DCP_NRC_003214
June 13, 2012

ENCLOSURE 4

10 CFR 50.46 Report for the AP1000 Standard Plant Design

Non - PROPRIETARY

Attachment 1

10 CFR 50.46 Reporting Text and Peak Cladding Temperature Rackup Sheet for the AP1000® DCD Revision 19 LBLOCA Analysis

Evaluation of Fuel Pellet Thermal Conductivity Degradation and Peaking Factor Burndown
(Non-Discretionary Change)

Background

Fuel pellet thermal conductivity degradation (TCD) and peaking factor burndown were not explicitly considered in the AP1000® Large Break Loss-of-Coolant Accident (LBLOCA) Analysis of Record (AOR) presented in AP1000 Design Control Document Revision 19 (Reference 2). NRC Information Notice 2011-21 (Reference 3) notified addressees of recent information obtained concerning the impact of irradiation on fuel thermal conductivity and its potential to cause significantly higher predicted peak cladding temperature (PCT) results in realistic emergency core cooling system (ECCS) evaluation models. This evaluation provides an estimated effect of TCD on PCT for the ECCS in the AP1000 plant design. This change represents a Non-Discretionary Change in accordance with Section 4.1.2 of WCAP-13451 (Reference 1).

Affected Evaluation Model

2004 Westinghouse Realistic Large Break LOCA Evaluation Model Using ASTRUM

Estimated Effect

A quantitative evaluation which utilized the methodology described in Attachment 3 was performed to assess the PCT effect of TCD and peaking factor burndown with other considerations of burnup and concluded that the estimated PCT impact on the AP1000 LBLOCA analysis presented in DCD Revision 19 is +139°F for 10 CFR 50.46 reporting purposes.

References

1. WCAP-13451, "Westinghouse Methodology for Implementation of 10 CFR 50.46 Reporting," October 1992.
2. DCP_NRC_003177, "Westinghouse Electric Company – Updated Application to Amend the AP1000® Nuclear Power Plant Design Certification Rule," June 13, 2011.
3. NRC Information Notice 2011-21, McGinty, T.J., and Dudes, L. A., "Realistic Emergency Core Cooling System Evaluation Model Effects Resulting From Nuclear Fuel Thermal Conductivity Degradation," December 13, 2011. (NRC ADAMS #ML 113430785).

Westinghouse LOCA Peak Clad Temperature Summary for ASTRUM Best Estimate Large Break

Plant Name: AP1000
Utility Name: Westinghouse Nuclear Power Plants
Revision Date: 6/11/2012

Analysis Information

EM:	ASTRUM (2004)	**Analysis Date:**	5/9/2008	**Limiting Break Size:**	Split
FQ:	2.6	**FdH:**	1.75		
Fuel:	RFA	**SGTP (%):**	10		
Notes:					

	Clad Temp (°F)	Ref.	Notes
LICENSING BASIS			
Analysis-Of-Record PCT	**1837**	**1**	
PCT ASSESSMENTS (Delta PCT)			
A. PRIOR ECCS MODEL ASSESSMENTS			
1 . None	0		
B. PLANNED PLANT MODIFICATION EVALUATIONS			
1 . None	0		
C. 2012 ECCS MODEL ASSESSMENTS			
1 . Evaluation of Pellet Thermal Conductivity Degradation and Peaking Factor Burndown	139	2	
D. OTHER*			
1 . None	0		
LICENSING BASIS PCT + PCT ASSESSMENTS **PCT =**	1976		

* It is recommended that the licensee determine if these PCT allocations should be considered with respect to 10 CFR 50.46 reporting requirements.

References

1. APP-GW-GL-700, Tier 2, Chapter 15, Revision 19, "Design Certification Document: Accident analysis," June 2011.
2. LTR-LIS-12-288, "Information Regarding the Evaluation of Fuel Pellet Thermal Conductivity Degradation and Peaking Factor Burndown Including Analysis Input Changes for AP1000 Large Break LOCA Analysis," June 2012.

Notes:

None

Attachment 2

Additional Information Regarding Evaluation for the DCD AP1000® Revision 19 LBLOCA Analysis

1.0 Background

The Nuclear Regulatory Commission (NRC)-approved 2004 Westinghouse Realistic Large Break LOCA Evaluation Model Using ASTRUM (Reference 1) is based on the PAD 4.0 fuel performance code (Reference 2). PAD 4.0 was licensed without explicitly considering fuel pellet thermal conductivity degradation (TCD) with burnup. Explicit modeling of fuel pellet TCD in the fuel performance code leads to changes in the fuel rod design parameters beyond beginning-of-life which are input to the large-break LOCA (LBLOCA) analysis. The effects of explicitly modeling fuel pellet TCD on the AP1000® plant LBLOCA analysis of record presented in the AP1000 Design Control Document (DCD) Revision 19 (Reference 5) have been evaluated. Modeling of fuel pellet TCD is considered a Non-Discretionary Change to the performed LBLOCA analysis in accordance with Section 4.1.2 of WCAP-13451 (Reference 3).

Fuel performance data that accounts for fuel pellet TCD (using an unlicensed model) was used as input to the AP1000 plant evaluation. The new PAD fuel performance data was generated with a representative model that includes explicit modeling of fuel pellet TCD. Therefore the evaluations performed consider the fuel pellet TCD effects cited in NRC Information Notice 2011-21 (Reference 4).

2.0 Large Break LOCA Input Parameters and Assumptions

An AP1000-specific evaluation was performed in order to estimate the effect of fuel pellet TCD and peaking factor burndown. The evaluation calculations were performed based on an AP1000 WCOBRA/TRAC model and ASTRUM analysis updated from the DCD Revision 19 model and analysis. The primary differences between the AP1000 WCOBRA/TRAC model and ASTRUM uncertainty analysis in the DCD Revision 19 and the updated WCOBRA/TRAC model and ASTRUM uncertainty analysis are:

- Changes to the fuel assembly design (primarily the grid design)
- Changes to the reactor coolant pump design and homologous curves
- Changes to the upper head structures
- Increase in the time before reactor coolant pump trip following a LBLOCA when offsite power is available
- Changed PBOT/PMID box
- Changed FdH limit (see additional information below)
- Update to HOTSPOT version 8.0 from HOTSPOT version 6.1

In the updated analysis, a limit of FdH = 1.72 was assumed. This is slightly lower than the FdH=1.75 value assumed in the ASTRUM analysis presented in DCD Revision 19. However, the FdH=1.72 limit remains conservative compared to the overall DCD Revision 19 FdH limit of 1.65.

As discussed in Attachment 3, determining an estimated PCT effect due to TCD and peaking factor burndown at higher PCTs may result in an exaggerated estimated PCT effect because of a calculated run-away zirconium –water reaction which could occur if the analysis contains excessive conservatism. Therefore, in order to evaluate the estimated effect of TCD, analysis conservatism in the updated analysis was evaluated. The following analysis input changes in the updated analysis were evaluated:

- Reduction in the as-analyzed FQ to a value closer to the desired FQ as defined by the ASTRUM evaluation method for the top two most limiting PCT cases from the updated analysis (see Table 1). This reduction removed analysis conservatism associated with using FQ values in code executions that exceeded the target values.

The magnitude of the PCT benefit from these analysis input changes is not directly applicable to the DCD Revision 19 analysis and therefore is not credited. Similar conservatism in the DCD Revision 19 analysis calculations exists and is conservatively retained.

The evaluation of fuel TCD and peaking factor burndown considered the following additional input parameter changes to the LBLOCA analysis:

- Fuel rod design data with PAD 4.0 + TCD
- Peaking factor burndown shown in Table 2

Westinghouse Electric Company LLC utilizes processes which ensure that the LOCA analysis input values conservatively bound the as-designed plant values for those parameters.

Table 1: Reduced Conservatism in Updated ASTRUM Analysis FQ Considered in the Evaluation of TCD

Case	FQ Conservatism(1),(2) (%)	Adjusted FQ Conservatism(1), (3) (%)
A	15	0.4
B	12	0.2

(1) Numbers reflect the percentage by which the as-analyzed FQ in the run exceeded the desired FQ as defined by the ASTRUM evaluation method.
(2) FQ conservatism in runs executed for updated ASTRUM analysis.
(3) FQ conservatism in the runs executed for evaluation of analysis input changes, and in runs executed for evaluation of fuel TCD and peaking factor burndown with the same analysis input changes.

Table 2: Peaking Factors Assumed in the Evaluation of TCD

Rod Burnup (MWD/MTU)	FDH(1)(2)	FQ Transient (1)	FQ Steady-State
0	1.72	2.60	2.10
30,000	1.72	2.60	2.10
49,000	1.55	2.30	1.85
65,000	1.55	2.30	1.85

(1) Includes uncertainties.
(2) Hot assembly average power follows the same burndown, since it is a function of FdH .

3.0 Large Break LOCA Description of Evaluation

Using the updated WCOBRA/TRAC model and associated ASTRUM uncertainty calculations, the evaluation method discussed in Attachment 3 was used to determine the estimated effect of fuel pellet TCD and peaking factor burndown. First, the integrated PCT was calculated to demonstrate compliance with the 10 CFR 50.46(b)(1) criterion when analysis input changes and TCD and burndown were considered. Then, the margin PCT was calculated, including only the analysis input changes.

For the integrated PCT calculation, a total of 31 WCOBRA/TRAC executions were performed. The uncertainty attributes of these executions were taken from among the most limiting cases from the updated 124-run ASTRUM analysis. The evaluation considered an adequate range of burnup such that the effects of TCD and related burnup effects were captured. HOTSPOT executions were performed for each WCOBRA/TRAC case to consider the effect of local uncertainties for both IFBA (Integral Fuel Burnable Absorber) and non-IFBA fuel.

For the margin PCT calculation, WCOBRA/TRAC executions were performed for the top two PCT cases from the updated ASTRUM analysis with the reduced conservatism in FQ described in Table 1. The margin PCT result was then determined as the limiting PCT from these two margin cases and the PCT results of the rank 3 through 124 cases from the updated ASTRUM analysis. The margin PCT calculation does not include effects of peaking factor burndown, consistent with the as-approved ASTRUM evaluation model.

The estimated effect of TCD was then taken as the difference between the integrated PCT and the margin PCT from the updated analysis.

The same WCOBRA/TRAC and HOTSPOT code versions were used in the updated ASTRUM analysis and in the calculations for evaluation of TCD and analysis input conservatism.

The following aspects of the DCD Revision 19 and updated analyses were considered:

- The similarity of plant design and behavior in the LBLOCA analysis presented in the DCD Revision 19 and the updated analysis.
- The HOTSPOT code differences between the Version 6.1 used in the DCD Revision 19 analysis and the Version 8.0 used in the updated analysis.
- Conservatism in the as-analyzed FQ values in several limiting cases in the DCD Revision 19 analysis.

Considering these aspects of the analyses, it was concluded that the estimated PCT effect of TCD calculated from the updated analysis is applicable to the DCD Revision 19 analysis.

4.0 Large Break LOCA Results

Consistent with the ASTRUM methodology, the most limiting PCT from each evaluation was taken as the representative PCT. The limiting integrated PCT case, considering all analysis input changes and TCD and burndown, was 1934°F, less than the 2200°F acceptance criterion. Considering only the analysis input changes, the margin PCT was 1795°F. The estimate of effect of TCD and burndown is the difference between the integrated PCT and the margin PCT, or 1934°F -1795°F =+139°F.

Given the current DCD Revision 19 analysis PCT of 1837°F, the estimated rackup PCT including effects of TCD is 1837°F+139°F = 1976°F. Due to the conservatism in the as-analyzed FQ values in several limiting cases in the DCD Revision 19 analysis, the overall rackup PCT of 1976°F is conservative.

5.0 References

1. WCAP-16009-P-A, "Realistic Large Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM)," January 2005.
2. WCAP-15063-P-A with Errata, Rev.1, "Westinghouse Improved Performance Analysis and Design Model (PAD 4.0)," July 2000.
3. WCAP-13451, "Westinghouse Methodology for Implementation of 10 CFR 50.46 Reporting," October 1992.
4. NRC Information Notice 2011-21, McGinty, T. J., and Dudes, L. A., "Realistic Emergency Core Cooling System Evaluation Model Effects Resulting From Nuclear Fuel Thermal Conductivity Degradation," December 13, 2011. (NRC ADAMS # ML 113430785)
5. DCP_NRC_003177, "Westinghouse Electric Company – Updated Application to Amend the AP1000® Nuclear Power Plant Design Certification Rule," June 13, 2011.

Attachment 3

Additional Information Regarding Method for Evaluation of Nuclear Fuel Thermal Conductivity Degradation

Fuel Performance and Design

Description of Methodology and Assumptions

The Nuclear Regulatory Commission (NRC) approved Performance Analysis and Design (PAD) 4.0 code, with NRC-approved models (Reference 1) for in-reactor behavior, is used as the basis for the assessment of the impact of thermal conductivity degradation (TCD) on fuel performance inputs to safety analyses. PAD 4.0 is a best-estimate fuel rod performance model, with established uncertainties for each of the major fuel and cladding performance models.

The licensed PAD 4.0 fuel performance models do not explicitly address the impact of TCD. The fuel thermal conductivity model in PAD 4.0 is: [

] [a,c]

[

]a,c

Figure 1: Comparison of Measured Minus Predicted Fuel Temperature as a Function of Burnup for PAD 4.0 and PAD 4.0 TCD

a,c

[ ]

Large Break Loss-of-Coolant Accident

Methodologies and Codes Used for TCD Evaluations

Westinghouse currently employs the ASTRUM best estimate Evaluation Model (EM) methodology for analysis of the AP1000 large break loss-of-coolant accident:

- 2004 Westinghouse Realistic LBLOCA Evaluation Model Using ASTRUM (Automated Statistical Treatment of Uncertainty Method) (ASTRUM EM, Reference 3)

The ASTRUM EM is executed assuming a LBLOCA to be [

]a,c The basis for the modeling approach and supporting sensitivity studies are discussed in Section 11-2-2 of Reference 3.

The ASTRUM EM was licensed using PAD 4.0. Both PAD 4.0 fuel temperature calculations indicate that [

]a,c

The ASTRUM EMs uses WCOBRA/TRAC and HOTSPOT for calculation of the thermal-hydraulic and peak cladding temperature (PCT) response to a LBLOCA. The WCOBRA/TRAC and HOTSPOT versions used in AP1000 ASTRUM analysis include options to use a fuel thermal conductivity model that accounts for TCD; these options were not used in AP1000 ASTRUM analysis. HOTSPOT also includes the ability to use pellet radial power profiles from WCOBRA/TRAC which are appropriate to the burnup modeled for a given rod. The ability for HOTSPOT to use pellet radial power profiles from WCOBRA/TRAC which are appropriate to the burnup modeled for a given rod was previously reported to the NRC per Reference 5 as a discretionary change; this feature was used in AP1000 ASTRUM analysis.

Calculations for AP1000 TCD evaluations will use code versions with these thermal conductivity and pellet radial profile features in order to appropriately initialize the WCOBRA/TRAC and HOTSPOT fuel rod to the input fuel temperatures and pressures from the fuel performance code and determine the impact of TCD with peaking factor burndown on PCT.

[

]a,c

Where:

[

]a,c

Evaluation Method Description

The purpose of the TCD evaluation is to consider fuel performance inputs generated with an updated PAD code that explicitly models TCD and peaking factor burndown, and utilize changes to design inputs to show continued compliance with the 10 CFR 50.46(b)(1) PCT acceptance criterion (2200°F). The codes used to assess thermal-hydraulic and PCT response also include explicit modeling of TCD through the use of a fuel thermal conductivity model which includes degradation as a function of burnup. Therefore, the LBLOCA evaluation considers the fuel TCD effects cited in NRC Information Notice 2011-21 (Reference 6).

As the calculated PCT approaches 2200°F, the impact of the zirconium-water reaction becomes more dominating, since it is an exothermic reaction. Therefore, determining an estimated PCT effect due to TCD and peaking factor burndown for analyses with higher PCTs may result in exaggerated estimated PCT effects because of a calculated run-away zirconium-water reaction which could occur if the analysis contains excessive conservatism. Therefore, to determine the estimated PCT effect of TCD, the following approach is taken.

A PCT is calculated to demonstrate that compliance with 10 CFR 50.46(b)(1) is maintained. The calculations include:

- Initial fuel temperatures and rod internal pressures that explicitly account for TCD
- Hot rod and hot assembly peaking factor burndown
- Pellet radial power profile appropriate to the burnup modeled for the rods
- Credit for changes to analysis inputs to remove existing conservatism

In addition, a margin PCT is calculated which includes only credits for changes to analysis inputs to remove existing conservatism. Westinghouse utilizes processes which ensure that LOCA analysis input values conservatively bound the as-designed plant values for those parameters.

Physically accounting for TCD leads to an increase in fuel temperature as the fuel is burned, while accounting for peaking factor burndown leads to a reduction in fuel temperature as the fuel is burned. As inferred from the decrease in fuel temperatures and stored energy in Figures 3 and 4 of Reference 7, TCD and peaking factor burndown are inter-related and should be coupled for the purposes of the evaluation. Therefore, the effect of TCD including peaking factor burndown is estimated to be the difference between a compliance PCT and a margin PCT.

The method used to calculate the PCT values for the ASTRUM EMs is as follows. The evaluation is based on running **[**

][a,c] The calculations are as discussed previously.

References

1) WCAP-15063-P-A, Revision 1 with Errata (Proprietary), Foster J. P., et al., *Westinghouse Improved Performance Analysis and Design Model (PAD 4.0)*, July 2000.
2) WCAP-15836-P-A (Proprietary), Harris, W. R., et al., *Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1*, April 2006.
3) WCAP-16009-P-A (Proprietary), Frepoli, C., et al., *Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM)*, January 2005.
4) NUREG/CR-6534, Volume 4, Lanning, D.D., et al., *FRAPCON-3 Updates, Including Mixed-Oxide Fuel Properties*, May 2005.
5) LTR-NRC-07-23, Maurer, B. F., *U. S. Nuclear Regulatory Commission,10 CFR 50.46 Annual Notification and Reporting for 2006*, May 15, 2007.
6) NRC Information Notice 2011-21, McGinty, T. J., and Dudes, L. A., *Realistic Emergency Core Cooling System Evaluation Model Effects Resulting From Nuclear Fuel Thermal Conductivity Degradation*, December 13, 2011.
7) McGinty, T. J. (NRC) to Gresham, J. A. (Westinghouse), *Nuclear Fuel Thermal Conductivity Degradation Evaluation for Light Water Reactors Using Westinghouse Codes and Methods (TAC NO. ME5186)*, December 16, 2011.