FRAMATOME ANP

January 25, 2002
NRC:02:007

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Requested Reference Material for Evaluation of PSC 1-99

Enclosed are two documents to assist the NRC in its evaluation of the Framatome ANP Preliminary Safety Concern 1-99, which addresses the modeling of the reactor coolant pump used in conducting LOCA analyses. Framatome had determined that this matter was not reportable under Part 21. This background information had been requested by Jack Cushing.

Very truly yours,

James F. Mallay

James F. Mallay, Director
Regulatory Affairs

/lmk

Attachments: 1. PSC 1-99, "RC Pump Modeling Relative to LOCA Evaluation."

2. FRA Engineering Information Record, "PSC 1-99 Resolution," File Number 51-5006132-00, January 18, 2000.

cc: J. S. Cushing
Project 693

D045

FRAMATOME TECHNOLOGIES

PRELIMINARY REPORT OF SAFETY CONCERNS

1	TO: Manager, Owners Group Services, FTG (cc: Quality Assurance) Consult FTG Owners Group Services for assistance in completing this form	Log No. 1-99
	FROM: John A. Klingenfus	File No. (Contract No.) 2051 T4.4
	ORGANIZATION: Analysis Services	Page 1 of 4

Attach and identify, by page number, any supporting information/documents.

2 When, how and on which plant was the safety concern identified?

During the development of the DB LBLOCA RELAP5 input model it was realized that the plant-specific RCP homologous curves had not been used in all previous LBLOCA EM analyses. (See attached writeup)

3 To your knowledge is customer aware? ☒ Yes ☐ No

When & How J Link via telephone - 1/5/99
G. Swindlehurst via telephone - 1/5/99
M. Byram via J. Link - 1/5/99

4 To your knowledge is NRC aware? ☐ Yes ☒ No

When & How

5 Other affected Utilities/Plants (name and location)

Oconee Units 1, 2, & 3, TMI-1, ANO-1

6 Description of safety concern-identify affected component(s), system(s), service(s) or activity/supplier, and impact on safety of plant operations.

The RCP modeling question led to the discovery that all previous EM analyses may not have used the appropriate RCP type in the LBLOCA analyses. Preliminary sensitivity studies preformed with either a Westinghouse or BJ pump produced slightly higher PCTs than the same analysis with a Bingham pump. Further preliminary studies have indicated that the lowered-loop plants will produce significantly higher PCTs when the minimum two-phase pump degradation model is used. This RCP degradation model impact on PCT behavior is contrary to the BAW-10192PA 205-FA RL RELAP5/MOD2 analyses. It is also contrary to the 177-FA LL CRAFT2 sensitivity studies in BAW-10103. The attached writeup provides additional details of the discovery of the concern and the preliminary analyses results.

7 Cause of the deficiency, deviation or failure, if known.

Engineering evaluations used to extend the RELAP5 RCP degradation studies from the 205-FA RL analyses to the 177 FA LL plants was not supported by actual analysis. Use of CRAFT2 EM sensitivity studies to provide additional confirmation for the engineering judgements was also not appropriate.

8 Suggested corrective action

Perform a plant-type specific RCP two-phase degradation sensitivity study. Perform a pump type model sensitivity study when two or more pump types are included in a bounding LBLOCA EM analysis. Reanalysis of existing LOCA LHR limits is necessary if the most limiting pump type or degradation was not used.

Responsible Unit Analysis Services Unit

Originator (Signature)	Date	Manager (Signature)	Date
J. A. Klingenfus	1/6/99	[signature]	1/6/99

177-FA LL Plant RCP Type and Degradation Effects on LBLOCA

A reactor coolant pump (RCP) modeling issue discovered during the development of the RELAP5-based EM model for Davis-Besse led to a review of the BAW-10192P-A RCP modeling requirements. That review determined that the LOCA analyses for some of the B&W 177 FA LL plants may not have been performed in accordance with Section 4.3.4.5 of Volume 1 of BAW-10192P-A. This section states that the plant-specific pump performance tables (namely the pump rated parameters and pump homologous curves) are used as input for the LOCA analyses. FTI has not performed all LBLOCA analyses in accordance with this provision.

Potentially deficient analyses are: (1) Oconee Unit 1 Mark-B9 and Mark-B10(OL) LOCA LHR limits, (2) TMI Mark-B9 15 % tube plugging LOCA LHR limits, and (3) TMI and ANO Mark-B9 20 % tube plugging LOCA LHR limits. The LOCA analyses that were performed for the Duke Power Oconee Units 1, 2, and 3 used inputs for the Bingham pumps operating in Oconee Units 2 and 3. Oconee Unit 1 has Westinghouse pumps. FTI did not perform a sensitivity study to confirm that the Bingham pump results were bounding and valid for Oconee Unit 1. The TMI and ANO analyses also used the Bingham pump performance curves, even though TMI-1 has Westinghouse pumps and ANO has Bryon Jackson (BJ) pumps.

The Bingham pump performance curves have the most negative head ratios on the HVN curve, which is where the broken and two unbroken loop pumps remain for most of the transient (i.e. less head if it is positive and more resistance where the head is negative). This HVN relationship coupled with the EM pump degradation sensitivity study (which showed the maximum degradation was worst) would suggest that the Bingham pump should produce the highest PCTs. FTI performed a 177 LL pump sensitivity study for the Oconee Mark-B10 analyses to confirm this engineering judgment and to show that the analyses that

were performed with the Bingham pumps were bounding for a plant analyzed with a Westinghouse or BJ pump.

The Oconee Mark-B10 6.021-ft LOCA LHR limit case was reanalyzed with the Westinghouse pump parameters inserted into the blowdown deck. This preliminary case showed that the switch from the Bingham to Westinghouse pump homologous curves resulted in an end-of-blowdown fuel temperature increase which could increase the PCT by roughly 60 F. Investigation into the changes in results led to the suspicion that a reduction in the pump two-phase degradation multiplier could also result in a PCT increase.

Several additional blowdown cases were run with different two-phase head difference curves and void fraction multipliers. The results indicated that a switch from the semiscale ANC fit used in all 177-FA LL analyses to the less resistive two-phase difference curves given in RELAP5 for the semiscale pump would produce an estimated PCT increase of roughly 70 F. Switching from the M1 degradation curve to the M3 curve again increased the EOB fuel temperatures and could result in a PCT increase of 30 F. The total increase from the head difference and void multiplier change for the Bingham pump is estimated at 100 F. This increase, when added to the existing Oconee 6-ft PCT of 1978 F, would push the temperature up to 2078 F (possibly higher due to the exponential metal-water increase with temperature). This implied that the Oconee 1 Westinghouse pump PCT could increase by an additional 60 F or more to roughly 2140 F or higher from metal-water energy.

This estimated increase forces reanalysis of the Mark-B10 fuel that was originally performed in August 1998. LOCA studies performed since that time have included modeling refinements to the core baffle, bypass, and lower plenum regions that could provide a slight PCT improvement. When these refinements are included with the bounding RCP model, the Oconee 1 PCT is expected be less than 2200 F, which supports the current LOCA limits and core maneuvering

analyses. The overall PCT increase must be determined by formal LOCA reanalysis.

The TMI 15 % SG tube plugging analyses must be evaluated with the proper homologous pump curve, RELAP5 two-phase head difference, and M3 void fraction multiplier. The PCT increase should be similar to the 160 F identified for Oconee 1. The TMI analyses also have input model conservatisms that can be used to offset this PCT increase. The bypass/baffle model, lower plenum model, and adjustment of the pressurizer level from minimum to nominal will somewhat offset the RCP modeling PCT increases for these analyses. The resulting PCTs should also be less than 2200 F, but formal LOCA analyses are needed to quantify the overall PCT increase.

The pump modeling changes also affect the BWOG 20 % SG tube plugging analyses for TMI and ANO. These analyses have already incorporated the bypass/baffle model revision and the nominal pressurizer level. The LHR limits are accordingly 0.3 to 0.6 kW/ft higher than the 15% SG tube plugging analyses for TMI. These analyses will likely require a LHR limit decrease to bring PCTs back within a licensable range. These analyses are not currently supporting operating limits.

The CR-3 Mark-B9 analyses that are currently in progress will include the worst-case degradation differences and the M3 multiplier curve. A RCP sensitivity study will be performed for Davis-Besse to ensure that the most limiting pump degradation model is used for those analyses.

20032-22 (12/95)

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DOCUMENT RELEASE NOTICE (DRN)

Release Date 1-18-00

Records Mgmt. Initials ARC

C…CT NO.	PLANT	CHARGE NO.	Page 1 of 1
4110176	177-FA RL and 177-FA LL		

PART NO. OR TASK-GROUP-SEQ.	FTG DOCUMENT NO.	DOCUMENT TITLE (30 Characters Maximum).	SAFETY CLASSIF.	PUL STAT (Y/N)	COM ATT? (Y/N)
	51-5006132-00	PSC 1-99 Resolution	S	N	N
		Key Words: Pump, Pump Type			
		Pump Degradation, M3			
		Mk-B10, Mk-B9, Gad			

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FRAMATOME TECHNOLOGIES

ENGINEERING INFORMATION RECORD

Document Identifier 51 - 5006132-00

Title PSC 1-99 Resolution

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Name D. R. Page	Name G. J. Wissinger
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Technical Managers Statement: Initials [initials]

Reviewer is Independent.

Remarks:

Summary:

A reactor coolant pump (RCP) modeling deficiency discovered during the development of the RELAP5-based EM model for Davis-Besse led to a review of the BAW-10192P-A RCP modeling requirements. That review determined that the LOCA analyses for some of the B&W 177-FA LL plants were not performed in accordance with Section 4.3.4.5 of Volume 1 of BAW-10192P-A. This section states that the plant-specific pump performance tables (namely the pump rated parameters and pump homologous curves) are used as input for the LOCA analyses. FTI had not performed all LBLOCA analyses in accordance with this provision. Corrected RCP studies resulted in unexpected PCT increases and suggested that the two-phase degradation model may not have been bounding.

Further investigation revealed that even higher PCTs could be obtained when the minimum two-phase degradation model is used, despite the fact that maximum degradation had been specified for EM analyses. On January 6, 1999, FTI identified this problem in a preliminary safety concern reported as PSC 1-99.

FTI has identified all of the LBLOCA cases affected by the pump performance and pump degradation issue, and the cases that seriously challenged 10 CFR 50.46 limits have been reanalyzed. The analyzed cases were used to develop PCT deltas (or LHR adjustments) that were applied to the non-limiting core elevations or times in life. This document summarizes the results of RCP pump degradation sensitivity studies, RCP pump reanalyses and associated PCT deltas or LHR adjustments for all affected plants. All PCTs, inclusive of all penalties, were less than 2150 F when corrected and reanalyzed or reevaluated. The limiting two-phase pump degradation for the 177-FA LL and 177-FA RL plants was determined to be the RELAP5 two-phase head difference curves combined with the M3 two-phase void-dependent multiplier. Table 4-1 summarizes the plant-specific reactor coolant pump types and limiting two-phase degradation for all B&W plants. An adequate margin of safety is maintained for the affected LOCA analyses and the resolution of PSC 1-99 is therefore not reportable under 10CFR21.

Record of Revision

Rev. No.	Change Sect/Para	Description/Change Authorization
00		Initial release, December 1999.

Table of Contents

List of Tables

List of References

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1. PSC 1-99 Resolution

A reactor coolant pump (RCP) modeling issue discovered during the development of the RELAP5/MOD2-B&W-based EM input deck for Davis-Besse led to a review of the BAW-10192P-A (Reference 1) RCP modeling requirements. That review determined that the LOCA analyses for some of the B&W 177-FA LL plants may not have been performed in accordance with Section 4.3.4.5 of Volume 1 of BAW-10192P-A. This section states that the plant-specific pump performance tables (namely the pump rated parameters and pump homologous curves) are used as input for the LOCA analyses. FTI had not performed all LBLOCA analyses in accordance with this provision, therefore sensitivity studies were immediately initiated to determine the effect on the LBLOCA results.

The 205-FA Raised-Loop (RL) RCP degradation sensitivity study (Reference 29) and CRAFT2 sensitivity studies (Reference 30) concluded that maximum pump degradation was limiting in terms of predicted PCT for LBLOCA analyses. The LOCA analyses that were performed for the Oconee Units 1, 2 and 3 plants (177-FA LL) used input for the Bingham pumps operating in Oconee Units 2 and 3. Oconee Unit 1 has Westinghouse pumps. The difference in the homologous relationships on the HVN curve (the dominant curve for CLPD breaks) was recognized as similar to a change in pump degradation. That is, the Westinghouse pump provided less resistance (appearing to be less degraded) than the Bingham pump. Since the Bingham pump performance curves have the most negative head ratios on the HVN curve, the Bingham pump was expected to produce the highest PCTs. Confirmatory analyses contradicted this conclusion when the Westinghouse pump with minimum pump degradation produced the limiting PCT. Since FTI was using the maximum RCP two-phase degradation model, it was realized that a higher PCT could be obtained when the minimum degradation model is used. On January 6, 1999, FTI identified this problem in a preliminary safety concern reported as PSC 1-99 (Attachment).

FTI has identified all of the LBLOCA cases affected by the pump type and two-phase degradation issues, and the cases that presented the most serious challenges to the 10 CFR 50.46 limits have been reanalyzed. These cases were used to develop PCT deltas (or LHR adjustments) that were applied to the non-limiting core elevations or times in life. This document summarizes the results of reactor coolant pump degradation sensitivity studies, reactor coolant pump reanalyses and associated PCT deltas or LHR adjustments for all affected plants. Finally, it is concluded that an adequate margin of safety is maintained for the affected units, and therefore PSC 1-99 does not constitute a significant safety hazard and is not reportable under 10CFR21.

2. Pump Degradation Sensitivity Studies

Reactor coolant pump sensitivity studies considered the plant-specific pump rated parameters and pump homologous curves to determine the limiting plant configurations and RCP head difference and two-phase degradation multiplier. Determination of the limiting pump-type is necessary for those generic analyses that consider plants with different RCP types. Table 2-1 summarizes the RCP type and head degradation sensitivity studies performed for different fuel-types for both the 177-FA LL and 177-FA RL plant types. For each study, the PCT difference is reported based on a representative base analysis performed in that study.

Table 2-1: RCP Type and Head Degradation Sensitivity Studies

Plant	RCP Type	RCP Head Difference	RCP Two-Phase Degradation Multiplier	Fuel-Type	Break Size	ΔPCT	Ref
177 FA-LL	Bingham	ANC	M1	B10OL	LB	Z	8
177 FA-LL	Westinghouse	ANC	M1	B10OL	LB	Z+30	8
177 FA-LL	Bingham	R5	M1	B10OL	LB	Z+70	8
177 FA-LL	Bingham	R5	M3-modified	B10OL	LB	Z+100	8
177 FA-LL	Westinghouse	R5	M3-modified	B10OL	LB	**Z+180**	8
177 FA-LL	Westinghouse	R5	M1	B9	LB	Y	5
177 FA-LL	Byron-Jackson	R5	M3-modified	B9	LB	Y-15	5
177 FA-LL	Byron-Jackson	R5	M1	B9	LB	Y-60	5
177 FA-LL	Westinghouse	R5	M3-modified	B9	LB	**Y+42**	5
177 FA-LL	Bingham	ANC	M1	B11	SB	**X**	7
177 FA-LL	Bingham	R5	M3-modified	B11	SB	X-23	7
177 FA-LL	Westinghouse	R5	M3-modified	B11	SB	X-6	7
177 FA-RL	Byron-Jackson	R5	M3-modified	B10K	LB	**W+>67**	4
177-FA RL	Byron-Jackson	R5	M1	B10K	LB	W	4

Based on the results of the sensitivity studies, the plant-specific parameters and fits to the two-phase pump degradation were found to play a vital role in the evolution of the blowdown transient. The basic characteristics of the pump performance (Section 2.1.5.2 of Reference 9) are characterized by a transformation of the four quadrant data (speed and flow versus head or torque) into a single head or torque curve having eight basic octants. The octants are formed from similarity relationships and defined based on the ratios between the rated and predicted speed (ω), head (H), torque (T) and flow (Q). These ratios are expressed in the following form,

$$\alpha = \frac{\omega}{\omega_R}, \qquad h = \frac{H}{H_R}, \qquad \beta = \frac{T}{T_R}, \qquad v = \frac{Q}{Q_R}.$$

RELAP5/MOD2-B&W also allows the option of accounting for two-phase degradation effects on pump performance. A set of homologous, two-phase curves for head and torque degradation are supplied in the form of difference curves. Thus, the fully-degraded two-phase head or torque may be expressed as a function of the standard single phase pump model. A multiplier as a function of void fraction is used to consider the ranges of void fraction to be applied to the head calculation. For two-phase conditions, the pump head and torque are calculated based on the single-phase (plant-specific) homologous data ($H_{1\Phi}$), the two-phase head difference ($H_{1\Phi} - H_{2\Phi}$) and the void dependent two-phase multiplier (M(α)).

$$H = H_{1\Phi} - M(\alpha)(H_{1\Phi} - H_{2\Phi})$$

$$\tau = \tau_{1\Phi} - M(\alpha)(\tau_{1\Phi} - \tau_{2\Phi})$$

A comparison of the single-phase homologous head data in octants 1 and 2 for the Bingham (B) (Reference 8), Westinghouse (W) (Reference 8) and Byron-Jackson (BJ) (Reference 5) pump types is shown in Figure 2-1. For the blowdown transient, the broken loop pump remains mainly in octant two (HVN). The main area of operation is shown in Figure 2-1 as the circled area. In this region, the axes are defined based on the flow ratio, v; therefore differences in the rated pump flow between the pump types will also have an effect on the final predicted pump head. For this region of negative pump head, the pump resistance is increased most significantly (most negative) for the Bingham pump type.

The two-phase degradation is determined by the head difference and the multiplier. Two representative two-phase head difference curves based on the Semiscale pump data are compared in Figure 2-2. The CRAFT2 Aerojet Nuclear Corporation fit (ANC) (Appendix E of Reference 10) data has been used in all the previous 177-FA LL analyses. Another representation of the Semiscale two-phase head degradation is presented in the RELAP5/MOD2-B&W Topical Report (R5) (Table 2.1.5-1 of Reference 9). In octant 2 (HVN), the R5 two-phase difference is less resistive than the ANC representation. A comparison of the multipliers (Reference 11) on the two-phase head

difference curve is shown in Figure 2-3. The M3-modified multiplier effectively decreases the degradation of the pump performance in comparison to the M1 multiplier.

After identifying the PSC, FTI immediately began reanalysis efforts on the BOL Oconee Mark-B10-OL analyses (Reference 8). At first, sensitivity studies were performed to quantify the worst pump two-phase degradation model. The two-phase head difference curves from the CRAFT2 Aerojet Nuclear Corporation fit to the Semiscale pump (ANC) used in all 177-FA LL analyses to date, were replaced with the two-phase difference curves given in the RELAP5/MOD2-B&W Topical Report (Reference 9). This switch produced an approximate PCT increase of 70 F for the core midplane peak. Next, the void-dependent multiplier on the head difference curves was switched from the M1 maximum degradation curve to the M3-modified minimum degradation curve. This degradation change increased the PCT by an additional 30 F. The total increase from the head difference and void multiplier change for the Bingham pump is estimated at 100 F. This increase, when added to the existing Oconee 6-ft PCT of 1978 F, would push the temperature up to 2078 F (possibly higher due to the exponential metal-water increase with temperature). Oconee Units 2 and 3 have Bingham pumps, but Oconee Unit 1 has Westinghouse pumps. The PCT increase for Oconee 1 must consider an additional 80 F due to the pump type. This implied that the Oconee 1 PCT could increase to approximately 2160 F or higher when the metal-water reaction energy addition is considered.

The results of the sensitivity studies (summarized in Table 2-1) for the 177 FA-LL and 177 FA-RL LBLOCA analyses determined that the calculated changes in the PCT are related to the core flow behavior during blowdown as influenced by the resistance of the pumps. Lower pump resistance has both a positive and negative effect on core cooling, depending on the core flow direction. During the initial positive core flow period (until ~10 sec), lower pump resistance allows for higher positive core flows that can remove more energy from the core during this time period. However, the lower pump resistance also allows for a higher pump side break flow that slightly alters the upper plenum liquid distribution. Therefore, lower pump resistance reduces the liquid inventory in the reactor vessel upper plenum region at the time of core flow reversal. With less liquid available to flow through the core, the boiling and flashing is reduced. This liquid deficit decreases the quality in the region of the core that has two-phase conditions, plus it reduces the steam velocities that are critical for core heat transfer in the lower portion of the core. This effect also makes the PCT change elevation-dependent, with the largest effect seen at the 4-ft elevation (References 5 and 8). Therefore, the least resistive pump degradation, modeled by the R5 two-phase head difference and the M3-modified two-phase difference multiplier, will provide limiting results.

The LHR analyses at EOL are limited by the TACO3 pin-pressure limit of 800 psia above system pressure (3000 psia), and provide PCT values that are significantly reduced from those at BOL or MOL. A LHR penalty is therefore unnecessary to account for the flow differences related to the pump type and degradation. The EOL

PCT increase will be significantly smaller than that at BOL or MOL because the PCT range remains below the metal-water reaction threshold of 1800 F. Therefore, the EOL condition is non-limiting in response to the reactor coolant pump type and two-phase degradation issue. For completeness, the BOL PCT increase may be conservatively applied to the previously analyzed EOL PCT to demonstrate that the PCT remains below the metal-water reaction threshold of 1800 F.

For generic LOCA analyses that consider more than one plant type, it is necessary to determine the limiting pump-type. The sensitivity studies performed in References 5 and 8 confirmed that the Westinghouse pump-type provides the most limiting blowdown results as compared to both the Bingham and Byron-Jackson pump-types. Figure 2-1 shows that the Byron-Jackson pump-type provides the least resistance in octant 2 (HVN, circled region), and therefore one would expect that the Byron-Jackson pump would provide limiting results. However, the pump is operating in octant 1 (HAN) at the initiation of the transient, where the Westinghouse pump-type exhibits a more degraded positive flow performance. Additionally, the rated flow for the Westinghouse pump-type is about 4 percent lower than the Byron-Jackson pump-type (88500 gpm versus 92400 gpm for BJ), which results in a lower predicted pump flow (Q) for the same value of ν ($=Q/Q_R$). Therefore, the Westinghouse pump-type exhibits significantly less cooling during the positive core flow period such that the cladding temperatures remain above that of the Byron-Jackson pump-type for the entire blowdown transient.

The effect of the pump-type for the SBLOCA transient was investigated in Reference 7. Comparisons of the most resistive to least resistive two-phase pump degradation (ANC/M1 versus RELAP5/MOD2/M3) and Bingham versus Westinghouse pump-type were performed. The comparisons showed that the liquid inventories and system depressurization during the SBLOCA transients were nearly identical for all cases. Differences in the predicted PCTs were related to the magnitude of a predicted flow oscillation occurring well after the time that the pump flow reaches zero. Therefore, it was concluded that the selection of the two-phase degradation and pump-type does not influence the progression of the SBLOCA transient. Nonetheless, for new analyses, it is recommended that the SBLOCA pump-type and two-phase degradation model be kept consistent with that used in the LBLOCA analyses, but this is not a requirement for the correct prediction of the SBLOCA transient. In addition to the choice of the pump-type rated conditions and two-phase degradation, a generic analysis should conservatively model the highest pump spill-over elevation, even if it is not consistent with the pump-type modeled.

Figure 2-1: Comparison of Single-Phase Homologous Head Curves, Octants 1 (HAN), 2 (HVN) (B, W, BJ)

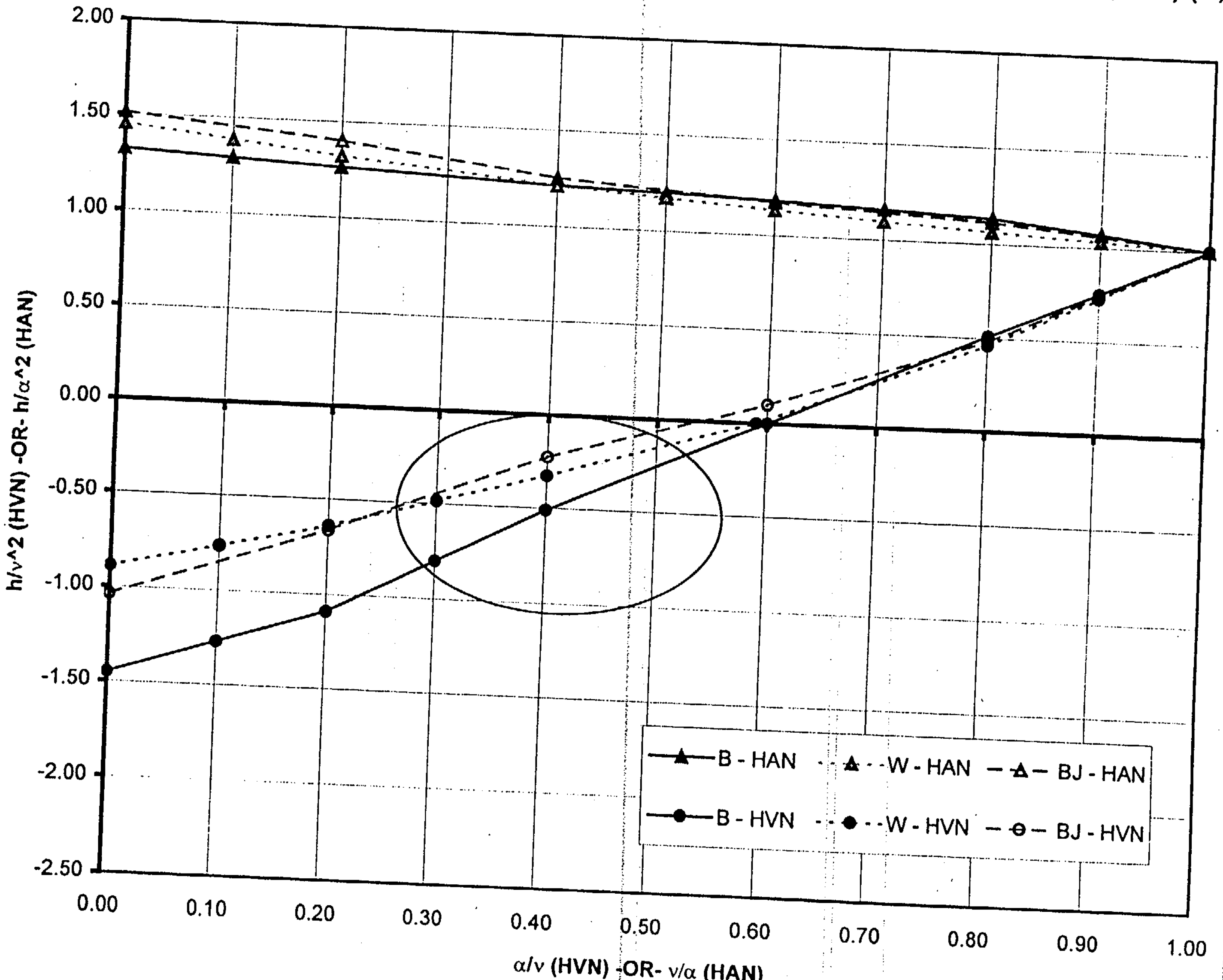


Figure 2-2: ANC and R5 Default Two-Phase Head Difference Curves, Octants 1 and 2

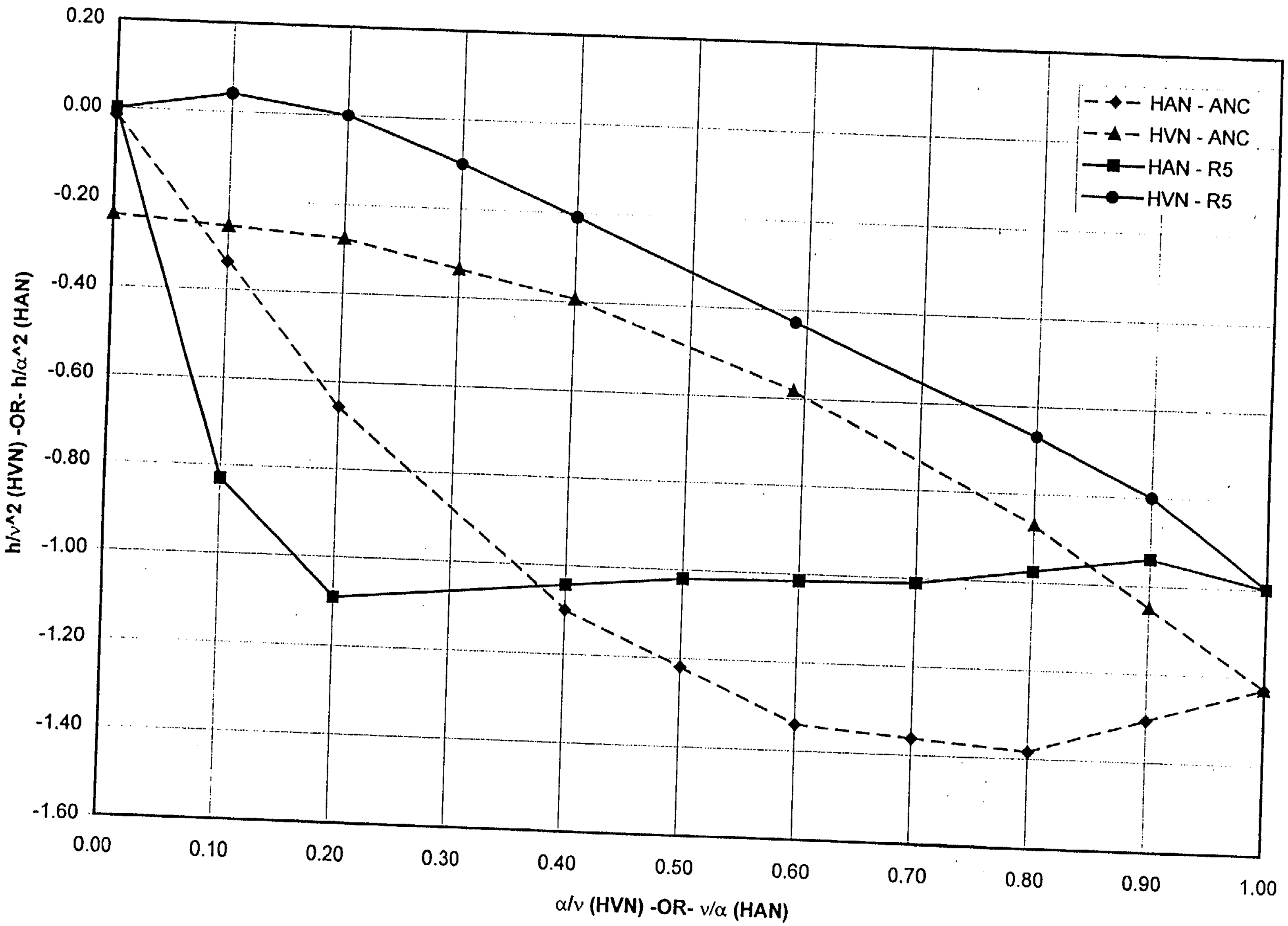
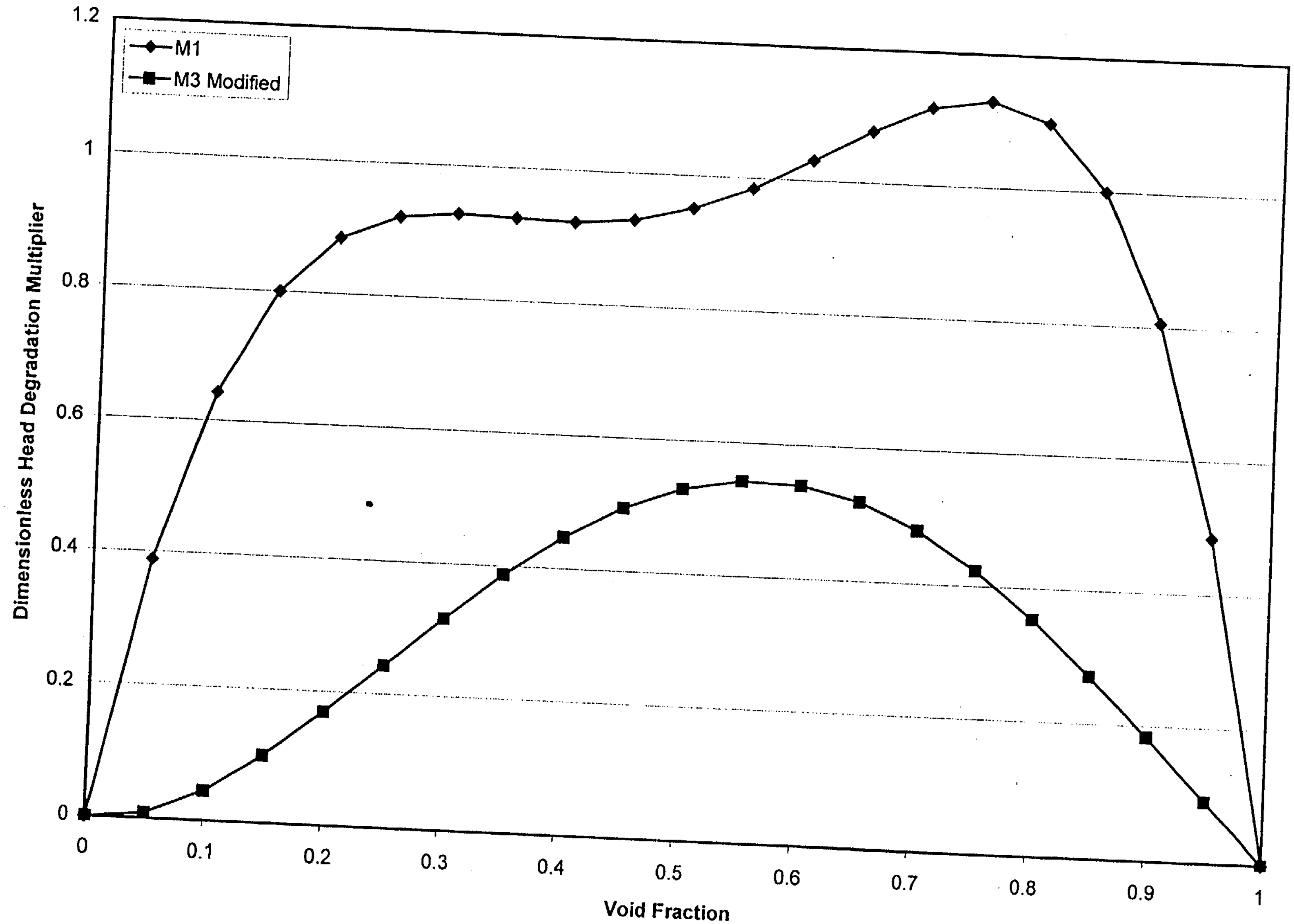


Figure 2-3: Pump Head Degradation Multipliers



3. Plant-Specific PCT Changes

There are three sets of BWNT Evaluation Model (Reference 1) LOCA linear heat rate (LHR) limits supporting current plant operation. Oconee units 1, 2, & 3 have Mark-B10-OL (also referred to as Mark-B10F) and Mark-B9 fuel LHR limits, and TMI-1 has Mark-B9 fuel LHR limits. The TMI Mark-B9 LHR limits have two significant PCT conservatisms included in the LOCA application analyses, and that is a low initial pressurizer liquid inventory and a conservative baffle/bypass model. As a result, the TMI reported PCTs for 15 percent steam generator tube plugging are approximately 100 F higher than would be produced with a nominal pressurizer inventory and more realistic baffle/bypass flow resistances. The Oconee Mark-B10-OL analyses do not have this conservatism, therefore, they will be most limiting in terms of PCT increase related to the RCP changes. FTI has also completed BWOG 20 percent tube plugging analyses (performed for TMI-1 and ANO-1) for future reference in core reload or FSAR applications that have non-conservative PCTs because of the RCP modeling. In addition to the resolution of PSC 1-99 on the pump-type and two-phase degradation, the BWOG 20 percent tube plugging analyses were subsequently reanalyzed because of incorrect modeling of the grid type for the Mark-B9 fuel assemblies. Table 3-1 summarizes the reanalyzed and/or adjusted B&W LOCA analyses by plant and fuel-type. Analyses have recently been completed for CR-3 Mark-B9, DB-1 Mark-B10K and DB-1 Mark-B9A fuel types with the correct RCP type and degradation. Reanalysis for Oconee 1, 2 and 3, TMI-1 and ANO-1 in response to PSC 1-99 are discussed in the following sections.

Table 3-1: Summary of Fuel-Type & Plant-Specific B&W LOCA Reanalyses

Plant	Fuel Type Mark-	PSC 1-99	Grid Type	Resolution
Oconee 1, 2, 3	B10-OL	X		Reanalysis & ΔPCT
	B9	X		Reanalysis & ΔPCT
	B11 LTA	X		Bounded
	B11 (M5)			Correct
TMI 1	B9	X	X	Reanalysis & ΔPCT, ΔLHR
	Mod B9 & AX		X	Bounded
	Gad B9		X	Reanalysis & ΔPCT
	B8 & B8V			Reevaluated & ΔLHR
ANO 1	B9	X	X	Reanalysis & ΔPCT
CR 3	B9			Correct
	Gad B9			Correct
DB 1	Mark-B10K (M5)			Correct
	B9A			Correct
	B8A			CRAFT2 Limits

3.1 Duke Power Company (Oconee-1, 2 and 3)

Framatome Technologies, Incorporated (FTI) has determined that the Oconee large break loss-of-coolant accident (LBLOCA) analyses have nonconservative peak cladding temperature (PCT) predictions due to nonconservative RCP degradation modeling. The emergency core cooling system (ECCS) analyses were performed with the BWNT LOCA Evaluation Model (Reference 1). The revised analyses resulted in significant PCT increases (>50F), that were reported within 30 days of discovery to the NRC and Duke Power Company in compliance with 10 CFR 50.46 Section (a)(3) (Reference 2).

All PCTs, inclusive of all penalties, were less than or equal to 2150 F when corrected and reanalyzed or reevaluated. An adequate margin of safety is maintained for the Oconee Units and the resolution of PSC 1-99 is therefore not reportable under 10CFR21. The change in results for each of the fuel types utilized for Oconee are summarized below.

3.1.1 Mark-B10-OL

The BOL Mark-B10-OL fuel was reanalyzed (Reference 8) with the limiting reactor coolant pump-type and limiting two-phase degradation model as discussed in the sensitivity studies in Section 1. A slight conservatism was found from the rounding-up of the TACO3 best-estimate fuel temperature uncertainty. The fuel temperature was increased by 12.0 percent, which is higher than 11.51 percent required. When this conservatism removal was included in the reanalysis of Oconee 1 with the worst pump type (Westinghouse) and pump degradation (RELAP5/MOD2-B&W semiscale head difference with the M3-modified multiplier), the maximum PCT was calculated to be 2150 F. This overall temperature increase of 186 F was calculated for the BOL 4.264-ft axial peak for the Mark-B10-OL fuel. The 2.506-ft PCT was 2135 F (up by 135 F), and the 6.021-ft PCT was 2104 F (up by 126 F). The 9.536-ft PCT increased by 55 F to 2079 F. The 7.779-ft BOL case was not reanalyzed because the PCT increase was extrapolated from the 6.021- and 9.536-ft cases. A PCT increase of 91 F was determined by linear interpolation between these two cases. The PCTs for the MOL and EOL LBLOCA analyses were conservatively increased by the amount determined for the BOL analyses, since the lower PCTs at MOL and EOL would generate lower PCT increases in response to the pump type and degradation model corrections. The maximum hydrogen generation remained below 0.30 percent and the maximum local oxidation was 3.64 percent. Table 3-2 summarizes the LHR limits and PCTs that are applicable for the Oconee 1 Mark-B10-OL LBLOCA analyses. The PCTs for Oconee units 2 & 3 are less than Oconee unit 1 by roughly 80 F because those two units have Bingham pumps, although these PCT reduction have not been applied to the PCT of record for these two units.

3.1.2 Mark-B9

Because the maximum PCT increase was calculated at the 4.264-ft elevation for the Mark-B10-OL LBLOCA analysis, the 4.264-ft Mark-B9 analysis from Reference 23 was reevaluated (Reference 24) with the limiting pump-type and two-phase degradation for the Oconee plants. This PCT increase was determined to be 70 F in the ruptured node and 82 F in the unruptured node, which was also conservatively applied to the remainder of the elevations and at EOL. The maximum PCT for all cases was 2062 F at the 2.506-ft elevation. The maximum hydrogen generation remained below 0.20 percent and the maximum local oxidation was 3.02 percent. Table 3-3 summarizes the LHR limits and PCTs that are applicable for the Oconee 1 Mark-B9 LBLOCA analyses. The PCTs for Oconee units 2 and 3 are less than Oconee unit 1 by up to 80 F because those two units have Bingham pumps, although these PCT reduction have not been applied to the PCT of record for these two units.

3.1.3 Mark-B11 LTA

The BOL and MOL LHRs calculated for the Mark-B11 (Zr-4) lead test assembly (LTA) had originally been calculated based on the flap flow diverter grid design, whereas the LTA design was subsequently modified to a standard mixing vane design with a significantly lower form loss coefficient. It was determined in Reference 25 that the original calculations remained conservative for application to the final mixing vane type. In addition to the grid form-loss conservatism, the LHRs were futher reduced by 5 percent to ensure that the LTA was not placed in a limiting position in the core. The EOL calculated LHR of 11.0 kW/ft was also conservatively reduced to 9.2 kW/ft (Reference 32) to account for the effects of decreased thermal conductivity after 40 GWd/mtU and for higher EOL energy deposition factors.

As summarized in the previous sections, PCT penalties were adequate to consider the effect of the RCP type and degradation. The conservatisms described above for the Mark-B11 LTA are adequate to absorb the effects of a PCT increase based on the reactor coolant pump-type and two-phase degradation. Therefore, the Mark-B11 LTA LHRs reported in Reference 25 still maintain conservative LHRs and assure that the assemblies are not placed in a limiting position in the core.

3.1.4 Mark-B11(M5)

New analyses have recently been completed for the Mark-B11 fuel-type with M5 cladding (Reference 26). These new analyses have modeled the limiting reactor coolant pump-type (Westinghouse) and two-phase degradation (R5 difference curve and M3-modified multiplier) for the combined Oconee 1, 2 and 3 analyses.

3.2 General Public Utilities Nuclear (TMI-1)

Framatome Technologies, Incorporated (FTI) determined that the TMI-1 15 percent steam generator tube plugging (SGTP) large break loss-of-coolant accident (LBLOCA) analyses had nonconservative peak cladding temperature (PCT) predictions due to the pump type and two-phase degradation input models used. The B&W Owners Group 20 percent SGTP analyses, which was under review by the NRC for TMI-1 via submittal Technical Specification Change Request (TSCR)-279 from GPUN, also contained the same deficiencies. Both of these emergency core cooling system (ECCS) analyses were performed with the BWNT LOCA Evaluation Model (Reference 1). The PCTs were underpredicted in both analyses because of nonconservative RCP type and degradation. These analyses were also found to have incorrect grid type modeling for the Mark-B9 fuel assembly. The cumulative effect on the PCT resulted in a significant PCT increase (>50F), which was reported within 30 days of discovery to the NRC and GPUN in compliance with 10 CFR 50.46 Section (a)(3) (References 2 and 3).

Since both analyses support TMI-1 and the 20 percent SGTP analysis had additional tube plugging conservatism, the 20 percent SGTP analyses were selected as the appropriate set of linear heat rate (LHR) limits to be reanalyzed. Additionally, the 15 percent SGTP TMI-1 analyses had two significant model conservatisms that could be used to offset the PCT increase. The core bypass/baffle model improvements and adjustment of the pressurizer level from minimum to nominal should reduce the PCT by approximately 100 F, as determined by sensitivity studies presented in Reference 13. Therefore, the PCTs from the 20 percent tube plugging analyses (Reference 12) that include the corrected RCP modeling, RCP degradation modeling, and grid type modeling were conservative estimates of the PCT because of the increased tube plugging. A tube plugging study performed in Reference 13 determined that higher tube plugging increased the 2.506-ft PCT approximately 0.4 F per percent TP in the intact loop and 2.0 F per percent SGTP in the broken loop. A reduction of 5 percent tube plugging in each loop would result in a PCT decrease of ~12 F at the 2.506-ft elevation. Therefore, consideration of the pressurizer level conservatism and the lower steam generator tube plugging amounts, the PCTs reported for the BWOG 20 percent steam generator tube plugging bound the 15 percent tube plugging analyses (Reference 14).

All PCTs, inclusive of all penalties and credits, were less than or equal to 2104 F when corrected and reanalyzed. The BWOG 20 percent SGTP LHR limits and PCT reported are bounding for the 15 percent SGTP limits used to currently license TMI-1 plant operation. An adequate margin of safety is maintained for TMI-1 and the resolution of PSC 1-99 is therefore not reportable under 10CFR21.

Please note that the grid input error had no effect on any small break LOCA analyses or any CRAFT2-based EM (Reference 10) LBLOCA cases, because these analyses do

not use the grid droplet breakup models. The change in results for each of the fuel types utilized at TMI-1 are summarized below.

3.2.1 Mark-B9

FTI reanalyzed all 20% SGTP LBLOCA analyses (Reference 5) to correct the reactor coolant pump type and two-phase degradation model inputs described in FTI preliminary safety concern (PSC) 1-99 (see Section 1). A sensitivity study was performed (Reference 5) that determined that the most limiting pump degradation for the TMI-1 Westinghouse pump-type was the RELAP5/MOD2-B&W two-phase difference curves with the M3-modified two-phase degradation multipliers. The effect on the analyses is most significant at the 4.264- and 6.021-ft elevations, where LHR reductions of 0.3 and 0.5 kW/ft were imposed on the base 20 percent SGTP analyses to maintain the PCT within the desired 1950 F to 2050 F range. The maximum PCT for the analyses revised for PSC 1-99 was 2046 F at the 2.506-ft elevation.

All BOL cases for the 20 percent SGTP were reanalyzed further to examine the effect of incorrect grid blockage factors (i.e. a mixing-vane grid input was used instead of the non-mixing vane grid fuel assembly input) (Reference 6). This modeling error affects the hot pin heat removal during the reflood phase, which is calculated by the BEACH code (Reference 31). When corrected, the grid blockage is reduced, which affects the grid droplet break up and the resultant LBLOCA PCT. The effect on the analyses is most significant in the upper half of the core and diminishes in consequence in the lower core regions. The maximum PCT increase due to the grid error was +165 F for the 9.536-ft BOL analysis at 16.8 kW/ft. The BOL PCT increases decrease with core elevation to + 149, +76, +24, and +13 F for the 7.779-, 6.021-, 4.264-, and 2.506-ft elevations, respectively. The 20 percent SGTP middle-of-life (MOL) or end-of-life (EOL) cases were not recalculated, because significant PCT margin was available in those analyses. The PCTs for the MOL and EOL LBLOCA analyses were conservatively increased by the amount determined for the BOL analyses, since the lower PCTs at MOL and EOL would generate lower PCT increases in response to the corrected grid.

Another EOL analysis was performed in Reference 16 to provide limits for operation at 2568 MWt, instead of the uprated power level of 2772 MWt. The lower power history was considered, because TMI-1 has not yet uprated the licensed power level and a higher EOL LHR at increased burnup may be obtained by using a lower power history. This base analysis considered the corrected reactor coolant pump and two-phase degradation, however it was subsequently reconsidered in Reference 17 for the corrected grid modeling. The EOL LHR for 2568 MWt and 62,000 MWd/mtU was determined to be 12.8 kW/ft with a PCT of 1658 F at the 2.506-ft elevation and less than 1800F for all other elevations.

All revised analyses remained well within the 10 CFR 50.46 criteria of 2200 F with the highest overall PCT calculated to be 2104 F for the 17.3 kW/ft 7.779-ft BOL analysis. The 7.779-ft elevation was reanalyzed at 16.8 kW/ft for BOL (equal to LHR for TMI-1 15 percent SGTP analyses at that elevation) and predicted a PCT of 1964 F. Based on the reanalysis for PSC 1-99 and the grid modeling correction, the whole-core hydrogen generation remained below 0.4 percent, and the maximum local oxidation remained below 5.5 percent. The reported EOL LHRs were revised in Reference 12 to clarify the treatment of the EDF during comparison of the LOCA limits to the core maneuvering analyses. Table 3-4 summarizes the LHR limits and PCTs that are applicable for the BWOG 20 percent SGTP analyses and are conservative for the TMI-1 15 percent SGTP analyses.

3.2.2 Modified Mark-B9

Similarly to the Mark-B9 analyses described above, the Modified Mark-B9, TMI-1 20 percent SGTP analyses were chosen for reanalysis to bound the effects of PSC 1-99 and the corrected grid modeling on the corresponding 15 percent SGTP analyses presented in Reference 15. The original Modified Mark-B9 analyses for 20 percent SGTP considered the corrected reactor coolant pump-type and two-phase degradation (Reference 16). Analyses at the 2.506-ft elevation for BOL and MOL at 2772 MWt and EOL at 2568 MWt were performed. The corrected grid modeling was subsequently addressed in Reference 17. The effect from the corrected grid modeling was determined to be consistent for all fuel-types, therefore the change in PCT between the Mark-B9 and Modified Mark-B9 was maintained. For BOL, the consequences for the Modified Mark-B9 analyses are bounded by the Mark-B9 results, while for MOL, a PCT penalty of 5 F is applied over the corrected Mark-B9 results reported in Reference 12. The BOL and MOL Modified Mark-B9 results also include the 0.5 kW/ft reduction in the 7.779-ft elevation LHR that was applied to the Mark-B9 results in response to the corrected grid model. At EOL, a lower power history (2568 MWt) was considered and a LHR of 12.8 kW/ft at 62,000 MWd/mtU resulted in a 3F penalty over Mark-B9 at the 2.506-ft elevation. Maintaining the PCT at 1800 F for other elevations at EOL remains appropriate because of the small difference between Modified Mark-B9 and Mark-B9. The 15 percent SGTP analyses from Reference 15 evaluated the EOL LHRs at the uprated power level of 2772 MWt and 60,000 MWd/mtU, therefore these results are no longer applicable without further consideration of PSC 1-99. Table 3-4 summarizes the LHR limits and PCTs that are applicable for the Modified Mark-B9 BWOG 20 percent SGTP analyses and are conservative for the Modified Mark-B9 TMI-1 15 percent SGTP analyses.

3.2.3 Mark-B9-Gad

Similar to the Mark-B9 analyses described above, the Mark-B9-Gad, TMI-1 20 percent SGTP analyses were chosen for reanalysis to bound the effects of PSC 1-99 and the corrected grid modeling on the corresponding 15 percent SGTP analyses presented in Reference 19. The original Mark-B9-Gad analyses for 20 percent SGTP considered the corrected reactor coolant pump-type and two-phase degradation (Reference 16). Analyses at the 2.506-ft elevation for BOL and MOL at 2772 MWt and EOL at 2568 MWt were performed. The corrected grid modeling was subsequently addressed in Reference 17. The effect from the corrected grid modeling was determined to be consistent for all fuel-types, therefore the PCT increase of 13 F determined for the Mark-B9 fuel rod in response to the corrected grid was maintained and the Mark-B9-Gad PCTs remain bounded by the Mark-B9 PCTs.

Reference 18 identified that in addition to considering the Gad/UO_2 power ratio of 0.95, a corrected transient energy deposition factor (EDF) for BOL and MOL must be considered for the Gad LHRs. The corrected EDF is applied because gadolinia pins may be surrounded by fuel pins with significantly higher powers such that the gamma energy entering the pin can be larger than the energy produced by the pin. Using the equation presented in Reference 20, the transient EDF for Gad pins should be 1.013, which is slightly higher than the transient EDF of 1.0 used for analysis of UO_2 pins. The BOL and MOL LHRs were reduced to account for the increased transient EDF for the Gad pins. Therefore, the BOL and MOL Gad-to-$U0_2$ power ratio was decreased to 0.937. The EDF applied to the Gad pins at EOL was determined to be appropriate as compared to the UO_2 pin, and an adjustment to the 0.95 Gad-to-$U0_2$ power ratio was not necessary.

Table 3-5 summarizes the LHR limits that are applicable for the Mark-B9-Gad BWOG 20 percent SGTP analyses and are conservative for the Mark-B9-Gad TMI-1 15 percent SGTP analyses. For a 2.0 weight percent concentration of gadolinia (Gad), PCTs corresponding to the above LHRs are bounded by corresponding PCTs for the Mark-B9 LHRs summarized in Table 3-4.

3.2.4 Mark-B8/B8V

The Mark-B8 and Mark-B8V LHRs were reevaluated in Reference 21 for consideration of more conservative EDFs than those specified in the current RELAP5/MOD2-B&W based EM (Reference 1) or CRAFT2 based EM (Reference 10), on which the LHRs for the Mark-B8/B8V were originally calculated. The analyses were based on a power level of 2772 MWt, and up to 10 percent SGTP has been considered.

The original CRAFT2 analyses used an EDF of 0.973 for the steady-state initialization and blowdown with an EDF of 0.96 during the reflood portion of the transient. New methods and predictions for the EDFs appropriate for use in LOCA analyses at various times in life have recently been evaluated by FCF (Reference 20). These calculations do not totally support the 0.973 value for high burnup, low power fuel or fuel that may be surrounded by higher power fuel. As a result, the LOCA evaluations may use different EDFs, depending on the time in life and fuel pin type. For the LOCA transient, an EDF of between 0.98 and 0.988 is more appropriate, therefore LHR and PCT adjustments were imposed to bound the consideration of the higher EDFs. An adjustment of –0.4 kW/ft was determined for the 2.506-ft elevation, -0.5 kW/ft for the 4.264-, 6.021- and 7.779-ft elevations and a combined –0.2 kW/ft and +20 F on the PCT was determined at the 9.536-ft elevation. Considering the combination with other LHR penalties and credits previously applied, the final adjustments from the CRAFT2 analyses was +30 F at the 2-ft elevation, –0.4 kW/ft applied at the 4-ft elevation, -0.8 kW/ft at the 8-ft elevation (-0.6 kW/ft imposed only to maintain symmetric limits with the 4-ft elevation), and +20 F with –0.5 kW/ft at the 10-ft elevation.

In consideration of the reactor coolant pump type and two-phase degradation, the LHR penalties applied to account for the differences in the CRAFT2 to RELAP5/MOD2-B&W methodology were reviewed to determine whether the pump issue was adequately covered. The CRAFT2 methodology (Reference 10) models a generic pump type for all plant types, therefore the PSC 1-99 issue does not apply to the CRAFT2 limits. Section 8 of Reference 27 compares the TMI-1 Mark-B9 LHRs for 15 percent SGTP analyses calculated based on the RELAP5/MOD2-B&W EM (Reference 1) to the TMI-1 Mark-B9 LHRs calculated based on the CRAFT2-based EM. The original CRAFT2 LHR limits were found to be more limiting at all but the 10-ft elevation, where a LHR limit penalty is required in comparison to the RELAP5/MOD2-B&W results (a LHR penalty was subsequently applied to the 8-ft case to maintain symmetric LHR values at the 2-ft and 8-ft elevations). Because the LHR limits for the TMI-1 15 percent SGTP analyses have remained appropriate for TMI-1 in response to PSC 1-99, the comparison between the CRAFT2 and RELAP5/MOD2-B&W results remains the same as determined in Reference 27.

Therefore, a LHR adjustment is not necessary to account for consideration of PSC 1-99 for the Mark-B8 or Mark-B8V fuel-types.

Please note that the grid input error has no effect on these CRAFT2-based LHRs because these CRAFT2 methodology (Reference 10) does not use the grid droplet breakup models.

3.3 Entergy (ANO-1)

Framatome Technologies, Incorporated (FTI) determined that the B&W Owners Group 20 percent SGTP LBLOCA analyses had nonconservative peak cladding temperature (PCT) predictions due to the pump-type and two-phase degradation input models used. This emergency core cooling system (ECCS) analysis was performed with the BWNT LOCA Evaluation Model (Reference 1). The PCTs were underpredicted because of nonconservative RCP type and degradation, and these analyses were subsequently found to have incorrect grid type modeling for the Mark-B9 fuel assembly. The cumulative effect on the PCT resulted in a significant increase (>50F), which was reported within 30 days of discovery to the NRC and Entergy in compliance with 10 CFR 50.46 Section (a)(3).

All PCTs, inclusive of all penalties and credits, were less than or equal to 2104 F when corrected and reanalyzed. An adequate margin of safety is maintained for ANO-1 and the resolution of PSC 1-99 is therefore not reportable under 10CFR21.

Please note that the grid input error had no effect on any small break LOCA analyses or any CRAFT2-based EM (Reference 10) LBLOCA cases because these analyses do not use the grid droplet breakup models. The change in results for the Mark-B9 fuel type utilized at ANO-1 is summarized below.

FTI reanalyzed all 20 percent SGTP LBLOCA analyses (Reference 5) to correct the reactor coolant pump type and two-phase degradation model inputs described in FTI preliminary safety concern (PSC) 1-99 (see Section 1). A sensitivity study was performed that determined that the most limiting pump degradation for the combined ANO-1 and TMI-1 analyses was the Westinghouse pump-type and the RELAP5/MOD2-B&W two-phase difference curves with the M3-modified two-phase degradation multipliers. The effect on the analyses is most significant at the 4.264- and 6.021-ft elevations, where LHR reductions of 0.3 and 0.5 kW/ft were imposed on the base 20 percent SGTP analyses to maintain the PCT within the desired 1950 F to 2050 F range. The maximum PCT for the analyses revised for PSC 1-99 was 2046.1 F at the 2.506-ft elevation.

All BOL cases for the 20 percent SGTP were reanalyzed further to examine the effect of incorrect grid blockage factors (i.e. a mixing vane grid input was used instead of the non-mixing vane grid fuel assembly input) (Reference 6). This modeling error affects the hot pin heat removal during the reflood phase, which is calculated by the BEACH code (Reference 31). When corrected, the grid blockage is reduced, which affects the grid droplet break up and the resultant LBLOCA PCT. The effect on the analyses is most significant in the upper half of the core and diminishes in consequence in the lower core regions. The maximum PCT increase due to the grid error was +165 F for the 9.536-ft BOL analysis at 16.8 kW/ft. The BOL PCT increases decrease with core

elevation to + 149, +76, +24, and +13 F for the 7.779-, 6.021-, 4.264-, and 2.506-ft elevations, respectively. The 20 percent SGTP middle-of-life (MOL) or end-of-life (EOL) cases were not recalculated because significant PCT margin was available in those analyses. The PCTs for the MOL and EOL LBLOCA analyses were conservatively increased by the amount determined for the BOL analyses, since the lower PCTs at MOL and EOL would generate lower PCT increases in response to the corrected grid.

All revised analyses remained well within the 10 CFR 50.46 criteria of 2200 F with the highest overall PCT calculated to be 2104 F for the 17.3 kW/ft 7.779-ft BOL analysis. The 7.779-ft elevation was reanalyzed at 16.8 kW/ft and predicted a PCT of 1964 F. Based on the reanalysis for PSC 1-99 and the grid modeling correction, the whole-core hydrogen generation remained below 0.4 percent, and the maximum local oxidation remained below 5.5 percent. The reported EOL LHRs were revised in Reference 12 to clarify the treatment of the EDF during comparison of the LOCA limits to the core maneuvering analyses. Table 3-6 summarizes the LHR limits and PCTs that are applicable for the BWOG 20 percent SGTP analyses (specifically the Mark-B9 limits for the ANO-1 unit).

Table 3-2: Summary of Mark-B10-OL LHR Limits for Oconee 20% SGTP

Elevation (ft)	LOCA LHR Limit, kW/ft (PCT, F) BOL, 2568 MWt	LOCA LHR Limit, kW/ft (PCT, F) MOL, 2568 MWt (30,000 MWd/mtU)	LOCA LHR Limit, kW/ft (PCT, F) EOL, 2568 MWt (62,000 MWd/mtU)
0.000	16.2 (<2135)	16.2 (<2017)	11.6 (<1700)
2.506	17.0 (2135)	17.0 (<2017)[7]	11.6 (<1700)[7]
4.264	17.3 (2150)	17.3 (<2075)[7]	11.6 (<1700)
6.021	17.3 (2104)	17.3 (<1884)[7]	11.6 (<1700)
7.779	17.3 (2082)[6]	17.3 (<1927)[7]	11.6 (<1700)
9.536	17.0 (2079)	17.0 (<1929)[7]	11.6 (<1700)
12.000	16.2 (<2079)	16.2 (<1929)	11.6 (<1700)

Notes:

1.) The LHR limits presented above represent the power generated by the pin (i.e. all sources of usable energy caused by the fission process).

2.) Analyses at BOL and MOL used a steady-state energy deposition factor (EDF) of 0.973 for initial core energy deposition and a transient EDF of 1.0. Analyses at EOL used a steady-state EDF of 1.0 and a transient EDF of 1.1.

3.) Linear interpolation for LHR limits is allowed between 30000 MWd/mtU and 62000 MWd/mtU.

4.) The LHR limits below 2.506 feet are reduced linearly to $0.95*LHR_{2.506}$ at 0.0 feet. The LHR limits above 9.536 feet are reduced linearly to $0.95*LHR_{9.536}$ at 12.0 feet while on the PCT-limited portion of the LHR versus MWd curve. The EOL LHRs are maintained constant at 11.6 kW/ft for all elevations, because these points are not limited based on the calculated PCT.

5.) LHRs are valid for fuel enrichments between 3.0 and 5.0 weight percent (wt%) and pin prepressure of 245 psia. Time-in-life LHRs are also valid for a pin prepressure of 370 psia with a fuel enrichment of 4.0 wt%.

6.) This PCT was not explicitly calculated. It was estimated by adding the average of the BOL 6- and 10-ft PSC 1-99 PCT increases to the PCT (Reference 8).

7.) The MOL and EOL PCTs were not explicitly calculated. The PCTs from Reference 22 were conservatively increased by the calculated BOL PCT penalty for the corrected reactor coolant pump type and two-phase degradation as described in Reference 8.

Table 3-3: Summary of Mark-B9 LHR Limits for Oconee 20% SGTP

Elevation (ft)	LOCA LHR Limit, kW/ft (PCT, F) MOL, 2568 MWt (28,000 MWd/mtU)	LOCA LHR Limit, kW/ft (PCT, F) MOL, 2568 MWt (45,000 MWd/mtU)	LOCA LHR Limit, kW/ft (PCT, F) EOL, 2568 MWt (62,000 MWd/mtU)
0.000	15.8 (<2062)	15.8 (<2062)	13.0 (<1750)
2.506	16.6 (<2062)[6]	16.6 (2062)[6]	13.0 (1750)[6]
4.264	17.0 (<2059)[6]	17.0 (2059)	13.0 (<1800)
6.021	17.0 (<1974)[6]	17.0 (1974)[6]	13.0 (<1800)
7.779	17.0 (<2014)[6]	17.0 (2014)[6]	13.0 (<1800)
9.536	16.6 (<1994)[6]	16.6 (1994)[6]	13.0 (<1800)
12.000	15.8 (<1994)	15.8 (<1994)	13.0 (<1800)

Notes:

1.) The LHR limits presented above represent the power generated by the pin (i.e. all sources of usable energy caused by the fission process).

2.) Analyses at MOL used a steady-state energy deposition factor (EDF) of 0.973 for initial core energy deposition and a transient EDF of 1.0. Analyses at EOL used a steady-state EDF of 1.0 and a transient EDF of 1.1.

3.) Linear interpolation for LHR limits is allowed between 45000 MWd/mtU and 62000 MWd/mtU.

4.) The LHR limits below 2.506 feet are reduced linearly to $0.95*LHR_{2.506}$ at 0.0 feet. The LHR limits above 9.536 feet are reduced linearly to $0.95*LHR_{9.536}$ at 12.0 feet while on the PCT-limited portion of the LHR versus MWd curve. The EOL LHRs are maintained constant at 13.0 kW/ft for all elevations, because these points are not limited based on the calculated PCT.

5.) LHRs are valid for fuel enrichments up to 4.0 weight percent (wt%) and pin prepressure of 355 psia.

6.) These PCTs were not explicitly calculated. It was estimated (Reference 24) by adding the bounding 4-ft PSC 1-99 PCT increases to the PCTs for all other elevations calculated in Reference 23.

Table 3-4: Summary of Mark-B9 and Modified Mark-B9 LHR Limits for BWOG (TMI-1) 20% SGTP

Elevation (ft)	LOCA LHR Limit, kW/ft (PCT, F) BOL, 2772 MWt	LOCA LHR Limit, kW/ft (PCT, F) MOL, 2772 MWt (40,000 MWd/mtU)		LOCA LHR Limit, kW/ft (PCT, F) EOL, 2772 MWt (60,000 MWd/mtU)	LOCA LHR Limit, kW/ft (PCT, F) EOL, 2568 MWt (62,000 MWd/mtU)	
	Mark-B9 & Mod-Mark- B9	Mark-B9	Mod-Mark-B9	Mark-B9 ONLY	Mark-B9	Mod-Mark- B9
0.000	15.9 (<2059)	15.9 (<1855)	15.9 (<1860)[7]	11.6 (<1535)	12.8 (<1800)	12.8 (<1800)[7]
2.506	16.8 (2059)	16.8 (1855)[6]	16.8 (1860)[7]	11.6 (1535)[6]	12.8 (1658)[6]	12.8 (1661)[7]
4.264	16.8 (2030)	16.8 (1883)[6]	16.8 (1888)[7]	11.6 (<1700)	12.8 (<1800)	12.8 (<1800)[7]
6.021	17.0 (2036)	17.0 (1864)[6]	17.0 (1869)[7]	11.6 (<1700)	12.8 (<1800)	12.8 (<1800)[7]
7.779	16.8 (1964)	16.8 (1864)[6]	16.8 (1869)[7]	11.6 (<1700)	12.8 (<1800)	12.8 (<1800)[7]
9.536	16.8 (2083)	16.8 (1935)[6]	16.8 (1940)[7]	11.6 (<1700)	12.8 (<1800)	12.8 (<1800)[7]
12.000	15.9 (<2083)	15.9 (<1935)	15.9 (<1940)[7]	11.6 (<1700)	12.8 (<1800)	12.8 (<1800)[7]

Notes:

1.) The LHR limits presented above represent the power generated by the pin (i.e. all sources of usable energy caused by the fission process).

2.) Analyses at BOL and MOL used a steady-state energy deposition factor (EDF) of 0.973 for initial core energy deposition and a transient EDF of 1.0. Analyses at EOL used a steady-state EDF of 1.0 and a transient EDF of 1.1.

3.) Linear interpolation for LHR limits is allowed between 40000 MWd/mtU and 60000 or 62000 MWd/mtU.

4.) The LHR limits below 2.506 feet are reduced linearly to $0.95*LHR_{2.506}$ at 0.0 feet. The LHR limits above 9.536 feet are reduced linearly to $0.95*LHR_{9.536}$ at 12.0 feet while on the PCT-limited portion of the LHR versus MWd curve. The EOL LHRs are maintained constant at 11.6 kW/ft (at 2772 MWt) or 12.8 kW/ft (at 2568 MWt) for all elevations, because these points are not limited based on the calculated PCT.

5.) LHRs are valid for fuel enrichments of 5.1 weight percent (maximum) and pin prepressure of 355 psia.

6.) The MOL and EOL PCTs were not explicitly calculated. The PCTs from Reference 5 were conservatively increased by the calculated BOL PCT penalty for the corrected hot channel reflood grid data as described in References 6 and 12.

7.) For the Modified Mark-B9, a 5 F PCT penalty is applied at MOL while a 3 F PCT penalty is applied at EOL over the Mark-B9 results. Because of the small PCT difference, maintaining the EOL PCT less than 1800 F for the Modified Mark-B9 remains appropriate.

Table 3-5: Summary of Mark-B9-GAD LHR Limits for TMI-1 20% SGTP

Elevation (ft)	LOCA LHR Limit, kW/ft BOL, 2772 MWt	LOCA LHR Limit, kW/ft MOL, 2772 MWt (40,000 MWd/mtU)	LOCA LHR Limit, kW/ft EOL, 2568 MWt (62,000 MWd/mtU)
0.000	14.9	14.9	12.1
2.506	15.7	15.7	12.1
4.264	15.7	15.7	12.1
6.021	15.9	15.9	12.1
7.779	15.7	15.7	12.1
9.536	15.7	15.7	12.1
12.000	14.9	14.9	12.1

Notes:

1.) For a 2.0 weight percent (wt/%) concentration of gadolinia (Gad), the PCTs corresponding to the above LHRs are bounded by corresponding PCTs for the Mark-B9 LHRs summarized in Table 3-4.

2.) The LHR limits presented above represent the power generated by the pin (i.e. all sources of usable energy caused by the fission process).

3.) Analyses at BOL and MOL used a steady-state energy deposition factor (EDF) of 0.973 for initial core energy deposition and a transient EDF of 1.013. Analyses at EOL used a steady-state EDF of 1.0 and a transient EDF of 1.1.

4.) Linear interpolation for LHR limits is allowed between 40,000 MWd/mtU and 62,000 MWd/mtU.

5.) The LHR limits below 2.506 feet are reduced linearly to $0.95*LHR_{2.506}$ at 0.0 feet. The LHR limits above 9.536 feet are reduced linearly to $0.95*LHR_{9.536}$ at 12.0 feet while on the PCT-limited portion of the LHR versus MWd curve. The EOL LHRs are maintained constant at 12.1 kW/ft for all elevations, because these points are not limited based on the calculated PCT.

6.) LHRs are valid for 2 wt/% gadolinia enrichments and a pin prepressure of 355 psia.

7.) The BOL and MOL LHR limits for Gadolinia fuel were calculated by considering a Gadolinia to UO_2 power ratio of 0.937 to increased transient EDF of 1.013 for Gadolinia fuel (Reference 18). The EOL EDF of the original analyses was found to be appropriate and the Gadolinia to UO_2 power ratio remains at 0.95. The LHR limit at 62,000 MWd/mtU was set by a maximum pin pressure of 3000 psia.

Table 3-6: Summary of Mark-B9 LHR Limits for BWOG (ANO-1) 20% SGTP

Elevation (ft)	LOCA LHR Limit, kW/ft (PCT, F) BOL, 2772 MWt	LOCA LHR Limit, kW/ft (PCT, F) MOL, 2772 MWt (40,000 MWd/mtU)	LOCA LHR Limit, kW/ft (PCT, F) EOL, 2772 MWt (60,000 MWd/mtU)
0.000	15.9 (<2059)	15.9 (<1855)	11.6 (<1535)
2.506	16.8 (2059)	16.8 (1855)[6]	11.6 (1535)[6]
4.264	16.8 (2030)	16.8 (1883)[6]	11.6 (<1700)
6.021	17.0 (2036)	17.0 (1864)[6]	11.6 (<1700)
7.779	16.8 (1964)	16.8 (1864)[6]	11.6 (<1700)
9.536	16.8 (2083)	16.8 (1935)[6]	11.6 (<1700)
12.000	15.9 (<2083)	15.9 (<1935)	11.6 (<1700)

Notes:

1.) The LHR limits presented above represent the power generated by the pin (i.e. all sources of usable energy caused by the fission process).

2.) Analyses at BOL and MOL used a steady-state energy deposition factor (EDF) of 0.973 for initial core energy deposition and a transient EDF of 1.0. Analyses at EOL used a steady-state EDF of 1.0 and a transient EDF of 1.1.

3.) Linear interpolation for LHR limits is allowed between 40000 MWd/mtU and 60000 MWd/mtU.

4.) The LHR limits below 2.506 feet are reduced linearly to $0.95*LHR_{2.506}$ at 0.0 feet. The LHR limits above 9.536 feet are reduced linearly to $0.95*LHR_{9.536}$ at 12.0 feet while on the PCT-limited portion of the LHR versus MWd curve. The EOL LHRs are maintained constant at 11.6 kW/ft for all elevations, because these points are not limited based on the calculated PCT.

5.) LHRs are valid for fuel enrichments of 5.1 weight percent (maximum) and pin prepressure of 355 psia.

6.) The MOL and EOL PCTs were not explicitly calculated. The PCTs from Reference 5 were conservatively increased by the calculated BOL PCT penalty for the corrected hot channel reflood grid data as described in References 6 and 12.

4. Summary

FTI has identified all of the LBLOCA cases affected by the descrepancies in the pump-type and degradation, and the most challenging cases have been reanalyzed. These cases were used to develop PCT deltas (or LHR adjustments) that were applied to the non-limiting core elevations or times in life. All PCTs, inclusive of all penalties and credits, were less than 2150 F when corrected and reanalyzed. An adequate margin of safety is maintained for the affected LOCA analyses and the resolution of PSC 1-99 is therefore not reportable under 10CFR21.

A summary of the limiting two-phase degradation models and plant-specific pump-types is listed in Table 4-1. For generic (or combined plant) analyses, a "level" is specified in Table 4-1 to illustrate which pump-types would provide more limiting results. Of the pump-types in operation at the plants considered in a generic analysis, the pump-type with the more significant "level" should be modeled for LBLOCA analyses to provide limiting results. For example, the pump type and degradation rated Level 1 should be used for a generic analysis of all 177-FA LL plants. It is important to note that although some plants utilize the same pump-type, the motor may be from different manufacturers. Therefore, the rated pump parameters such as moment of inertia and pump torque versus pump speed should be verified specific to the plant with the limiting pump configuration. A summary of the limiting pump-type and two-phase degradation will be provided in a revision to the LOCA EM Limitations and Restrictions document (Reference 28).

Table 4-1: Limiting Plant-Specific RCP and Head Degradation Configurations

Plant	Pump Type	RCP Head Difference	RCP 2 Phase Degradation	Level
Oconee 1	Westinghouse	R5	M3-modified	1
Oconee 2,3	Bingham	R5	M3-modified	3
TMI 1	Westinghouse	R5	M3-modified	1
ANO 1	Byron-Jackson	R5	M3-modified	2
CR 3	Byron-Jackson	R5	M3-modified	2
DB 1	Bryon-Jackson	R5	M3-modified	NA

Attachment

Preliminary Report of Safety Concerns
Log Number 1-99

51-5006132-00

20208-9 (4/98)

FRAMATOME TECHNOLOGIES

PRELIMINARY REPORT OF SAFETY CONCERNS

1	O: Manager, Owners Group Services, FTG (cc: Quality Assurance) — Consult FTG Owners Group Services for assistance in completing this form	Log No. 1-99
	FROM: John A. Klingenfus	File No. (Contract No.) 2051 T4.4
	ORGANIZATION: Analysis Services	Page 1 of 4

Attach and identify, by page number, any supporting information/documents.

2 When, how and on which plant was the safety concern identified?
During the development of the DB LBLOCA RELAP5 input model it was realized that the plant-specific RCP homologous curves had not been used in all previous LBLOCA EM analyses. (See attached writeup)

3 To your knowledge is customer aware? ☒ Yes ☐ No
When & How J Link via telephone - 1/5/99
G. Swindlehurst via telephone - 1/5/99
M. Byram via J. Link - 1/5/99

4 To your knowledge is NRC aware? ☐ Yes ☒ No
When & How

5 Other affected Utilities/Plants (name and location)
Oconee Units 1, 2, & 3, TMI-1, ANO-1

6 Description of safety concern-identify affected component(s), system(s), service(s) or activity/supplier, and impact on safety of plant operations.
The RCP modeling question led to the discovery that all previous EM analyses may not have used the appropriate RCP type in the LBLOCA analyses. Preliminary sensitivity studies preformed with either a Westinghouse or BJ pump produced slightly higher PCTs than the same analysis with a Bingham pump. Further preliminary studies have indicated that the lowered-loop plants will produce significantly higher PCTs when the minimum two-phase pump degradation model is used. This RCP degradation model impact on PCT behavior is contrary to the BAW-10192PA 205-FA RL RELAP5/MOD2 analyses. It is also contrary to the 177-FA LL CRAFT2 sensitivity studies in BAW-10103. The attached writeup provides additional details of the discovery of the concern and the preliminary analyses results.

7 Cause of the deficiency, deviation or failure, if known.
Engineering evaluations used to extend the RELAP5 RCP degradation studies from the 205-FA RL analyses to the 177 FA LL plants was not supported by actual analysis. Use of CRAFT2 EM sensitivity studies to provide additional confirmation for the engineering judgements was also not appropriate.

8 Suggested corrective action
Perform a plant-type specific RCP two-phase degradation sensitivity study. Perform a pump type model sensitivity study when two or more pump types are included in a bounding LBLOCA EM analysis. Reanalysis of existing LOCA LHR limits is necessary if the most limiting pump type or degradation was not used.

Responsible Unit: Analysis Services Unit

Originator (Signature)	Date	Manager (Signature)	Date
J. A. Klingenfus	1/6/99	[signature]	1/6/99

30

177-FA LL Plant RCP Type and Degradation Effects on LBLOCA

A reactor coolant pump (RCP) modeling issue discovered during the development of the RELAP5-based EM model for Davis-Besse led to a review of the BAW-10192P-A RCP modeling requirements. That review determined that the LOCA analyses for some of the B&W 177 FA LL plants may not have been performed in accordance with Section 4.3.4.5 of Volume 1 of BAW-10192P-A. This section states that the plant-specific pump performance tables (namely the pump rated parameters and pump homologous curves) are used as input for the LOCA analyses. FTI has not performed all LBLOCA analyses in accordance with this provision.

Potentially deficient analyses are: (1) Oconee Unit 1 Mark-B9 and Mark-B10(OL) LOCA LHR limits, (2) TMI Mark-B9 15 % tube plugging LOCA LHR limits, and (3) TMI and ANO Mark-B9 20 % tube plugging LOCA LHR limits. The LOCA analyses that were performed for the Duke Power Oconee Units 1, 2, and 3 used inputs for the Bingham pumps operating in Oconee Units 2 and 3. Oconee Unit 1 has Westinghouse pumps. FTI did not perform a sensitivity study to confirm that the Bingham pump results were bounding and valid for Oconee Unit 1. The TMI and ANO analyses also used the Bingham pump performance curves, even though TMI-1 has Westinghouse pumps and ANO has Bryon Jackson (BJ) pumps.

The Bingham pump performance curves have the most negative head ratios on the HVN curve, which is where the broken and two unbroken loop pumps remain for most of the transient (i.e. less head if it is positive and more resistance where the head is negative). This HVN relationship coupled with the EM pump degradation sensitivity study (which showed the maximum degradation was worst) would suggest that the Bingham pump should produce the highest PCTs. FTI performed a 177 LL pump sensitivity study for the Oconee Mark-B10 analyses to confirm this engineering judgment and to show that the analyses that

were performed with the Bingham pumps were bounding for a plant analyzed with a Westinghouse or BJ pump.

The Oconee Mark-B10 6.021-ft LOCA LHR limit case was reanalyzed with the Westinghouse pump parameters inserted into the blowdown deck. This preliminary case showed that the switch from the Bingham to Westinghouse pump homologous curves resulted in an end-of-blowdown fuel temperature increase which could increase the PCT by roughly 60 F. Investigation into the changes in results led to the suspicion that a reduction in the pump two-phase degradation multiplier could also result in a PCT increase.

Several additional blowdown cases were run with different two-phase head difference curves and void fraction multipliers. The results indicated that a switch from the semiscale ANC fit used in all 177-FA LL analyses to the less resistive two-phase difference curves given in RELAP5 for the semiscale pump would produce an estimated PCT increase of roughly 70 F. Switching from the M1 degradation curve to the M3 curve again increased the EOB fuel temperatures and could result in a PCT increase of 30 F. The total increase from the head difference and void multiplier change for the Bingham pump is estimated at 100 F. This increase, when added to the existing Oconee 6-ft PCT of 1978 F, would push the temperature up to 2078 F (possibly higher due to the exponential metal-water increase with temperature). This implied that the Oconee 1 Westinghouse pump PCT could increase by an additional 60 F or more to roughly 2140 F or higher from metal-water energy.

This estimated increase forces reanalysis of the Mark-B10 fuel that was originally performed in August 1998. LOCA studies performed since that time have included modeling refinements to the core baffle, bypass, and lower plenum regions that could provide a slight PCT improvement. When these refinements are included with the bounding RCP model, the Oconee 1 PCT is expected be less than 2200 F, which supports the current LOCA limits and core maneuvering

analyses. The overall PCT increase must be determined by formal LOCA reanalysis.

The TMI 15 % SG tube plugging analyses must be evaluated with the proper homologous pump curve, RELAP5 two-phase head difference, and M3 void fraction multiplier. The PCT increase should be similar to the 160 F identified for Oconee 1. The TMI analyses also have input model conservatisms that can be used to offset this PCT increase. The bypass/baffle model, lower plenum model, and adjustment of the pressurizer level from minimum to nominal will somewhat offset the RCP modeling PCT increases for these analyses. The resulting PCTs should also be less than 2200 F, but formal LOCA analyses are needed to quantify the overall PCT increase.

The pump modeling changes also affect the BWOG 20 % SG tube plugging analyses for TMI and ANO. These analyses have already incorporated the bypass/baffle model revision and the nominal pressurizer level. The LHR limits are accordingly 0.3 to 0.6 kW/ft higher than the 15% SG tube plugging analyses for TMI. These analyses will likely require a LHR limit decrease to bring PCTs back within a licensable range. These analyses are not currently supporting operating limits.

The CR-3 Mark-B9 analyses that are currently in progress will include the worst-case degradation differences and the M3 multiplier curve. A RCP sensitivity study will be performed for Davis-Besse to ensure that the most limiting pump degradation model is used for those analyses.