump operates. Operating the pump would augment proper seating of the check valves in the recirculation piping to the other pumps. But after the pump is shutdown, the differential pressure across the check valves may equalize, possibly unseating them.

The McGuire and Summer plants have Westinghouse Model D preheat steam generators and separate AFW nozzles to the steam generator. For these plants, the AFW system is connected to the steam generator via the MFW bypass piping rather than to the MFW nozzle as is the case for older Westinghouse steam generator designs. A small feedwater flow rate is maintained in the bypass piping to prevent backleakage from the steam generator. However, the AFW system is still connected to the MFW piping at an upstream location. At McGuire, one motor-driven pump and the turbine-driven pump share a common discharge header. There are two check valves between each AFW pump and the connection to the MFW piping and the remotely-operated valve is normally open. Both plants have temperature indicators on the MFW bypass piping near the auxiliary feedwater nozzle and downstream of the intersection of the AFW and MFW piping. The purpose of this instrumentation is to detect steam in the feedwater bypass piping to prevent water hammers in this piping, rather than to detect backleakage to the AFW pumps from the MFW system. The instrumentation is not capable of monitoring for backleakage to the pumps because of its location.

In general, all AFW systems in Westinghouse operating plants have at least one check valve and a remotely-operated valve in series which can isolate an AFW train from the main feedwater system. However, the remotely-operated valve is normally open in most systems. As a result, only the check valve(s) provide the isolation function between the AFW and MFW systems. The flow control valve is normally closed in some plants, but this valve is not intended to be an isolation valve. In about two-thirds of the Westinghouse designs, at least two of the AFW pumps share a common discharge header with a single check valve between the header and a pump. For some plants, only the motor-driven pumps share a common discharge header; in other designs, all three pumps share a common header. A few designs have separate flow paths to the steam generators from each pump. Backleakage has occurred in each of the designs. For most AFW systems, all pumps share a common suction header from the condensate storage tank and are connected by the recirculation piping.

2.2 Babcock and Wilcox Plants

The review of the AFW designs at Babcock and Wilcox (B&W) operating plants found that the AFW system is connected only to the steam generator in all designs except for Crystal River which is connected to both the steam generators and the MFW system.

Only Davis Besse, Oconee and Arkansas Unit 1 employ normally closed isolation valves in addition to check valves to isolate the interfacing systems. The other B&W plants use only check valves to isolate the AFW system because the isolation valves are normally open. The flow control valves are normally closed in most plants, but these are not intended for isolation purposes. All designs have a common pump discharge header except for Davis Besse, Oconee and Crystal River. The recirculation piping and the piping from the condensate storage tank are common to all pumps in all designs. For discussion purposes, a diagram of the AFW system for Crystal River is shown in Figure 2.

At Crystal River the pumps consist of a full-capacity turbine-driven pump and a full-capacity motor-driven pump (some B&W plants have 3 AFW pumps). The piping arrangement is that either pump can deliver emergency feedwater to both steam generators. The piping is separated so that the pumps do not share a common discharge header, e.g., isolation valves exist between the pumps and the piping connection to the steam generators. The recirculation piping, however, is common to both pumps with two check valves available to prevent cross-flow between pumps.

The AFW flow for B&W plants is through separate nozzles in the upper region onto the steam generator tubes. As a result, the termination of the AFW discharge piping is in a slightly superheated steam environment. This design subjects the AFW system to higher pressures and temperatures from the steam generator than other AFW designs. The Crystal River design also

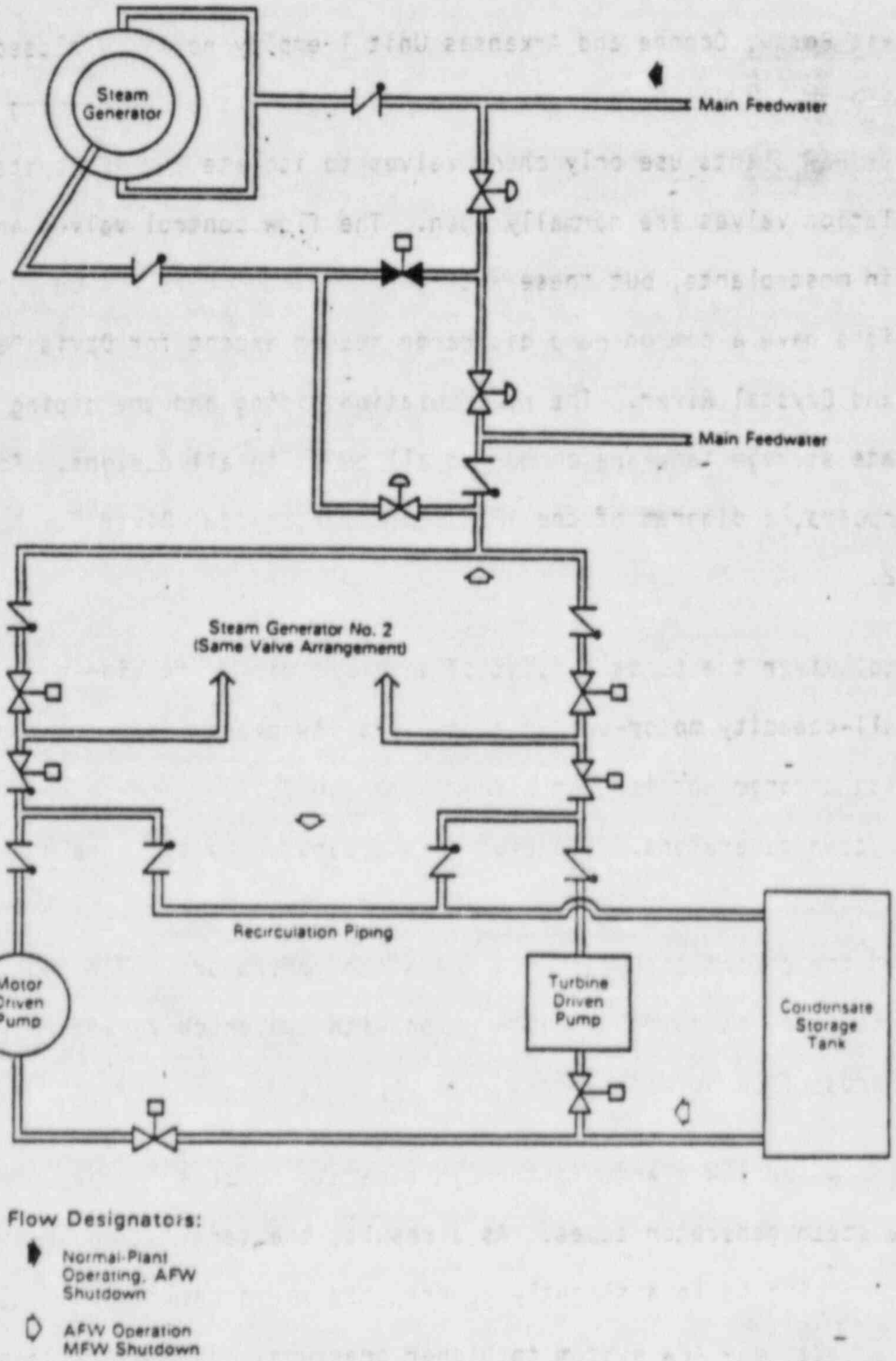

Figure 2 Schematic of Crystal River Auxiliary Feedwater System

connects the AFW and MFW piping as shown in Figure 2. During normal operation, four check valves isolate the interfacing systems to prevent hot MFW from leaking into the AFW system, since the remotely-operated valves are normally open. Three of these check valves and an additional check valve near the steam generator separate the steam environment from an AFW pump.

The other B&W designs do not interface with the MFW system. However, steam binding of the AFW pumps could result from the steam formed in the system if the AFW is heated to saturation conditions by the leakage of steam from the steam generators. Backleakage to an AFW pump is prevented in these designs by four check valves and a normally closed remotely-operated valve in the Oconee plants and two check valves in the Rancho Seco plant (the motor operated valves are normally open) or a combination of at least two check valves and a normally closed motor-operated valve at the Davis Besse and Arkansas Unit 1 plants.

The pumps in most designs share a common discharge header and recirculation piping. At least one check valve is available to prevent backflow to the other pump if one pump becomes steam bound in all designs except for Crystal River (discussed above) and Davis Besse. The latter plant does not have a common discharge header, but the recirculation piping connects both pumps with a check valve to protect each pump as is the case for other B&W plants.

2.3 Combustion Engineering Plants

The designs of the AFW systems for Combustion Engineering (CE) plants differ between plants and there does not appear to be an AFW design that is typical for operating CE plants. A diagram of the Calvert Cliffs AFW system is shown in Figure 3 for reference.

The AFW pumps usually consist of either a 100% capacity motor- and a 100% capacity steam-driven pump or one full-capacity turbine-driven and two half-capacity motor-driven pumps (Calvert Cliffs has two 100% capacity turbine-driven pumps and a 100% capacity motor-driven pump). Except for Arkansas Nuclear One, Unit 2, the other CE AFW designs employ a common discharge header for at least two pumps. The recirculation piping is common to all pumps with a single check valve to prevent backleakage from another pump. Typically, the AFW designs employ two check valves and one normally closed remotely-operated valve to isolate the AFW from the steam conversion system, except for Calvert Cliffs, where the remotely-operated valves are partially open. The discharge of the AFW system is connected either directly to the steam generator downcomer by separate nozzles or to the MFW piping upstream of the main feedwater nozzle. For some of the plants that have the separate AFW nozzles, the AFW piping is also connected to the main feedwater piping.

2.4 Summary of AFW Designs

To summarize the review of the various AFW designs, all systems contain multiple check valves and at least one remotely-operated valve in series that can isolate the steam conversion and AFW systems. The operation and designs of AFW systems vary considerably among operating PWRs. The primary difference between the AFW designs for the three PWR vendors is that the remotely-operated valve(s) is normally open in Westinghouse plants (except Robinson, Sequoyah,

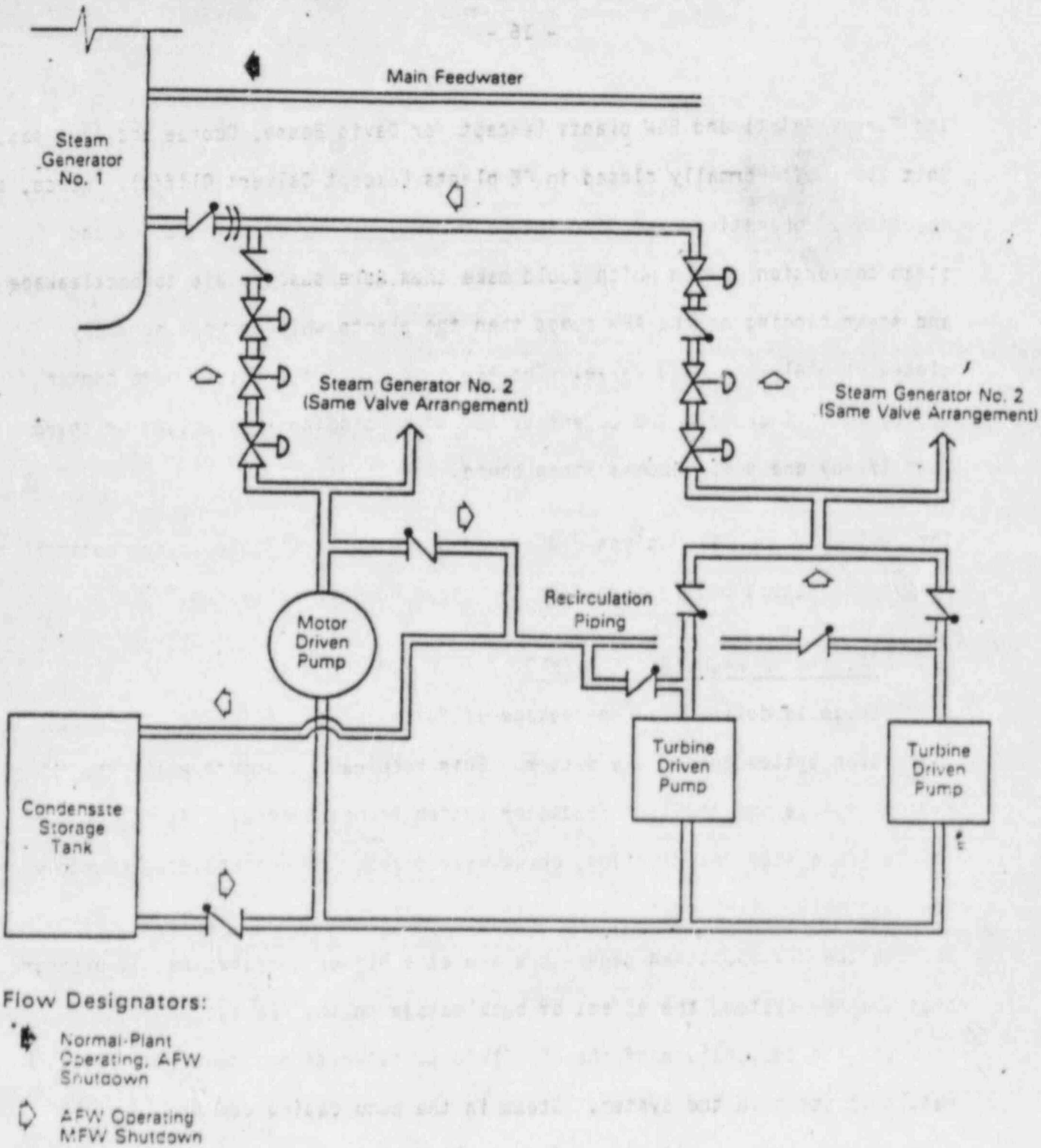

Figure 3 Schematic of Calvert Cliffs Auxiliary Feedwater System

and Turkey Point) and B&W plants (except for Davis Besse, Oconee and Arkansas, Unit 1) and is normally closed in CE plants (except Calvert Cliffs). Hence, a majority of operating PWRs have only check valves to isolate the AFW and steam conversion system which could make them more susceptible to backleakage and steam binding of the AFW pumps than the plants which have a normally closed remotely-operated valve. The AFW pumps in most designs have common piping which increases the potential for steam binding of a second or third pump if any one pump becomes steam bound.

The review of the AFW designs did not identify any available instrumentation to monitor or detect backleakage from the steam conversion system.

3.0 ANALYSIS OF BACKLEAKAGE EVENTS

Backleakage is defined as the leakage of feedwater or steam from the steam conversion system to the AFW system. This backleakage occurs while the AFW system is idle and the main feedwater system is operational. As discussed in the AFW system descriptions, check valves and, in some designs, remotely-operated valves isolate the AFW system from the steam conversion system. Because the MFW and steam generators are at a higher temperature and pressure than the AFW system, the effect of backleakage on the AFW system is to increase the temperature of the AFW fluid to saturation conditions that can result in steam in the system. Steam in the pump casing can prevent full flow or cause pump cavitation and possible damage to the pump due to overspeed and vibration.

The potential exists for steam binding of the redundant AFW pumps because the trains are cross-connected in most designs by a common discharge header and/or by common recirculation piping. In order for a single pump to experience steam binding, it is relevant to note that leakage must occur through multiple valves in series. However, after one pump is exposed to steam in most plants, only a single check valve in connecting piping is usually available to prevent leakage and potential steam binding of another pump.

3.1 Operational Experience

Since 1981 and more frequently in 1983, events involving backleakage were reported at H. B. Robinson (Refs. 2-5), D. C. Cook Unit 2 (Refs. 6-8), William B. McGuire Unit 1 (Ref. 9), Crystal River Unit 3 (Refs. 10 and 11), Surry Power Station Unit 2 (Ref. 12), and KRSKO Nuclear Project (Yugoslavia, Ref. 13). Table 1 provides a tabulation of these events. The events at H. B. Robinson and D. C. Cook are described in Reference 1, which is enclosed in Appendix A. The reader is referred to the Appendix for details of these events, particularly the events at Robinson.

The event at the Surry Power Station, Unit 2, is the most significant operating event because it is considered a precursor to a potentially serious accident scenario involving the loss of all feedwater (MFW and AFW). While at power with MFW available, one of the AFW motor-driven pumps and the turbine-driven pump were simultaneously steam bound leaving only a one-half capacity motor-driven pump available. Thus, the AFW system was not capable of performing its design function, although one pump may be sufficient to remove decay heat (see Section 3.2). The system was inoperable pursuant to the technical specifications, and this event highlights the common cause failure potential of the AFW system due to backleakage and steam binding of the pumps. Backleakage had occurred previously, but it had affected only a single AFW train. Fortunately in the event of loss of all feedwater, at Surry Unit 2, there is the capability for the AFW system at Unit 1 to supply emergency feedwater to Unit 2.

The coincident failures of two AFW trains was the identified concern resulting from the previous analyses of the Robinson events (see the Appendix). Separate trains had failed at different times at Robinson, but elevated AFW temperatures provided evidence that multiple pumps could be simultaneously affected. This led to the conclusion that the failures of single AFW trains should not only be considered as random failures, but also as contributing events leading to the potential common mode failure of the AFW system. The Surry event provides additional evidence to support this conclusion.

It is noteworthy that backleakage in these events was detected indirectly and reported only because the AFW train was declared inoperable. For example, three events at Robinson involved an automatic trip of either a motor- or steam-driven AFW pump due to low discharge pressure after an automatic start which caused the train to be declared inoperable. The events at Crystal River involved a single train of AFW system being declared inoperable because a flow sensor failed. The backleakage at D. C. Cook was detected during a routine operator tour by feeling the piping before the pumps were required to operate, but was reported only after the pump was isolated to work on the check valves. Backleakage from the steam generators at KRSKO was identified after experiencing a severe waterhammer. The events at Surry were reported because the pumps were steam bound.

At Crystal River, recurring failures of the ultrasonic AFW flow instrument were attributed to backleakage which increased the temperature of the AFW piping and fluid and caused steam formation in the system which resulted in erratic indications and subsequent failure of the instrumentation. The train was declared inoperable. The pump was not thought to be affected by the leakage, although the pump casing was not checked after the event for high temperatures indicative of backleakage. For this case, three additional check valves were available between the leaking check valve and the pump. Thus, instrument readings and eventual failure provided an indirect indication of check valve leakage.

The events reported at the William B. McGuire (Ref. 9) and H. B. Robinson (Ref. 14) plants involved backleakage which caused the suction piping of the AFW system to be overpressurized. These events were caused by either the slow closing (McGuire) or improper seating of the discharge check valve (Robinson) which permitted the MFW to pressurize the piping. Although these events involved gross backleakage, they represent another mode where the AFW pumps can become steam bound.*

Gross backleakage from the steam generators to the AFW pumps occurred at the KRSKO plant in July 1981 during hot functional testing. KRSKO is a two-loop Westinghouse plant with preheat (Type D) steam generators (separate AFW nozzle to the steam generator). The significance of the event was that a

*AEOD had previously analyzed these events as they related to overpressurization in an Engineering Evaluation Report (Ref. 15).

severe waterhammer caused damage to the AFW piping and hangers associated with both steam generators. The damage was not discovered until several weeks after the incident was believed to have occurred. The main feedwater system was probably not in operation at the time (Ref. 14). Based on the information available, the AFW pumps were started and stopped during the testing. It could not be ascertained whether the AFW pumps tripped or the intermittent starting and stopping of the pumps was performed by the operator. Two check valves in the piping to each motor-driven pump leaked while the pumps were idle between restarts, and was indicated by evidence of high temperatures (blistered or discolored paint) on the AFW piping back to the motor-driven AFW pumps. The turbine-driven pump is believed not to have been affected, although this train was not checked for leakage at the time of the event. The AFW pumps were not required to be operable because the event occurred during preoperational testing.

As the result of the KRSKO event, temperature instrumentation was installed on the MFW bypass piping near the steam generators at McGuire and Summer to detect and prevent waterhammer events similar to the one that occurred at KRSKO because the steam generator design (Type D) and AFW piping layout are similar. This instrumentation is not intended to detect leakage to the AFW pumps because the connection of the AFW and MFW piping is upstream of the instrumentation. A small constant flow rate is also maintained in the bypass piping to prevent steam formation or backleakage in this small section of the AFW piping. The AFW and MFW systems are connected at an upstream location, providing a potential leakage path to the AFW system.

TABLE 1

SUMMARY OF BACKLEAKAGE EVENTS (Since 1981)

Plant	Date	No. of Valves Leaking	Comments
Cook-2	7/12/81	2 check valves (CV)	Turbine-driven AFW pump (TDAFWP) casing was hot. Pump isolated and the train declared inoperable.
Cook-2	10/29/81	2CV	TDAFWP casing was hot. Pump isolated and the train declared inoperable.
Cook-2	1/16/83	2CV	TDAFWP casing was hot. Plant in operational mode not requiring pumps to be operable.
Crystal River-3	12/20/82	1CV	Train declared inoperable. Backleakage caused flow sensor to fail.
Crystal River-3	10/03/83	1CV	Train declared inoperable. Backleakage caused flow sensor to fail.
Robinson-2	6/11/81	2CV and 1 motor-operated valve (MOV)	Motor-driven AFW pump (MDAFWP) tripped during plant startup.
Robinson-2	6/16/81	2CV and 1 MOV	MDAFWP tripped after reactor trip.
Robinson-2	6/19/81	Unknown	MDAFWP tripped on low discharge pressure after reactor trip. TDAFW out of service. Pump trip believed to be caused by improper discharge valve throttle setting. Same pump tripped on 6/16/81 due to steam binding.
Robinson-2	4/19/83	2CV and 1 MOV	MDAFWP tripped after reactor trip. Steam vented from pump casing.
Robinson-2	4/20/83	4CV and 2 MOV or 3CV and 1 MOV	Both MDAFWP casings were hot. The leakage path for the hot water to the second pump was not identified. Leakage to the second pump may have been through either the common discharge header or the recirculation piping through a single check valve. (See Figure 1).
Robinson-2	7/21/83	1CV and 1 MOV	TDAFWP casing was hot and steam vented from the casing. Train inoperable.

TABLE 1 (contd)

SUMMARY OF BACKLEAKAGE EVENTS (Since 1981)

Plant	Date	No. of Valves Leaking	Comments
Surry-2	11/18/83	4CV	MDAFWP steam bound and failed to develop flow.
Surry-2	11/20/83	8CF	MDAFWP and TDAFWP steam bound, AFW system was inoperable.
Surry-2	12/06/83	4CV	MDAFWP steam bound. Train declared inoperable.
Farley-1/2	Ongoing since mid-83*	4-12CV per unit	MDAFWP and TDAFWP casings were hot, sometimes at the same time. Pumps were run to reduce temperature. No pump declared inoperable by licensee.
KRSKO	7/81	4CV	Waterhammers occurred when AFWP started. Event occurred during pre-operational testing. (Pumps not required to be operable.)
McGuire-1	8/25/81	2CV	Slow closing of CVs caused the AFW pump suction piping to be overpressurized.

* A minimum of six events are assumed to have occurred at both Farley units although each train has been affected more than one time since 1983.

A search of the operating experience data bases did not identify backleakage problems affecting AFW pumps at other operating plants. It could not be ascertained whether other plants had not experienced this problem or whether the problem existed, but was not identified as the root cause for the reported events involving inoperable AFW trains. For example, when H. B. Robinson experienced failures (LERs 79-32, 33 and 34) of the AFW pump discharge motor-operated valve to open, the initial causes were attributed to either the Limitorque operator or the inadvertent operation of the power supply breaker. The final evaluation of the valve failures concluded that thermal binding caused the valve to stick closed, which ultimately affected the interaction between the torque switch and valve internals. Backleakage was the reason identified for the thermal binding. Crystal River has also reported failures of the motor-operated valve to open, but the cause was attributed to other reasons, although backleakage is known to have occurred in their AFW system. H. B. Robinson had also reported AFW pump trips due to improper throttle valve settings. It is possible that backleakage may have caused the trip because the trip was initiated by the same low discharge pressure instrumentation that caused the pump trip when steam binding of the pump was positively identified.

It should be noted that unless the backleakage results in an event which is otherwise reportable by the technical specifications, the fact that backleakage occurred is not reportable. We have been told informally that other operating plants, in addition to D. C. Cook (Ref. 9), have experienced leakage of the AFW discharge valves. This leakage has occurred in both AFW trains several times and was never judged to be a reportable event.

On several occasions since very early in the plant life of Farley Nuclear Plant, usually after stopping flow through the check valves, leakage past the stop check and the check valve downstream of the flow control valve (FCV) has been observed. In each case the AFW pumps were started to flush water through the check valves and, when the pumps were secured, the check valves would reseat.

In the summer of 1983, the symptoms of check valve leakage changed. The valves started leaking without an initiating event, i.e., without flow through the valve. When this occurred, surveillance of the feedwater line temperature was increased to once every 4 hours. In late July, backleakage was detected past the motor-driven and turbine-driven AFW pumps discharge check valves. The existing on hand spare parts were used to repair the motor-driven AFW pump check valve. Sufficient parts to repair all the valves were not in stock at that time. Some parts were already on order and additional parts were placed on order to repair all the check valves. The leakage past the check valves was slowly getting worse and the surveillance of the auxiliary feedwater piping temperature was increased. In order to keep the temperature below 180°F, the AFW Pumps were typically being run once a day.

In November 1983, some of the parts were obtained and the worst leaking check valves were repaired. However, the leakage continued to require the periodic running of the auxiliary feedwater pump to cool down the lines downstream of the motor-driven and the turbine-driven pumps' discharge check valves.

On December 4, 1983, the motor-driven AFW pump was run about 20 minutes to cool down the auxiliary feedwater lines. During the check of the feedwater line temperature after running the pump, the pump discharge piping was found to be hot and the suction relief valve was relieving. The pump was started to cool down the lines but was immediately secured when pump cavitation occurred. The other pump was started and the system cooled down and the motor-driven pump was declared inoperable and isolated. It was determined that the back leakage through the check valve nearest the pump was caused by one missing and one worn hinge pin bushing in the valve. These parts were replaced by bushings designed by the valve manufacturer to prevent recurrence of the problem. It should be noted that the valve failure which resulted in steam binding of the motor-driven AFW pump was a sudden type failure with substantially greater back leakage than had previously occurred.

The only event reported by the Farley plant (Ref. 17) was the backleakage through the check valve closest to the motor-driven AFW pump at Unit 1. The AFW train was declared inoperable to repair the valve. No mention was made in the report that the three upstream valves had also leaked in order for this valve to leak, and that the backleakage caused the relief valve on the AFW pump suction to lift. An operator during his routine rounds noticed that the relief valve was opening, and measured piping temperatures in excess of 200°F. For some time, both units of the Farley plant have experienced recurring events involving backleakage through check valves that were not reported. Presently, the AFW pumps at both units are run periodically to reduce the AFW fluid temperature.

There have been numerous AFW check valve failures reported in Licensee Event Reports. The descriptions of the events address single valves and do not identify multiple check valve failures that could lead to steam binding of the AFW pumps. As a result, these events have not been included in this study. These events, particularly the failures of the check valves to close and separation of the disc from the disc arm, contribute to the potential for backleakage and steam binding of the AFW pumps. In addition, there have been reported failures of the single check valve in the recirculation piping that could provide a path for steam or hot water to reach the other AFW pumps.

Operational experience shows that check valves, in general, have a history of leakage problems in all systems. Most plants consider check valve leakage as routine and expected. Operating experience shows that the check valves in the AFW system also fail open or leak.

Steam binding of the AFW pumps can also result when the AFW pumps are exposed to hot water besides leakage from the MFW systems. On April 7, 1980, both AFW pumps lost suction due to steam binding at Arkansas Nuclear One, Unit 2 (Ref. 16). The suction of the AFW pumps was aligned to both the condensate storage tank and to the startup and blowdown demineralizer effluent. The hot water from the startup and blowdown demineralizers flashed to steam at the pump suction and caused cavitation of both pumps. The operators isolated the flow from the demineralizers and vented the pumps. The procedures were revised to isolate the effluent from the demineralizers when MFW is available.

There are other systems in PWRs where the interface between operating systems at high temperatures and pressures are separated from standby systems by check valves and remotely-operated valves in series, e.g., the emergency core cooling system (ECCS). Thus, the potential also exists for backleakage to these systems. Although there are reports of these valves leaking, no event is known to involve steam binding of the pumps. The remotely-operated valve is normally closed which should minimize the potential for backleakage to the pump. Additionally, these valves are periodically leak tested (the AFW valves are not) to ensure their leak integrity (see Section 5). However, the reverse leakage through the check valve can adversely affect the operability of the motor-operated valve as evident by the Robinson events (see Section 4). An AEOD study (Ref. 18) of valve operator-related events also found that check valve leakage can cause failure of the motor-operated valve to open when required. Thus, check valve leakage has other safety implications in addition to steam binding of pumps.

The potential also exists for backleakage from the MFW system to safety-related systems in boiling water reactors (BWRs). For example, a check valve and a normally closed motor-operated valve isolate the high pressure coolant injection (HPCI) system from the MFW system. (Note that this represents a smaller number of valves in series than in the AFW systems that experienced backleakage.) This valve arrangement is also true for the Reactor Core Isolation Cooling (RCIC) system. Events have been reported at BWRs involving the backleakage from the MFW and reactor coolant systems to the HPCI and RCIC systems. This study did not attempt to evaluate the safety implications of backleakage to these systems. However, a separate AEOD effort will review the operating experience and safety implications of backleakage in BWR systems.

3.2 Safety Significance

The safety implications of backleakage of feedwater or steam to the AFW system is that it represents a potential common cause failure that could render both trains of the AFW system inoperable. Some plants are more vulnerable than others depending on the piping configuration and layout, the number of pumps, the number and type of isolation valves, the normal operating position of the valves, and the maintenance and surveillance practices in effect. The events involving single AFW trains, particularly the recurring events at H. B. Robinson, should not only be considered random failures of single AFW trains, but as contributing events which portend the potential loss of AFW capability due to a common cause failure. The loss of a single train by itself is significant because its failure may not be detected until it is required to operate. This jeopardizes the capability of the AFW system to meet single failure criterion. That is, the margin inherent in the design of the system to meet single failure criterion is reduced due to the potential degradation of the remaining single check valve to isolate the two trains of the AFW system, i.e., common cause failure.

Since 1981, the 22 reported events involving backleakage to the AFW system represent about 60 check valve failures to prevent leakage. In 1983, there were 14 events that rendered an AFW train inoperable (only six events were counted at Farley Units 1 and 2 although every pump was affected more than one time). Thirteen of these events occurred at operating Westinghouse plants.

AEOD assessed the safety significance of the loss of the AFW system due to steam binding of the pumps using a risk-based approach. The accident sequence considered is the loss of the steam conversion system after a transient event other than loss of offsite power. This sequence (TML) is a dominate contributor to risk based on a probabilistic risk assessment for the Sequoyah plant and results in a category PWR-3 release (Ref. 19). The fault trees for the AFW system do not include steam binding as a separate failure mode for the AFW pumps.

The loss of both the MFW and the AFW systems is a severe accident sequence that terminates all feedwater flow to the steam generators. Without feedwater, the steam generator secondary side boils dry, resulting in the loss of the heat sink to remove energy from the reactor coolant system (RCS). The RCS pressure will then increase, causing the safety and relief valves to open. The RCS inventory will be lost through the valves, which require the operation of ECCS systems for makeup in order to avoid core uncovery and eventual core melt.

The feed and bleed mode of decay heat removal is an alternate method of providing adequate core cooling when the AFW system is unavailable to provide emergency feedwater to the steam generators. Although some other probabilistic risk assessments incorporate this mode of decay heat removal, the Sequoyah analyses (Ref. 19) did not take credit for it. Due to the design of equipment and human factors considerations, credit for this mode of heat removal is plant specific, and must be evaluated on a case by case basis.

For Westinghouse-designed plants, the steam generator dryout times range from approximately 13 to 40 minutes. In the event the AFW pumps are steam bound, the operator must identify that this is the failure mode of the AFW system, stop the pumps before permanent damage occurs, and restore their function in order to interrupt this sequence. Unless the operator immediately recognizes that the pumps are steam bound and recovery actions (which must be performed locally at the pumps and coordinated with the control room) are timely and successful, the likelihood of preventing steam generator dryout is small. Boiling the steam generators dry does not always result in core melt scenarios, e.g., feed and bleed may be an alternate method of removing core decay heat at some plants.

The probabilistic risk assessments for some plants show that successful AFW system operation (sufficient to remove decay heat after shutdown) requires the flow equivalent to one pump to one steam generator. Hence, the flow from a one-half capacity pump may be sufficient to prevent steam generator dryout based on best estimate analyses. However, the expected increase in the reliability of the AFW system, assuming successful operation with only one pump, may be reduced by the potential common mode failure contribution in determining the overall reliability of the system.

Using a risk-based approach for determining safety importance, the unavailability of an AFW system containing three pumps is calculated based on the operating experience for PWRs for 1983 (a conservative approach since most events were reported in 1983). First, the unavailability of one or more AFW pumps due to steam binding is about $7x10^{-3}$/demand (13 events at 47 operating plants each with 3 AFW pumps subject to 15 demands per reactor year (RY) based on 12 surveillance tests and three AFW challenges after reactor trips). Secondly, the conditional failure probability for a second pump to fail due to steam binding is 0.23 (3 of the 13 events involved two pumps). For this calculation, a pump is conservatively considered to be steam bound when hot water is detected at the pump, i.e., the hot water flashes to steam when the pump starts and binds the pump. Two of the events involved this condition; the third event involved actual steam binding of two pumps. The probability of a third pump becoming steam bound is assumed to be 0.1 based on the common cause dependency for the hardware between trains having the same design and subject to the same environment. Combining the failure probabilities for the three pumps, the unavailability of the AFW system is about 1.5×10^{-4}/demand. For designs with two AFW pumps, the unavailability is increased by 50%.

The unavailability of the AFW system for the Sequoyah plant without loss of ac power (low unavailability for the onsite power) is about 4×10^{-5} per demand. Therefore, the core-melt probability considering the steam binding of the AFW pumps for the TML sequence is increased from about 2.8×10^{-6}/RY to about 1.1×10^{-5}/RY (an increase by a factor of four). This is obtained by adding the unavailability of the AFW system due to steam binding to the Sequoyah value and using the probabilities contained in the Sequoyah analysis for transients (7/RY) and loss of the power conversion system (10^{-2}/demand). This increase doubles the contribution of the TML sequence to the probability of a category PWR-3 release, which is already the most probable release category at Sequoyah. For a PWR-3 release, this would represent a risk increase of about 45 man-rems/RY based on a dose calculation for a PWR and typical mid-western meteorology (NUREG/CR-2800). Using this technique, the estimated risk increase is about 60 thousand man-rems for the remaining lifetime of all operating PWRs (47 units with an average remaining life of 27 years).

These estimates are based on known operating experience involving backleakage to the AFW system and assumes that the events are unrelated and independent. Although the events may not be clearly distinct (this was one reason the number of events was limited at Farley), this conservatism is believed to be tempered by using only the number of reported events in gaining a risk perspective associated with steam binding. As discussed previously, reported operating experience may not accurately reflect the number or frequency of steam binding events, or the number of pumps that are affected, because backleakage is not by itself a reportable event. In addition, the reasons are not clear for the absence of steam binding events at CE and B&W operating plants since the AFW designs are very similar to the Westinghouse designs. Consequently, the small population of steam binding events are not sufficient to predict future occurrences with certainty, and the risk could be higher than indicated by the point estimates based on the reported operating experience. On the other hand, there may be plant specific features that make some plants less susceptible to steam binding than other plants. Thus, there is some uncertainty associated with the estimates, but they still provide some perspective on the safety implications associated with steam binding.

The lessons learned from the evaluation of the operating experience for reactor trip breakers after the Salem anticipated transient without scram (ATWS) events should not be forgotten in assessing the significance of available operating experience for steam binding events. One of the important lessons was that routine statistical analyses of single failures and failure rate data cannot by itself predict potential common mode failures, even when a relatively large population exists (as in the case of trip breakers), as compared to the paucity of available steam binding data.

Similar to the observed pattern for reactor trip breaker failures, the operating experience for steam binding events shows that a small number of plants are apparently experiencing difficulties with the check valves failing to prevent backleakage. Thus, the random nature and low frequency of steam binding events should be regarded as potentially important safety problems. But like reactor trip breaker events, the licensee reports fail to connect root causes (when identified) with common mode failure potential. Thus, a major common mode failure may exist that may not be fully recognized by licensees and evidenced by their operating experience. Furthermore, the operational capability of the check valves to perform their isolation function is apparently receiving less licensee attention than did the reactor trip breakers before the Salem ATWS events, e.g., testing and maintenance (See Section 5). However, one important difference between the operating experience for the two events is that a precursor event exists for steam binding events to support the identified potential common mode failure of the AFW system.

In summary, steam binding of the AFW pumps represents a potentially significant safety issue. Steam binding of a pump(s) is presently an undetectable failure that could result in the common mode failure of the AFW system. Further, the operating experience (and AFW designs) shows that the potential for common mode failure of the AFW system due to steam binding of the pumps exists and that the unavailability of the AFW system due to this failure mode contributes significantly to risk of core melt in PWRs.

4.0 CAUSES FOR VALVE LEAKAGE

In order for the hot main feedwater to reach an AFW pump, the water must leak past multiple valves in series. Operational experience showed that multiple check valves in series or in one case even two check valves and a closed motor-operated valve, have leaked in a single AFW train and leakage has occurred in two trains, sometimes simultaneously. Hence, an unexpected number of valves are leaking concurrently. The purpose of this section is to evaluate the causes for the valve leakages.

H. B. Robinson experienced recurring leakage through the check valve(s) and the closed motor-operated valve in both the motor- and turbine-driven AFW trains at different times. One event involved both motor-driven pumps. The identified causes of check valve leakage have included a burr on the hinge, a pin hole in the seal weld, leakage by the seat assembly, and slow closing. The check valves (4-inch Crane, Model 973, drawing NY 434112-5379-306) were replaced with units of the same design, and leakage has continued to occur. The licensee has now decided to replace the check valves with a different design in the near future.

The motor-operated valves at Robinson were replaced in 1979 with a different valve design. Backleakage through the check valve apparently caused thermal binding of the originally installed motor-operated valve, which the licensee believes caused the valve to leak and fail to open on several occasions. However, leakage has also occurred through the replacement valves. After the turbine-driven pump was steam-bound on July 21, 1983, the licensee reworked two of the three motor-operated valves in the steam powered train. A pin hole was weld repaired on one valve and the seats in the other valves were lapped to ensure a good seal.

Until the check valves are replaced, H. B. Robinson has made changes and additions to the procedures to minimize and detect backleakage in the AFW system. First, the AFW pumps are now vented each shift (the initial time interval was four hours before corrective action on the valves) to prevent a temperature increase sufficient to cause steam binding of the pumps. Secondly, the procedure for shutting down the AFW pumps has been changed to delay closing the motor-operated valves until the check valves have had time to seat properly. No AFW pump trips or backleakage have been reported since these procedural changes were made in July 1983.

The preventive action taken by Robinson suggests that the check valves were not seating properly due to an inadequate pressure differential across the valves. For check valves in series, it is not clear how all the check valves can seat properly unless all the valves close at the exact same time, which appears unlikely. As a result, the available number of check valves in series to isolate the AFW system may be misleading because only one check valve may be effectively preventing the backleakage due to the differential pressure available to seat valves in series. This hypothesis is supported by the Surry evaluation of check valve leakages where only three of the twelve leaking check valves showed any damage and the reasons for the other valves leaking could not be determined. The damaged valves were ones located closest to the MFW piping.

At Surry Power Station Unit 2 in December 1983, four check valves in each train leaked and each of the two pumps became steam bound. The motor-operated valves are normally open. A single check valve near the discharge of the remaining pump prevented it from also becoming steam bound. All pumps share a common discharge header. Because of previous external leakage problems, the check valves were replaced with units of the same type (3 and 6-inch Crane, Model 175.5X, Dwg. B-363-534) during the December 1981 refueling outage. An evaluation of the valves' internals revealed that the check valves nearest the MFW piping had steam cuts on their seats caused by the flashing of the hot water as it leaked by the valve. The other check valves did not show any visible damage. All valves were refurbished. Hence, the reasons for the failures of these latter check valves to seat properly are not known. Even after the check valves were repaired in December 1983, leakage was again identified in January 1984. The 3-inch valves were removed from the system and sent to the vendor for refurbishment. The 6-inch valves were reworked by the licensee. The causes for some of the check valves to leak were excessive movement in the valve disk and small holes in the valve seat. The plant procedures now require frequent checking of the AFW system for elevated temperatures by using a hand held pyrometer during operator rounds. In addition, the valves will be tested for leak integrity during future refueling outages.

The only check valve failure reported by the Joseph M. Farley Plant was caused by one missing and one worn hinge pin bushing. The check valve failed to close after surveillance testing. However, the three upstream valves were known to be leaking before the test. As a result, gross backleakage caused the relief valve at the AFW pump suction to open. The causes for the other check valves to leak could not be determined. One possible reason being evaluated by the licensee and valve manufacturer is the valves (Anchor-Darling, 4-inch, Model 900) are not suitable for preventing backleakage to the AFW system, e.g., large differential pressures are required to close the valve.

In January 1984, Farley initiated design changes to replace the auxiliary feedwater check valves (Anchor-Darling) with a different valve design. However, after conversations with Anchor-Darling and with Bechtel Power Corporation (the A/E for this system), Farley management decided not to replace the valves but rather to modify the existing valves.

The licensee has modified the AFW check valves in both Farley units. This modification consists of adding additional weight to the backside of the check valve discs to ensure proper seating of the discs against the backpressure in the system. In addition, design changes were initiated in January 1984 to install temperature monitoring with annunciators locally and in the control room on the auxiliary feedwater systems. The local annunciation modification is currently in planning for implementation. The control room annunciation modification is currently scheduled for the next refueling outage on each unit. Farley continues to monitor the auxiliary feedwater systems to detect backleakage which may occur.

Both Surry and Farley plants indicated that they were considering replacing the check valves in the AFW system (a second time for Surry). Ironically, the replacement valves under consideration by each plant were the valves with which the other plant was experiencing problems, i.e., Surry was evaluating the replacement of the Crane valves with Anchor-Darling valves, while Farley was evaluating just the opposite. As a result of our discussions and suggestions, the plants coordinated with each other to resolve the backleakage problem.

The cause for the backleakage through the two check valves at D. C. Cook, Unit 2, was identified as incorrect assembly of the check valve internals. The corrective action was to assemble the check valves properly and to hand-check the temperature of the AFW system during routine shift rounds by the operators. The motor-operated valves at Cook are normally open.

Backleakage through a check valve at Crystal River Unit 3, was identified indirectly because the water heated by the steam increased the pipe temperature which adversely affected the AFW flow indicator. Although it was certain that at least one check valve leaked, the licensee did not check for leakage of other check valves at the time of the events. The plant had experienced numerous failures of this flow instrumentation, but only two of the reported events identified backleakage as the root cause. The latest event (Ref. 12) identified steam in the piping which caused the indicator to fail due to high temperature. The causes for the check valve leakage were not identified. The check valve has been reworked and an additional engineering evaluation by the licensee will be performed to determine if additional corrective actions are necessary. Upon receiving erratic instrument indications, an AFW pump is run to put cool water into the AFW piping. Backleakage to a pump has not been experienced.

The William B. McGuire event (Ref. 10) did not involve leakage of the check valve, but rather, slow closing of the check valve which permitted MFW to flow into the AFW system, overpressurizing it. To mitigate future events, relief valves were installed in the AFW pump suction piping. However, this action does not address the concern for steam binding. Slow check valve response or failure to close represents another means which could cause failure of the AFW system due to steam binding of the AFW pumps.

The reason for the check valves leaking at the KRSKO plant was not reported. Reference 14 only indicated that the check valves were refurbished.

The plants that have experienced backleakage were not always successful in precisely identifying the root cause for check valve leakage. In general, evaluations are still underway by the affected plants to identify and correct check valve leakage problems.

There appears to be no pattern or single major cause for check valve leakage. The causes differ between the events discussed at the six plants where leakage has occurred, and involve different valve designs or manufacturers. In most cases, the check valves have experienced recurring leakage, even after repair and replacement. The causes for check valve leakages will continue to be evaluated.

5.0 LEAK DETECTION

Existing regulatory requirements were reviewed to determine if there are any requirements for the check valves or remotely-operated valves to be leak tested or whether monitoring the AFW system for valve leakage is part of existing surveillance requirements contained in the technical specifications. These issues were discussed with members of the Containment Systems Branch, the Mechanical Engineering Branch, the Auxiliary Systems Branch, and the Standardization and Special Projects Branch from the Office of Nuclear Reactor Regulation. The discussions indicated that neither leak testing nor temperature monitoring of the AFW system are required for the reasons discussed below.

Regulatory requirements to leak test valves are contained in 10 CFR 50, Appendix J for containment leakage testing and in 10 CFR 50.55a, paragraph g for the Inservice Testing (IST) program. Leak testing is primarily required only for containment isolation valves. For the valves that receive an automatic containment isolation signal, the technical specifications require that the valves can be closed within a specified time interval.

Although a remotely-operated valve in the AFW system piping is identified as a containment isolation valve pursuant to GDC 57, the valve is not included in the containment leakage testing pursuant to Appendix J because the AFW piping is assumed to be filled with water, precluding air leakage. As a result, the valve is not required to close automatically on a containment isolation signal. The Appendix J leakage limits apply to the integrated containment leakage rate and not to specific valve leakage. Thus, even if the valves were included in Appendix J testing, they could be leaking but the total leakage of all valves could be below the allowable leakage rate for the containment, and thus corrective action would not be required for any particular valve or valves.

The IST program for valves includes those valves designated as Class 1, 2, or 3 under Section III of the ASME Code and whose function is required for safety, and also includes those valves not categorized as ASME Class 1, 2, or 3 but which are considered safety-related. The valve test procedures are prescribed by Section XI of the ASME Code and the type of testing depends on the category of the valve as defined by Regulatory Guide 1.26. The AFW valves are identified as Category C valves and the IST program requires the safety function of the valves to be verified.

For the AFW valves, the identified safety function of the AFW valves is to open to provide a emergency feedwater flow path to the steam generator. Hence, the IST requirements ensure that the valve disc opens freely. The AFW valves are, therefore, not required to be leak tested as part of the IST program.

Expanding the definition of the safety function of the AFW valves to include the isolation of the AFW system from the steam conversion system to prevent leakage could result in defining them as Category A valves which would require leak testing of the valves in the IST program. However, the time interval between tests (e.g., during refueling outages) would not appear to provide an effective method by itself to prevent steam formation in the AFW system, especially when small leakages are a concern. This is not to say that inservice testing would not be effective as part of an overall program. For example, the combination of the IST program and periodic surveillance for leakage during the interval between IST tests could minimize the likelihood for steam formation in the AFW system.

The IST program could identify reverse leakage through individual valves and when corrected, minimize the potential for gross leakage to occur simultaneously through all the valves in series. By including these valves in the IST program, the leak testing could additionally ensure that each valve performs its intended function of preventing reverse rotation of the pump impeller.

The existing technical specification requirements for the AFW system verify the capability of the pumps and valves in the system to deliver emergency feedwater to the steam generator. The surveillance requirements do not include monitoring the AFW fluid for elevated temperature to detect back-leakage from the steam conversion system. The review of the various AFW designs did not identify any existing instrumentation that could be used for this purpose.

At a small number of operating plants surveyed, the AFW piping and pump casings are touched by an operator during his routine rounds of the plant to determine if the piping temperature is hot. This practice was limited to those plants that had previously experienced backleakage. Typically, the operator checks the piping and pump casings each shift and checks more frequently when elevated temperatures are detected. Although this procedure has usually been effective at the affected plants, a pump became steam bound at Robinson although the pump was checked every four hours.

The most effective method of reducing the potential for steam binding of the AFW pumps is to continuously monitor the AFW piping for elevated temperatures between the pump discharge and the interface with the steam conversion system.

For example, temperature instrumentation with an alarm in the control room could alert the operators that inleakage to the AFW system has occurred such that corrective actions could be taken before the hot water reaches saturation conditions and flashes to steam before or after the AFW pump is started.

6.0 FINDINGS AND CONCLUSIONS

The evaluation of the operating experience for leakage of hot MFW into the AFW system found that 20 of the 22 events occurred at Westinghouse-designed plants: thirteen events occurred in 1983 at five plants. Some of the events, particularly at Surry, Farley, and Robinson, indicated that backleakage can be a potential common cause failure for the AFW system. Although the other events affected single AFW trains, AEOD concludes that these events should not only be considered random failures of single AFW trains, but also as contributing events that can lead to potential loss of AFW capability due to a common cause.

AEOD believes that the number of identified events is not a true indication of leakage problems at operating plants because leakage into the AFW system is not, by itself, a reportable event. Thus, backleakage may be a more frequent occurrence than indicated by the operating experience. This backleakage is causing an unwarranted challenge to a safety system. The generic safety significance of this leakage in the AFW system has apparently not been fully recognized.

AEOD's assessment of the safety significance of the identified events found that (1) loss of a single train due to steam binding is significant because it is presently an undetectable failure that jeopordizes the capability of the AFW system to meet single failure criterion, i.e., common mode failure and (2) the unavailability of the AFW system due to steam binding contributes significantly to risk of core melt in PWRs.

The potential for backleakage may be generic to other safety systems in both BWRs and PWRs because the standby safety systems are isolated from the operating systems, which are at higher pressures and temperatures, by check valves and a normally closed motor-operated valve. However, there are no known reports of steam binding of the pumps in other safety systems. Operating experience shows, however, that check valve leakage can cause the motor-operated valve to fail to open due to thermal binding (Robinson) or other reasons (Ref. 18)--a safety concern different from steam binding. In Reference 18, AEOD recommended measures to ensure the function of the motor-operated valves, which when implemented, should address this concern. In addition, the safety implications of check valve failures to open or leak in other safety systems will be further evaluated.

The review of the AFW system designs for the three types of PWRs found that the potential for backleakage is generic to all AFW designs because check valves isolate the AFW system from the steam conversion system in most operating plants. Some designs also employ a normally closed remotely-operated valve in addition to check valves to isolate the interfacing systems. There may be plant specific features that make the AFW systems at some plants less suceptible to backleakage and steam binding than other plants. The AFW designs at Westinghouse plants appeared more susceptible to backleakage than the other designs because the remotely-operated valve is normally open in most Westinghouse plants. Operating experience supports this conclusion although multiple events occurred at Robinson, which employs a normally closed motor-operated valve to isolate the interfacing systems.

The study concludes that the potential for common mode failure of the AFW systems due to steam binding of the pumps is present whenever one pump is steam bound because the pumps are connected by common piping (discharge header and/or recirculation piping) with only a single check valve to prevent backleakage of hot water to a second or third pump. In addition, the capability of these check valves to prevent cross flow between pumps is uncertain because of a low pressure differential across the valves to ensure they are properly seated.

The 22 events represent approximately 60 check valve failures to prevent reverse leakage. The analyses of the causes for check valve leakage did not identify any pattern or single major cause for check valve leakage. The causes differed between plants and involved different valve designs and manufacturers.

This study did not identify any regulatory requirements or uniform plant practice to reduce the likelihood of steam binding of the AFW pumps. Presently, there are no regulatory requirements to leak test any of the valves isolating the AFW system from the MFW system as part of the containment leak rate testing or inservice testing programs to ensure the isolation function of the valves. Existing technical specifications presently do not contain surveillance requirements to monitor or detect leakage into the AFW system. A small number of plants presently have ad hoc procedures for the operator to touch the AFW piping to detect elevated temperatures during routine shift rounds. This practice exists primarily at those plants that have experienced backleakage. One of the plants that experienced steam binding of the AFW pumps has installed temperature instrumentation on the AFW piping with indication in the control room. This is a commendable self-initiated monitoring method that we endorse for operating plants, especially those which have experienced backleakage.

The loss of the AFW system due to steam binding of the pumps is a potentially significant safety issue requiring attention. The loss of the AFW system is a major contributor to dominant core melt accident sequences. Although an Information Notice was issued to alert licensees to the potential for backleakage and steam binding of the pumps, adequate measures to detect and monitor backleakage do not now exist in all plants to minimize the likelihood of the common mode failure of the AFW system.

7.0 RECOMMENDATION

AEOD recommends that the Office of Nuclear Reactor Regulation either (1) require the regular monitoring of the AFW system to detect leakage and ensure that the fluid conditions are well below saturation conditions; (2) confirm that such a practice is already being implemented; or (3) determine that backleakage is not a safety problem and no additional actions are necessary.

The purpose of this recommendation is to minimize the potential for steam binding of the AFW pumps due to backleakage to the AFW system from the steam conversion system. The method should include two basic elements: first, preventive measures to ensure that the valves can perform their intended function; and second, surveillances to ensure that the valves' isolating function has not degraded with time.

For example, the first element could include leak testing of the isolation valves in the AFW system as part of the operability requirements for the system. This testing could ensure that the valves can perform their intended function and be maintained in an operational condition required for safety equipment. In addition, this testing could identify individual leaking valves and minimize the potential for gross reverse leakage through all valves. Leak testing could be required prior to a startup from an outage if testing had not been completed in the previous six months. However, this element by itself is not considered to be fully acceptable, because of the long time interval between leakage tests.

The second element suggests a technical specification surveillance requirement to monitor and detect backleakage during the leak test interval as part of the operability requirements for the AFW system. For example, a temperature limit on the AFW fluid could be required as a Limiting Condition for Operation. In order to meet the Limiting Conditions for Operation, the temperature of the fluid must be known. The fluid temperature could be obtained either by (1) installing instrumentation to continuously monitor the temperature near the discharge of the AFW pump with an alarm in the control room, or (2) measuring the temperature periodically using a hand-held pyrometer. The plant procedures should adequately address corrective actions to be taken in response to a high temperature condition. The frequency in the latter case might be adjusted based on the history of measurement results, i.e., increase the frequency if the temperature is frequently found high, or decrease the frequency if the temperature is routinely found acceptable. Depending on the design and operation of the AFW system, there may be site specific provisions that preclude backleakage and no additional licensee actions may be necessary.

In the interim, until an approved method is implemented at operating PWRs, plant administrative procedures should require an operator to measure the temperature of the AFW piping and pump casings with a pyrometer and record the reading in the check-off lists that are used during plant tours. Monitoring of the AFW piping temperature should be completed after AFW system surveillance testing or whenever the AFW pumps are operated to ensure that the isolation valves are properly seated.

These actions should ensure that backleakage is minimized and detected before a pump becomes steam bound, and reduce the likelihood for the common mode failure of the AFW system.

8.0 REFERENCES

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5. Carolina Power and Light Company, Licensee Event Report 79-34, Rev. 1, Docket No. 50-261, dated March 25, 1982.*

6. Indiana and Michigan Electric Company, Licensee Event Report 81-063, Docket No. 50-316, dated November 30, 1981.*

7. Indiana and Michigan Electric Company, Licensee Event Report 81-032, Docket No. 50-316, dated August 11, 1981.*

8. Personal communication with Eric Swanson, Senior Resident Inspector, D. C. Cook Nuclear Power Plant. Event similar to References 4 and 5 occurred on January 16, 1983 but the plant was in an operational mode which did not require a report from the licensee.

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13. Letter from T. R. Tramm, Commonwealth Edison Company, to H. Denton, NRC, Subject: Byron Station Units 1 and 2, Water Hammer Protection for Dockets 50-454, 50-455, 50-456, and 50-547, dated September 9, 1982.*

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* Available in NRC PDR for inspection and copying for a fee.

15. Memorandum from D. Zukor to C. Michelson, NRC, Subject: Engineering Evaluation Report on McGuire Overpressurization Event of August 25, 1981, AEOD/E248, dated November 2, 1982.*

16. Arkansas Power and Light Company, Licensee Event Report 80-18, Docket Number 50-368, dated May 5, 1980.*

17. Alabama Power Company, Licensee Event Report 83-84, Docket Number 50-348, dated December 27, 1983.*

18. Memorandum from C. Michelson to Multiple Addressees, NRC, Subject: Survey of Valve Operator-Related Events Occurring During 1978, 1979, and 1980, AEOD/C203, dated May 28, 1982.*

19. U.S. Nuclear Regulatory Commission, "Reactor Safety Study Methodology Applications Program: Sequoyah #1 PWR Power Plant," NUREG/CR-1659, Vol. 1, dated April 1981.*

* Available in NRC PDR for inspection and copying for a fee.

APPENDIX A

VAPOR BINDING OF AUXILIARY FEEDWATER PUMPS

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

NOV 21 1983

MEMORANDUM FOR: Richard C. DeYoung, Director
Office of Inspection and Enforcement

Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: C. J. Heltemes, Jr., Director
Office for Analysis and Evaluation
of Operational Data

SUBJECT: VAPOR BINDING OF AUXILIARY FEEDWATER PUMPS

Enclosed is an engineering evaluation report on the vapor binding of the auxiliary feedwater (AFW) pumps at H. B. Robinson Nuclear Power Plant, Unit 2. The safety implication of the events at Robinson is that the leakage of main feedwater to the AFW system constitutes a common cause failure that can render both trains of the AFW system inoperable, although only single trains have been adversely affected to date. Similar events have also occurred at D. C. Cook, Unit 2.

The potential for the loss of AFW system due to backleakage appears generic because the designs of the systems at Robinson and Cook are typical of other PWRs, i.e., isolation between the steam conversion system and the AFW system is accomplished by check valves and motor-operated valves. AEOD has initiated a case study to better define the generic implications and establish the bases for revising the technical specifications to ensure that the AFW temperature is monitored and/or that the inservice inspection programs test the isolation capability of the check valves.

In the interim until the case study is completed, the Office of Inspection and Enforcement is requested to issue an Information Notice to promptly notify PWR licensees of these events and alert them to the potential for leakage from the feedwater system to the AFW system and steam binding of the AFW pumps.

The Office of Nuclear Reactor Regulation is provided a copy of the report at this time to highlight the significance of the events and provide an input into ongoing NRR activities. We have only recently become aware of TIA 82-66 entitled, "Robinson/Crystal River 3 - AFW Check Valve Leakage," and endorse the action to evaluate generic technical specification changes. It is important to note that Robinson events analyzed in the enclosed report have occurred since the TIA was initiated in 1982. These events may provide additional information pertinent to the resolution of the TIA.

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If you require any additional information, please contact Wayne Lanning at 492-4433. He is available to assist you in resolving this important issue.

C. J. Heltemes, Jr., Director
Office for Analysis and Evaluation
of Operational Data

Enclosure:
As stated

cc w/enclosure:
JOlshinski, Region II
GHolahan, NRR
JPage, NRR
RBaer, IE

AEOD ENGINEERING EVALUATION REPORT*

UNIT: H. B. Robinson, Unit No. 2
DOCKET: 50-261
LICENSEE: Carolina Power & Light Company
NSSS/AE: Westinghouse/Ebasco

EE REPORT NO.:AEOD/E325
DATE: November 21, 1983
EVALUATOR/CONTACT: W. Lanning

SUBJECT: VAPOR BINDING OF AUXILIARY FEEDWATER PUMPS AT ROBINSON, UNIT 2

EVENT DATE: April 19, 1983

REFERENCE: Carolina Power & Light Company, Licensee Event Report 83-044, Docket 50-261, dated May 18, 1983.

SUMMARY

Robinson has experienced 4 failures of AFW pumps due to low discharge pressure trips caused by steam formation in the AFW piping and pump casings. The steam was formed when hot water from the feedwater system leaked through two check valves and a motor-operated valve in the piping to either the motor- or steam-driven AFW pumps. Although the backleakage has caused only a single train of the AFW system to fail, the potential exists for both trains to fail simultaneously since backleakage has occurred repetitively in both trains. Three events have also occurred at Cook-2 involving backleakage and elevated temperature of the AFW piping and pump casing.

The evaluation concludes that Robinson has implemented acceptable corrective actions to prevent steam formation in the AFW system. Since the design of the Robinson AFW system is typical of other operating PWRs, an IE Information Notice should be issued to inform other licensees of the potential for steam binding of the AFW system.

An AEOD case study is recomended to further evaluate the generic implications for other AFW systems and develop appropriate recommendations to minimize the potential for steam binding of the system. Generic technical specification changes should be evaluated to require that appropriate surveillance procedures be implemented, if not already available, to detect leakage and prevent steam formation in the AFW system.

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*This document supports ongoing AEOD and NRC activities and does not represent the position or requirements of the responsible NRC program office.

DISCUSSION

During the review of operating experience, the referenced LER was identified as a significant event and warranted AEOD evaluation because of the potential for common mode failure of the auxiliary feedwater (AFW) system. The purpose of this engineering evaluation is to summarize the event, evaluate the safety implications, and determine whether additional licensee or NRC actions are necessary.

Following a manual reactor trip on April 19, 1983, the two motor-driven auxiliary feedwater pumps started automatically on low steam generator level. After about 2 minutes, the "B" AFW pump tripped. During testing of the pump, a significant amount of steam was vented from the pump casing. The pump trip was attributed to a protection trip signal generated by the pressure instrumentation in response to a low discharge pressure.

The discharge piping from the motor-driven AFW train is connected to the main feedwater piping near the steam generator. Hot water (about 425°F) from the feedwater system leaked through two check valves and a motor-operated valve in the piping to the AFW pumps. This water flashed in the discharge piping and pump casing because the AFW system was at a lower pressure than the feedwater system. When the AFW pumps started, the instrumentation in the discharge piping sensed a low pressure and signalled a pump trip. The low discharge pressure was caused by steam binding of the pump which reduced the flow and prevented the discharge pressure from increasing above the low pressure setpoint in the 30 seconds required for the discharge pressure sensor to time out. Condensation effects would contribute to the low pressure condition.

The potential exists for both motor-driven AFW pumps to trip due to backleakage in any one of the discharge piping runs to the steam generators because both pumps share a common discharge header. This is evidenced by the elevated temperature measurements obtained for both pump casings during the licensee's investigation of the event. The steam-driven pump has separate discharge piping and was not affected directly. However, the motor-driven and steam-driven pumps share a common suction header from the condensate storage tank and backleakage could affect all pumps.

Although the pumps have a common suction header, the relatively cold condensate storage tank water would tend to mix with the hotter water from the steam generators reducing the potential for water at the suction of the AFW pumps to be near saturation conditions and flash when pumped. This would depend, of course, on the leakage rate and the time available to raise the temperature of the suction water. Based on this event, the combination of these two factors did not adversely affect either the second motor-driven AFW pump since it did not cavitate or the steam-driven pump since the suction water remained cooled.

Robinson had experienced prior leakage through the discharge piping and consequent trips of the motor-driven AFW pump "A" on June 11 and 16, 1981 (LER 81-016). The unit was at 93% power during the second event with only a single AFW pump remaining to provide emergency feedwater because the steam-driven pump was inoperable. The valves were repaired and the backleakage significantly reduced. The pump tripped again on June 19, 1981 (LER 81-017) after a reactor trip, but the cause was attributed to improper throttle valve setting of the discharge valve although steam binding could have caused the low pressure trip.

On July 21, 1983, a similar event (LER 83-016) occurred resulting in the steam-driven AFW pump being declared inoperable due to potential steam binding. Hot water from the feedwater system leaked through the discharge check valve and the motor-operated valve producing steam at the suction vent and discharge drain of the pump. The discharge piping from the steam-driven pump is connected to the feedwater bypass piping. The potential existed for pump cavitation and trip on low discharge pressure following an automatic start. The steam was discovered during a routine check of the AFW train and the pump had not been required to operate. On August 17, 1977, the steam-driven train experienced a failure of a check valve to close which caused the relief valves on the suction header to lift.

Other failures of the motor-operated valves occurred on September 5, 6 and 16, 1979 when they failed to open (LERs 79-32, 79-33 and 79-34). The cause for the failures was due to a thermal overcurrent relay trip resulting from the failure of the torque switch to de-energize the motor after the valve was fully closed. Excessive wear of the worm gear prevented proper operation of the torque switch. The excessive wear is believed to have occurred during previous events when the valve stuck closed due to thermal binding caused by the leaking upstream check valve. Thermal binding can lead to deformation of the valve internals and leakage. The three check valves and the three motor-operated valves were replaced with the same type (4-inch Crane, model 973, drawing N:434112-5379-306) in 1980 to correct the backleakage.

The design of the AFW system at other operating plants also generally include check valves and motor-operated valves in series to prevent backleakage from the feedwater system to the AFW system. This suggests a potential generic concern. However, a review of operating experience for the past 2 years identified only three similar events. These events occurred at Cook-2 (LERs 81-32, and 81-63) where the valves leaked in the steam-driven train and an abnormally high temperature was observed for the pump casing, suction and discharge piping. The pump had not been required to operate in any event. The Resident Inspector identified the third event which occurred on January 6, 1983. This event was not reported in an LER because the mode of operation did not require the AFW system to be operable.

Although the design of the AFW system at Cook is similar to Robinson, the motor-operated valve in the pump discharge piping is locked-open during operation. The isolation of the AFW system from the main feedwater system is achieved by two check valves (4-inch Atwood Morrill, drawing #20016F). The reason for the check valve leakage is attributed to improper valve assembly rather than design deficiencies reported for the Robinson valves. Nevertheless, the potential for backleakage may be greater at Cook than Robinson, because the motor-operated valve does not provide isolation capability. However, the consequences of backleakage at Cook is significantly less, because the motor-driven pumps do not share a common discharge header, e.g., both pumps cannot become steam bound due to leakage in a single discharge line. All the pumps do share a common suction from the condensate storage tank. Like Robinson, there are no temperature indicators for the auxiliary feedwater. The events at Robinson and Cook suggest that backleakage is a potential generic concern since different check valve designs are employed in the AFW system and both units have experienced backleakage resulting in inoperable trains of the AFW system.

A special interim procedure has been implemented at Robinson to vent both the motor- and steam-driven pumps once each shift. In addition, the temperature of the pump casings are monitored locally and the pumps are operated as necessary to ensure that the water in the AFW system remains cool and well below saturation conditions. Cook also monitors the temperature during routine checks by the auxiliary operator during shift inspections.

In the longer term, Robinson is evaluating a design change or replacement of the check valves located in each of the AFW pump discharge piping. Depending on the results of the evaluation, the check valve leakage should be corrected during the refueling outage beginning in December 1983 or during the steam generator replacement outage beginning in June 1984. A program is also underway to improve the performance of limitorque valves by developing valve performance histories to monitor and identify valve degradation in the future.

FINDINGS AND CONCLUSIONS

Robinson has experienced four events in the past two years involving failures of AFW pumps due to steam binding resulting from leakage of feedwater to the AFW system. It appears that the failure of the check valve to prevent backflow causes the motor-operated valve to leak and is the primary cause for the events. Based on operating experience the leakage in one AFW train has not affected the other train although the potential exists for common mode failure. The primary concern is, however, that backleakage will occur simultaneously in each of the AFW trains causing failure of the AFW system to perform its safety function.

The safety implications of the four events at Robinson is that the leakage of feedwater to the AFW system constitutes a common cause failure that can render both trains of the AFW system inoperable. Although the events to date have involved the failure of a single train, all of the events have been caused by the simultaneous leaking of two or three isolation valves in series. These events should not be considered random failures of single AFW trains, but as contributing events leading to potential loss of AFW capability due to a common cause failure. The trend of these events compare similarly to the trend of the reactor trip breaker failures at Salem and other plants before the Salem ATWS events.

Since the design of the AFW system at Robinson is typical of other PWRs, the potential for backleakage exists in other operating plants evidenced by the events at Cook-2. Monitoring of the temperature of the AFW pump casing, suction and discharge piping should be performed c a routine schedule to detect leakage into the AFW system and prevent steam binding of the system.

Robinson has implemented procedures to ensure that the water in the AFW system remains cool to prevent steam formation. These preventive actions should ensure that the AFW pumps are available to perform their safety function until the check valves are redesigned or replaced to correct the leakage problem. Efforts to improve the performance of the motor-operated valves are also underway. The licensee's actions appear acceptable and no additional actions are believed necessary at this time.

RECOMMENDATIONS

The Office of Inspection and Enforcement should consider issuing an information notice to inform other licensees of the potential for loss of AFW capability due to backleakage and steam formation in the AFW system.

In the near future, AEOD should complete a case study to evaluate the generic implications for all PWRs and identify and establish the bases for changes to technical specifications. In addition, the requirements to include the AFW pump discharge motor-operated and check valves in the inservice testing programs should be evaluated.