AEOD/C205

ABNORMAL TRANSIENT OPERATING GUIDELINES (ATOG)

AS APPLIED TO THE APRIL 1981 OVERFILL EVENT

AT

ARKANSAS NUCLEAR ONE - UNIT 1

Case Study prepared by

Reactor Operations Analysis Branch

Office for Analysis and Evaluation
of Operational Data

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NOTE: This report documents results of studies completed to date by the Office for Analysis and Evaluation of Operational Data with regard to a particular operating event. The findings and recommendations contained in this report are provided in support of other ongoing NRC activities concerning this event. Since the studies are ongoing, the report is not necessarily final, and the findings and recommendations do not represent the position or requirements of the responsible program office of the Nuclear Regulatory Commission.

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PREFACE

This report represents a detailed analysis of the April 8, 1981 steam generator overfill (or overcooling) transient at Arkansas Nuclear One, Unit 1 (ANO 1). The potential consequences and effects of this event are also discussed in terms of a postulated severe overfill event.

In addition, the report presents an analysis of the draft "Abnormal Transient Operating Guidelines" (ATOG) (Reference 1) prepared by Babcock and Wilcox (B&W) for ANO-1, and its guidance on mitigating steam generator overfill transients. This report provides a simple comparison of the draft ATOG with an actual overfill transient.

The conclusion reached is that the draft ATOG prescribes a series of operator actions which can be used to successfully mitigate an overfill transient. However, during a severe overfill transient, the available time margin is probably insufficient to allow proper operator action. Even a mild overfill such as the April 8 event at ANO 1 (where the operator took proper corrective action) requires action in less than ten minutes. Those units which rely on manual operator action in this time frame to mitigate overfill transients will likely require equipment modifications and additions to supplement emergency procedures.

1.0 EVENT DESCRIPTION*

Arkansas Nuclear One, Unit 1 (ANO 1) was operating at about 100% power on April 8, 1981, when an electrical short occurred in the channel "C" inverter during maintenance with the channel "B" reactor protection system (RPS) in the test mode. The integrated control system (ICS) reactor power input is derived from the 4 RPS neutron power channels. Channels "A" and "B" are averaged [(A+B)/2] as are "C" and "D" [(C+D)/2], then the higher average is selected via auctioneering diodes. Placing an RPS channel in the test mode sets the output of the associated averaging device at zero. Loss of the "C" inverter with RPS "B" in test resulted in a loss of reactor power input to the ICS (because the "C" inverter powered the "C" associated averaging device both averager outputs were zero). Therefore, ICS received an actual power signal of zero coincident with 100% power demand and feedwater flow. In order to correct this indicated mismatch, ICS ran back feedwater (FW) toward zero percent and started to withdraw control rods (see Figure 1 for additional information and detail). The resulting power and FW flow mismatch (high power/low flow) produced an undercooling transient. The transient was terminated by a reactor trip due to high reactor coolant system (RCS) pressure.

At the time of the reactor (Rx) high pressure trip, the once-through steam generator (OTSG) levels had been depressed 15 to 20%. After the Rx trip, the plant control systems (including ICS) performed the standard FW control operations for a trip (i.e., trip one main feedwater pump (MFP) and run the other back to minimum speed, open the cross connect valve, and close all main FW valves). However, due to a maladjusted limit switch, the "B" main FW block valve (MFBV) did not fully close resulting in overfilling of the "B" OTSG, overcooling instead of undercooling the primary coolant system and, consequently, causing a rapid decrease in RCS pressure and pressurizer level.

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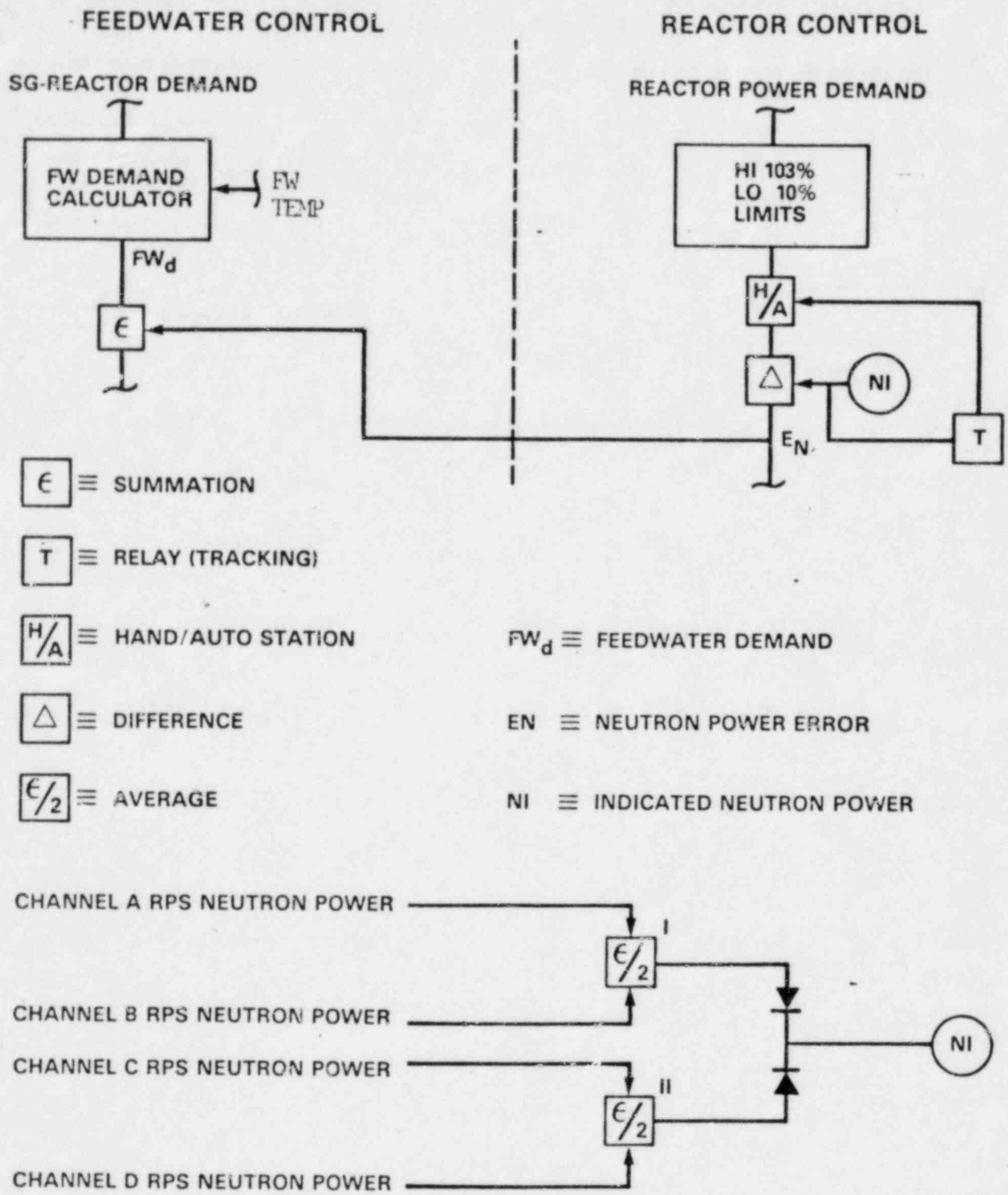
*This information is principally from Reference 2.

FIGURE 1 - ICS ACTION TO INITIATE TRANSIENT*



When channel B was placed in the test mode, the output of I was set to zero. II was powered from the C inverter so when it shorted the output of II went to zero. This produced an indicated power of zero with 100% demand and feedwater flow. The ICS then attempted to correct the indicated mismatch and ran back feedwater while pulling control rods.

*From ref. 3

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The principal operator actions taken to mitigate the overcooling transient were:

(1) initiating high-pressure injection (HPI) to restore pressurizer level,
(2) tripping the remaining MFP to stop feedwater flow (which also initiates logic to start the emergency feedwater (EFW) pumps),
(3) throttling EFW, and
(4) closing of the qualified FW isolation valve to reduce OTSG fill rate.

Subsequent to pressurizer level recovery, the operator secured HPI and reestablished normal makeup. The plant then proceeded through a normal shutdown (see Table 1 for a sequence of occurrences).

2.0 EVENT ANALYSIS

2.1 The Transient

The April 8, 1981 transient at ANO-1 was composed of an undercooling transient followed by an overfilling/overcooling transient, separated by a Rx trip.

The undercooling transient was produced by a failure in the neutron power indication to the ICS, and it behaved as predicted in Babcock and Wilcox's "Integrated Control System Reliability Analysis" (Reference 3; see page 4-38, item 3-35 of the "Failure Modes and Effects Analysis"). This transient is bounded by more severe undercooling events and produced no unacceptable results. Moreover, the consequences of the initial undercooling transient (depressed OTSG levels, increased RCS pressure, increased RCS temperature, and increased pressurizer level) were beneficial in moderating the magnitude of the subsequent overfilling/overcooling transient.

Table 1

Sequence of Occurrences*

Elapsed Time (seconds)	Event
0	RPS C shorts to 0; RPS B in test
5	Auctioneered power goes to 0; FW flow starts decreasing; SG levels start decreasing
15	RCS pressure spike starts; Pressurizer level starts up
25 (0)**	Rx trip; RCS temperature increasing
35 (10)	RCS peak pressure reached; RCS peak temperature reached; Pressurizer level starts to fall
55 (30)	SG "B" FW flow stabilizes; SG "B" level starts increasing
85 (60)	Pressurizer level falls off scale; RCS minimum pressure reached; SG "A" operating level stabilizes at 10%
105 (90)	Pressurizer level recovers on scale
205 (180)	SG "B" level peaks at 80% and event terminated by operator action

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* Obtained principally from Reference 2.

** Time in parenthesis refers to elapsed time from reactor trip.

At Rx trip, the undercooling transient was terminated and all secondary side functions for a trip were accomplished, except that an MFBV failed to close completely. This produced the subsequent overfilling event which was partially mitigated by the effects of the preceding undercooling (the depressed OTSG levels may have made the overcooling more severe because reduced mass would increase the temperature effects of the cold feedwater). The OTSG "B" overfill was also somewhat alleviated by the fact that prior to the event liquid level in OTSG "B" was lower than normal, while the level in OTSG "A" was higher than normal. (The plant had operated in this configuration to compensate for the increased differential pressure across OTSG "A" due to fouling of the tube support plates.) It should be noted that if the overfill had occurred in OTSG "A," the transient could have been aggravated by the higher OTSG initial levels.*

The operator's actions successfully terminated the overfilling/overcooling and allowed primary system pressure and pressurizer level to recover. As discussed in the event description, the operator correctly diagnosed the nature of the event and performed four essential actions to mitigate it within three minutes of Rx trip.

The OTSG level would have gone over 100% on the operating range** if any one of the following mitigating factors had not occurred (based on a simple review of Table 2): (a) the preceding undercooling transient; (b) MFBV failure on OTSG "B" (initial level about 150") rather than OTSG "A" (initial

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* However, it was noted in the peer review comments that increased level may not represent increased OTSG mass inventory. It has been observed that following trips, levels in both OTSGs have been similar. This indicates that mass of coolant in each is similar.

** Note that a water level of 100% on the operating range (394 inches above lower tube sheet) does not imply water would have entered the steam lines. The level must go above 100% on the wide range (606 inches above lower tube sheet) for water to enter the OTSG steam annulus.

Table 2

Transient Severity*

1. OTSG "A" initial level: 88%**
2. OTSG "A" level at Rx trip: 72%
3. OTSG "A" level change (during undercooling transient: 1-2): 16%

4. OTSG "B" initial level: 69%
5. OTSG "B" level at Rx trip: 48%
6. OTSG "B" level change (during undercooling transient: 4-5): 21%
7. OTSG "B" minimum level: 20%
8. OTSG "B" level change (decay heat - FW mismatch***: 5-7): 28%
9. OTSG "B" Final level: 80%
10. OTSG "B" level change (during overcooling transient: 7-9): 60%

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* Level changes were calculated. Other information is from Reference 2.

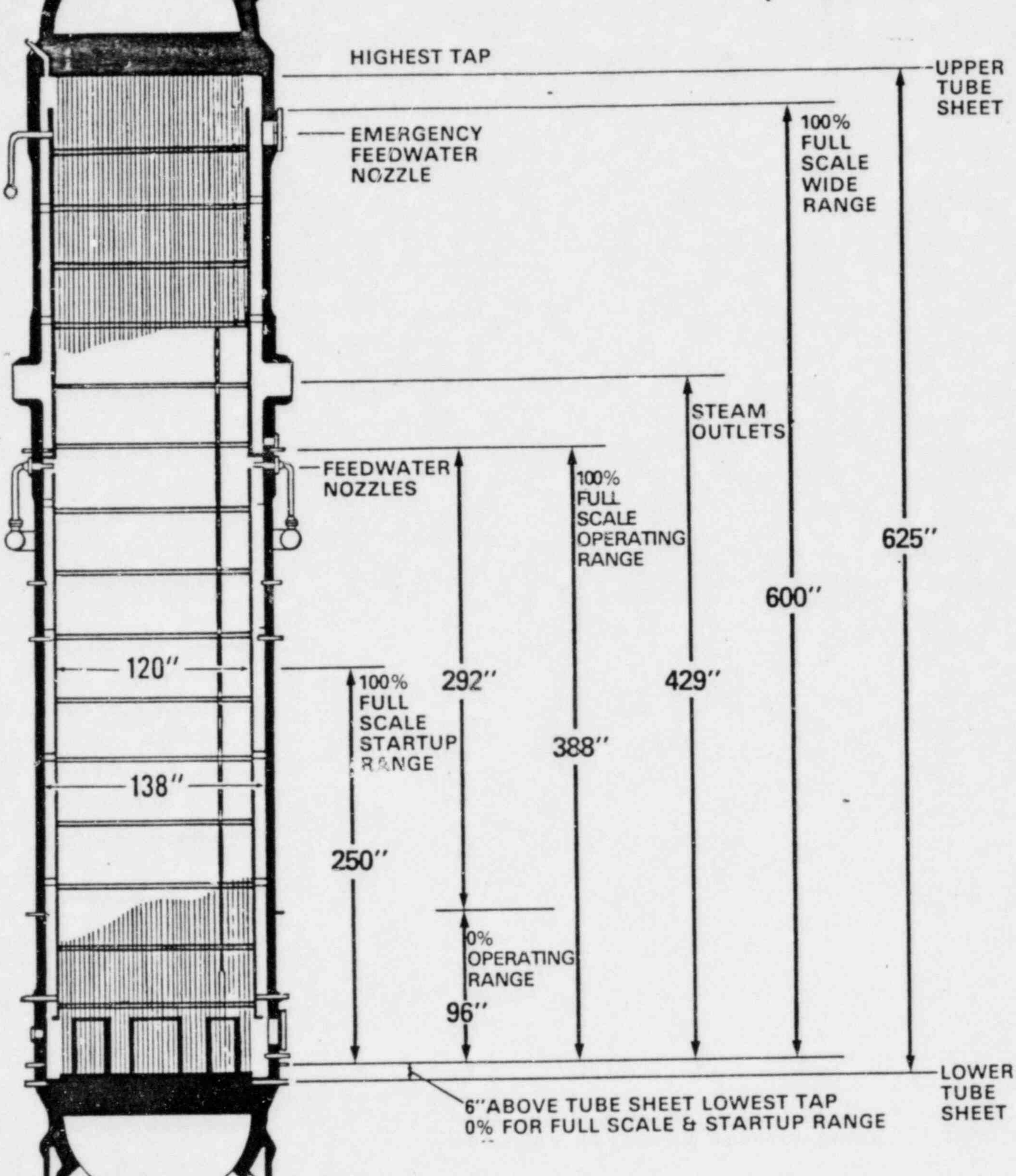
** Level information refers to percentage on the operating range. See Figure 2 for OTSG operating range level information.

*** This is the OTSG level decrease due to decay heat levels higher than the remaining FW flow immediately after the Rx trip.

FIGURE 2 - OTSG LEVEL RANGES

SCALE: |—| = 23"

LEVEL/RANGE	0%	100%	RANGE
STARTUP	6"	256"	250"
OPERATING	102"	394"	292"
WIDE	6"	606"	600"



Compilation of ref. 2

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level about 200"), or (c) correct operator action within four minutes. (See Table 2 and the Appendix for information on transient severity and time margins for operator action, respectively, and Figure 2 for OTSG level ranges.) Figure 2 presents information on OTSG level ranges with respect to actual OTSG levels. Note that this analysis does not discuss nor credit the nonqualified ICS level limiting feature.

If a similar situation were to be encountered without an undercooling transient preceding the Rx trip, the OTSG "B" would have gone slightly above the 100% level on the operating range. If the "A" FW had similarly not isolated, OTSG "A" would also have gone slightly above the 100% level on the operating range even with the preceding undercooling. This is based on the estimate presented in Table 2.

If the preceding undercooling transient had not occurred and "A" FW had failed, OTSG "A" would have gone approximately 10% above full scale on the operating range (based on Table 2). As Figure 2 indicates, this is still substantially below the level required for water to enter the main steam lines (just above 100% on the wide range).

For the April 8, 1981 event, based on a fill rate of 0.4%/second (from Reference 2), the time that was available for operator action following the Rx trip was approximately four minutes to 100% of operating range, and approximately seven minutes to 100% of wide range (see Appendix for derivation of these times and limitations of the analysis).

Three facts stand out about the April 8, 1981 event. First, the operator took exactly the right actions very quickly. Second, an unusual set of circumstances acted to mitigate the event. Finally, if the transient had occurred without OTSG fouling/crud buildup and initiated from a normal reactor trip, water could have entered the main steam lines within five minutes without prompt operator action (see Appendix for more discussion on available time margins).

2.2 Operator Performance During the Transient Versus the ANO-1 Abnormal Transient Operating Guidelines (ATOG)

Operator actions taken during the ANO-1 transient were essentially the same as those in the ATOG report (Reference 1) as illustrated below.

Actions Taken During Transient*	ATOG Procedures**
Start second charging pump	Initiate HPI
Open all HPI injection valves	(Initiation of HPI opens injection valves)
Trip MFP	Trip MFP
Close MFBV	Close MFBV
Close safety FW isolation valve	Close safety FW isolation valve
Throttle EFW***	Start and throttle EFW

* From Reference 2.

** In Reference 1 these procedures are given for an overcooling transient produced by excess MFW flow. Not listed in order in Reference 2. Rearranged to aid comparison.

*** At ANO 1, EFW is automatically initiated when the second MFP is tripped.

The only major question raised by a comparison of the actual transient with ATOG procedures (Reference 1) is that of the time available for operator action. Reference 1 states that two to three minutes are available for operator action during an overcooling transient consisting of 100% main feedwater flow after a Rx trip. Note that a single failure in any one of several control grade (non-safety grade) systems can result in an overfill. During the April 8, 1981 transient, with a feedwater flow limited to less than 20% of normal flow to one OTSG, only about seven minutes were available prior to level going above 100% of the wide range and water entering the steam lines. The Appendix presents operator time margins calculated from this event for several other overfill transients. In view of the approximations made in the Appendix calculations, the time margins found are in general agreement with those of Reference 1.

3.0 FINDINGS AND CONCLUSIONS

Overfill transients involving water carryover into the main steam lines can challenge plant safety in several ways.* The principal concerns are associated with the fact that the secondary side pressure boundary and MSIVs are not typically designed to perform their safety function with subcooled or saturated water in the main steam lines. This is discussed in detail in Reference 6. Some effects that have not been analyzed which are discussed in Reference 6 include: (1) water hammer loads; (2) secondary safety valve failure; and (3) MSIV failure to close. A history of overfill events and a generic discussion of potential causes, consequences, and scenarios leading from overfill events is also presented in Reference 6.

The time margin available for operator action to mitigate an overfill transient as calculated in this analysis is reasonably close to that stated in the referenced ATOG given the approximations used here. During some overfill events, operator action is required in about two minutes to preclude water carryover into the main steam lines. Requiring proper operator diagnosis and mitigative action in this time frame is not acceptable.

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* This report makes no attempt to quantify the amount of saturated or subcooled water carryover into the steam lines necessary to affect the secondary side safety functions. It does note that such a threshold does exist, although the author has not conducted the extensive study required to determine that threshold. For additional information on the potential effects of overfill the reader is referred to Reference 6.

If OTSG overfill is considered a credible design basis event** (see Unresolved Safety Issue A-47, Ref. 7), then the plant must be designed to withstand it. Given this, the ANO-1 design does not appear to conform to several General Design Criteria (GDC) as set forth in 10 CFR, Part 50 (Ref. 8). For example, GDC-13 controls have not been provided to maintain OTSG level as required to assure adequate safety (i.e., maintain the plant within its design envelope); GDC-54 and GDC-57 containment isolation provisions (secondary side pressure boundary and MSIVs) are not designed as required to assure performance of their isolation function during a severe OTSG overfill event which results in subcooled water entering the steam lines.

The overcooling transient at ANO-1 on April 8, 1981 was mitigated by proper operator action in a timely fashion. The transient confirmed the validity of the ATOG's generalized set of procedures to mitigate an overcooling transient.

4.0 RECOMMENDATIONS

There are two basic methods of resolving the overfill concern. These are: (1) design the plant so as to preclude overfill as a credible event or (2) design the plant to enable it to withstand a worst-case overfill (via procedure or equipment modification). As noted above, designing the plant to withstand overfill is difficult and would be extremely costly, especially for an operating plant. This analysis shows that for B&W plants there is insufficient time to credit operator action to mitigate a severe overfill or overcooling event. This leaves only "precluding overfill" as the method of resolving the concern.

Therefore, AEOD recommends the following to NRR to resolve OTSG overfill concerns at all B&W plants.

** Based on the B&W FMEA of the ICS (Ref. 3) and ORNL's review of that analysis (Ref. 5), it appears that overfilling of the OTSGs is a likely operational occurrence for the B&W plants.

1. The overfill concern portion of Unresolved Safety Issue A-47 on the Safety Implications of Control Systems (Reference 7) should focus on equipment modifications or additions to preclude overfill as a credible event. Note that FW/EFW upgrades in progress may adequately address this issue.

2. The time margins available for operator action presented in this analysis should be considered in the human factors control room review and evaluation for B&W plants (e.g., Ref. 9).

5.0 REFERENCES

1. Babcock and Wilcox, "Arkansas Nuclear One, Unit 1 Abnormal Transient Operating Guidelines," Parts I and II, Draft, released on July 30, 1980.

2. Arkansas Power and Light Company letter from D. C. Trimble to J. F. Stolz dated November 12, 1981, DCS Accession No. 8111190554.

3. Babcock and Wilcox "Integrated Control System Reliability Analysis," BAW-1564, August 1979.

4. Babcock and Wilcox Technical Paper, "Once-Through Steam Generators on the Line," No. BR-1013, presented November 1973.

5. Review of Babcock and Wilcox report, "Integrated Control System Reliability Analysis," BAW-1564, by Oak Ridge National Laboratory (DCS Accession No. 8002150257), January 21, 1980.

6. USNRC, "AEOD Observations and Recommendations Concerning the Problem of Steam Generator Overfill and Combined Primary and Secondary Side Blowdown," December 17, 1980.

7. USNRC, NUREG-0705, "Identification of New Unresolved Issues Relating to NPSS" (Safety Implications of Control Systems - Task A-47), published February 1981.

8. USNRC Code of Federal Regulations, Title 10, Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," January 1, 1981.

9. XYZYX Corporation, "Evaluation of Abnormal Transient Operating Guidelines (ATOG) for Arkansas Nuclear One," DCS Accession No. 8103170505.

Appendix

TIME MARGINS AVAILABLE FOR OPERATOR ACTION

This appendix details an extremely simplistic analysis of very complex, multiphase steam generator transient response. It is an attempt to provide independent confirmation via diverse analytical technique of the time margin presented in ATOG for operator action during overfill transients. The report recognizes the limitations of this analysis and cautions against its use in any but a general confirmatory matter. Also, please note the the numbers presented are of very limited precision due to limits of the input data.

Time margins available for operator action can be calculated based on data from the April 8, 1981 transient at ANO-1. The margins for the actual, as well as several potential, overfill transients were calculated below by AEOD using the following data from reference A-1:

Main FW flow @ 100% power: 5.3 MLB/HR (million pounds per hour) = FWF (100%), and

Fill rate (OTSG B) during overfill: 0.4%/second* = FR(DO).

In general, the fill rate (FR) of an OTSG may be expressed as the difference between the FW flow rate (FWF) and the steam flow rate (SR) as shown in equation (1):

(1) FR = (FWF - SR) x C

where C is a unit conversion factor (MLB/HR to %/second).

Therefore, noting that after an Rx trip the steam rate is decreasing to zero, a conservative estimate of the fill rate may be made by assuming SR = 0. Equation (1) may then be written as:

(2) FR = FWF x C

It should be noted that C will vary with FW temperature since it includes FW density. (For a FW temperature of 450°F, $C = 0.4 \frac{\%/\text{second}}{\text{MLB/HR}}$)

Since FR (DO) is known, FWF (DO) may be calculated from equation (2):

FWF (DO) = 1 MLB/HR

Given the above information, FR (100%) may be calculated from:

(3) FR (100%) = FR (DO) x [FWF (100%)/FWF (DO)]

Using equation (3) yields:

FR (100%) = 2%/second or 370 inches/minute*

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* Fill rate percentages refer to the operating range. (See Figure 2 of the text for range information.)

The operator time margins for various types of overfill events were calculated by AEOD using the measured fill rate during the April 8, 1981 transient and the fill rate calculated (see Equation 3 above) for 100% feedwater flow to one OTSG. The operator time margin (T), where D is the distance to be filled, is given by:

(4) T = D/FR + delay for FWF to match decay heat

The delay to allow FWF to match decay heat is only important in mild transients such as the April 8 event (where it was about 30 seconds). It represents the time required for the decay heat rate (and steam rate) to decrease below the remaining FW flow rate. During this period OTSG level will decrease (e.g., during the ANO-1 event level decreased 28%* immediately after the Rx trip which was the start of the overfill and prior to increasing due to the overfill). For events involving a trip with no FW runback, this delay is zero.

The following factors should be kept in mind when considering the time margins below. Water enters the main steam lines in substantial amounts just after reaching 100% on the wide range. Small amounts may be carried into the steam lines by steamflow at somewhat lower water levels. Also, additional OTSG fouling beyond that experienced at ANO-1 will decrease fill times due to reduced secondary side volume.

For the April 8, 1981 ANO-1 event (initial conditions for overfill: OTSG level 20%, FR (DO) = 0.4%/second*):

T(100% of Operating Range) = 3 minutes 50 seconds
T(100% of Wide Range) = 6 minutes 50 seconds

For an event similar to the above ANO-1 event but with no initial undercooling (initial conditions for overfill: OTSG level 70%, FR (DO) = 0.4%/second*):

T (100% of Operating Range) = 1 minute 15 seconds
T (100% of Wide Range) = 4 minutes 15 seconds

For a more severe transient (initial conditions for overfill: OTSG dry, FR (100%) = 2%/second*):

T(100% of Operating Range) = 1 minute
T(100% of Wide Range = 1 minute 40 seconds

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* Ibid p. A-1

This represents an event which allowed the OTSGs to boil dry and then receive 100% of main FW flow.

For a very severe transient (i.e., Rx trip from 100% power with no FW runback; initial conditions for overfill: OTSG level 70%, FR (100%) = 2%/second*):

T(100% of Operating Range) = 15 seconds
T(100% of Wide Range) = 50 seconds

This represents the time margin for operator action given a Rx trip from normal conditions with no runback of feedwater. This is probably the most severe overfill transient likely to be encountered.

References

A-1 Arkansas Power and Light Company letter from D. C. Trimble to J. F. Stolz dated November 12, 1981, DCS Accession No. 8111190554.

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* Ibid p. A-1.