

## Catawba Unit 1 Cycle 16

### Core Operating Limits Report Revision 28

April 2005

Duke Power Company

**INFORMATION ONLY**

		Date
Prepared By:	<u>Nicholas R Hager</u>	<u>4/26/05</u>
Checked By:	<u>Jeff J. Pa</u>	<u>4/26/2005</u>
Checked By:	<u>RJA-1/tjt</u>	<u>4/26/2005</u>
Approved By:	<u>Scott B. Chum</u>	<u>4/26/2005</u>

### QA Condition 1

The information presented in this report has been prepared and issued in accordance with Catawba Technical Specification 5.6.5.

## INSPECTION OF ENGINEERING INSTRUCTIONS

Inspection Waived By:

Scott B. Thum  
(Sponsor)

Date:

4/26/05

CATAWBAInspection  
Waived

MCE (Mechanical &amp; Civil)



Inspected By/Date: \_\_\_\_\_

RES (Electrical Only)



Inspected By/Date: \_\_\_\_\_

RES (Reactor)



Inspected By/Date: \_\_\_\_\_

MOD



Inspected By/Date: \_\_\_\_\_

Other ( \_\_\_\_\_ )



Inspected By/Date: \_\_\_\_\_

OCONEEInspection  
Waived

MCE (Mechanical &amp; Civil)



Inspected By/Date: \_\_\_\_\_

RES (Electrical Only)



Inspected By/Date: \_\_\_\_\_

RES (Reactor)



Inspected By/Date: \_\_\_\_\_

MOD



Inspected By/Date: \_\_\_\_\_

Other ( \_\_\_\_\_ )



Inspected By/Date: \_\_\_\_\_

MCGUIREInspection  
Waived

MCE (Mechanical &amp; Civil)



Inspected By/Date: \_\_\_\_\_

RES (Electrical Only)



Inspected By/Date: \_\_\_\_\_

RES (Reactor)



Inspected By/Date: \_\_\_\_\_

MOD



Inspected By/Date: \_\_\_\_\_

Other ( \_\_\_\_\_ )



Inspected By/Date: \_\_\_\_\_

## **Catawba 1 Cycle 16 Core Operating Limits Report**

### **Implementation Instructions for Revision 28**

#### **Revision Description and PIP Tracking**

Revision 28 of the Catawba Unit 2 COLR contains limits specific to the Catawba 1 Cycle 16 reload core. There is no PIP associated with this revision.

#### **Implementation Schedule**

Revision 28 may become effective any time during No MODE between Cycles 15 and 16 but must become effective prior to entering MODE 6 which starts Cycle 16. This revision replaces the current revisions (CNEI-0400-24, Rev. 27).

#### **Data files to be Implemented**

No data files are transmitted as part of this document.

#### **Insertion/Deletion Instructions**

<b>Remove</b>	<b>Insert</b>
pages 1- 34, of rev 27  (including Appendix A*)	pages 1- 35 of rev 28  (including Appendix A*)

\* Appendix A contains power distribution monitoring factors used in Technical Specification Surveillance. Appendix A is only included in the electronic COLR copy sent to the NRC.

**Catawba 1 Cycle 16 Core Operating Limits Report****REVISION LOG**

<b><u>Revision</u></b>	<b><u>EI Date</u></b>	<b><u>Pages Affected</u></b>	<b><u>COLR</u></b>
0 – 1	Superceded	N/A	C1C07
2 – 5	Superceded	N/A	C1C08
6 – 8	Superceded	N/A	C1C09
9 – 11	Superceded	N/A	C1C10
12 - 14	Superceded	N/A	C1C11
15 – 17	Superceded	N/A	C1C12
18 - 21	Superceded	N/A	C1C13
22 - 23	Superceded	N/A	C1C14
24	November 2003	All	C1C15 (Orig. Issue)
25	March 2004	1-34	C1C15 (Revision 1)
26	September 2004	1-34	C1C15 (Revision 2)
27	March 2005	1-34	C1C15 (Revision 3)
28	April 2005	1-35	C1C16 (Orig. Issue)

## Catawba 1 Cycle 16 Core Operating Limits Report

### 1.0 Core Operating Limits Report

This Core Operating Limits Report (COLR) has been prepared in accordance with the requirements of Technical Specification 5.6.5. The Technical Specifications that reference this report are listed below:

TS Section	Technical Specifications	COLR Parameter	COLR Section	COLR Page
2.1.1	Reactor Core Safety Limits	RCS Temperature and Pressure Safety Limits	2.1	9
3.1.1	Shutdown Margin	Shutdown Margin	2.2	9
3.1.3	Moderator Temperature Coefficient	MTC	2.3	11
3.1.4	Rod Group Alignment Limits	Shutdown Margin	2.2	9
3.1.5	Shutdown Bank Insertion Limit	Shutdown Margin Rod Insertion Limits	2.2 2.4	9 11
3.1.6	Control Bank Insertion Limit	Shutdown Margin Rod Insertion Limits	2.2 2.5	9 11
3.1.8	Physics Tests Exceptions	Shutdown Margin	2.2	9
3.2.1	Heat Flux Hot Channel Factor	$F_Q$ AFD $OT\Delta T$ Penalty Factors	2.6 2.8 2.9 2.6	15 24 27 17
3.2.2	Nuclear Enthalpy Rise Hot Channel Factor	$F\Delta H$ Penalty Factors	2.7 2.7	23 24
3.2.3	Axial Flux Difference	AFD	2.8	24
3.3.1	Reactor Trip System Instrumentation	$OT\Delta T$ $OP\Delta T$	2.9 2.9	27 28
3.3.9	Boron Dilution Mitigation System	Reactor Makeup Water Flow Rate	2.10	29
3.4.1	RCS Pressure, Temperature and Flow limits for DNB	RCS Pressure, Temperature and Flow	2.11	29
3.5.1	Accumulators	Max and Min Boron Conc.	2.12	29
3.5.4	Refueling Water Storage Tank	Max and Min Boron Conc.	2.13	29
3.7.15	Spent Fuel Pool Boron Concentration	Min Boron Concentration	2.14	31
3.9.1	Refueling Operations - Boron Concentration	Min Boron Concentration	2.15	31
5.6.5	Core Operating Limits Report (COLR)	Analytical Methods	1.1	6

The Selected License Commitments that reference this report are listed below:

SLC Section	Selected Licensing Commitment	COLR Parameter	COLR Section	COLR Page
16.7-9.3	Standby Shutdown System	Standby Makeup Pump Water Supply	2.16	32
16.9-11	Boration Systems – Borated Water Source – Shutdown	Borated Water Volume and Conc. for BAT/RWST	2.17	32
16.9-12	Boration Systems – Borated Water Source – Operating	Borated Water Volume and Conc. for BAT/RWST	2.18	33

## Catawba 1 Cycle 16 Core Operating Limits Report

### 1.1 Analytical Methods

The analytical methods used to determine core operating limits for parameters identified in Technical Specifications and previously reviewed and approved by the NRC are as follows.

1. WCAP-9272-P-A, "WESTINGHOUSE RELOAD SAFETY EVALUATION METHODOLOGY," (W Proprietary).

Revision 0

Report Date: July 1985

**Not Used for C1C16**

2. WCAP-10054-P-A, "Westinghouse Small Break ECCS Evaluation Model using the NOTRUMP Code, " (W Proprietary).

Revision 0

Report Date: August 1985

3. WCAP-10266-P-A, "THE 1981 VERSION OF WESTINGHOUSE EVALUATION MODEL USING BASH CODE", (W Proprietary).

Revision 2

Report Date: March 1987

**Not Used for C1C16**

4. WCAP-12945-P-A, Volume 1 and Volumes 2-5, "Code Qualification Document for Best-Estimate Loss of Coolant Analysis," (W Proprietary).

Revision: Volume 1 (Revision 2) and Volumes 2-5 (Revision 1)

Report Date: March 1998

5. BAW-10168P-A, "B&W Loss-of-Coolant Accident Evaluation Model for Recirculating Steam Generator Plants," (B&W Proprietary).

Revision 1

SER Date: January 22, 1991

Revision 2

SER Dates: August 22, 1996 and November 26, 1996.

Revision 3

SER Date: June 15, 1994.

**Not Used for C1C16**

## Catawba 1 Cycle 16 Core Operating Limits Report

### 1.1 Analytical Methods (continued)

6. DPC-NE-3000PA, "Thermal-Hydraulic Transient Analysis Methodology," (DPC Proprietary).

Revision 3

SER Date: September 24, 2003

7. DPC-NE-3001PA, "Multidimensional Reactor Transients and Safety Analysis Physics Parameter Methodology," (DPC Proprietary).

Revision 0

Report Date: November, 1991, republished December 2000

8. DPC-NE-3002A, "UFSAR Chapter 15 System Transient Analysis Methodology".

Revision 4

SER Date: April 6, 2001

9. DPC-NE-2004P-A, "Duke Power Company McGuire and Catawba Nuclear Stations Core Thermal-Hydraulic Methodology using VIPRE-01," (DPC Proprietary).

Revision 1

SER Date: February 20, 1997

10. DPC-NE-2005P-A, "Thermal Hydraulic Statistical Core Design Methodology," (DPC Proprietary).

Revision 3

SER Date: September 16, 2002

11. DPC-NE-2008P-A, "Fuel Mechanical Reload Analysis Methodology Using TACO3," (DPC Proprietary).

Revision 0

SER Date: April 3, 1995

**Not Used for C1C16**

12. DPC-NE-2009-P-A, "Westinghouse Fuel Transition Report," (DPC Proprietary).

Revision 2

SER Date: December 18, 2002

13. DPC-NE-1004A, "Nuclear Design Methodology Using CASMO-3/SIMULATE-3P."

Revision 1

SER Date: April 26, 1996

**Not Used for C1C16**

## **Catawba 1 Cycle 16 Core Operating Limits Report**

### **1.1 Analytical Methods (continued)**

14. DPC-NF-2010A, "Duke Power Company McGuire Nuclear Station Catawba Nuclear Station Nuclear Physics Methodology for Reload Design."

Revision 2

SER Date: June 24, 2003

15. DPC-NE-2011PA, "Duke Power Company Nuclear Design Methodology for Core Operating Limits of Westinghouse Reactors," (DPC Proprietary).

Revision 1

SER Date: October 1, 2002

16. DPC-NE-1005-P-A, "Nuclear Design Methodology Using CASMO-4 / SIMULATE-3 MOX", (DPC Proprietary).

Revision 0

SER Date: August 20, 2004

17. BAW-10231P-A, "COPERNIC Fuel Rod Design Computer Code" (Framatome ANP Proprietary)

Revision 1

SER Date: January 14, 2004



## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.0 Operating Limits

The cycle-specific parameter limits for the specifications listed in Section 1.0 are presented in the following subsections. These limits have been developed using NRC approved methodologies specified in Section 1.1.

#### 2.1 Reactor Core Safety Limits (TS 2.1.1)

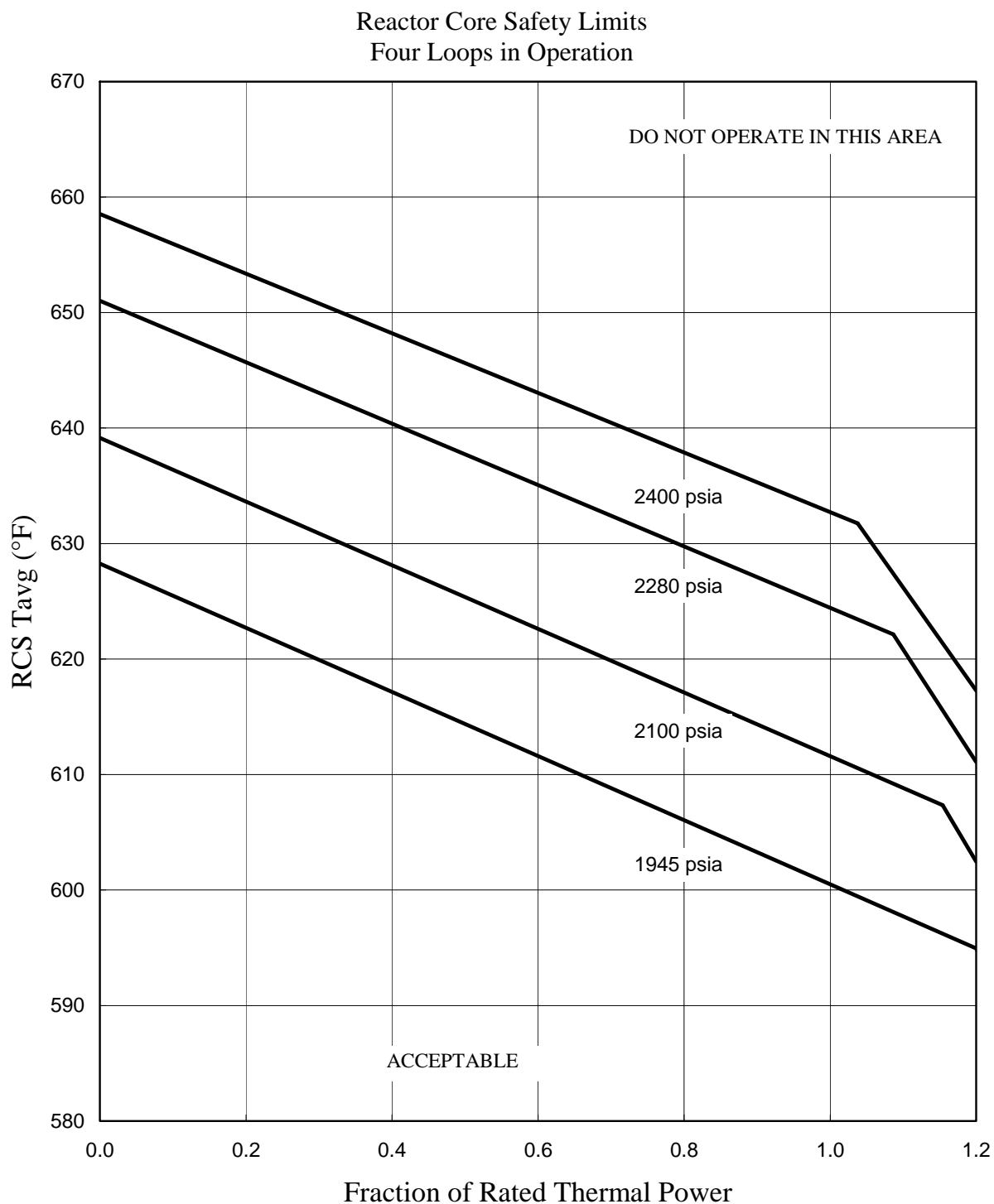
The Reactor Core Safety Limits are shown in Figure 1.

#### 2.2 Shutdown Margin - SDM (TS 3.1.1, TS 3.1.4, TS 3.1.5, TS 3.1.6, TS 3.1.8)

- 2.2.1 For TS 3.1.1, shutdown margin shall be greater than or equal to 1.3%  $\Delta K/K$  in mode 2 with  $K_{eff} < 1.0$  and in modes 3 and 4.
- 2.2.2 For TS 3.1.1, shutdown margin shall be greater than or equal to 1.0%  $\Delta K/K$  in mode 5.
- 2.2.3 For TS 3.1.4, shutdown margin shall be greater than or equal to 1.3%  $\Delta K/K$  in mode 1 and mode 2.
- 2.2.4 For TS 3.1.5, shutdown margin shall be greater than or equal to 1.3%  $\Delta K/K$  in mode 1 and mode 2 with any control bank not fully inserted.
- 2.2.5 For TS 3.1.6, shutdown margin shall be greater than or equal to 1.3%  $\Delta K/K$  in mode 1 and mode 2 with  $K_{eff} \geq 1.0$ .
- 2.2.6 For TS 3.1.8, shutdown margin shall be greater than or equal to 1.3%  $\Delta K/K$  in mode 2 during Physics Testing.

## Catawba 1 Cycle 16 Core Operating Limits Report

Figure 1



## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.3 Moderator Temperature Coefficient - MTC (TS 3.1.3)

#### 2.3.1 The Moderator Temperature Coefficient (MTC) Limits are:

The MTC shall be less positive than the upper limits shown in Figure 2. The BOC, ARO, HZP MTC shall be less positive than  $0.7\text{E-}04 \Delta\text{K/K/}^\circ\text{F}$ .

The EOC, ARO, RTP MTC shall be less negative than the  $-4.3\text{E-}04 \Delta\text{K/K/}^\circ\text{F}$  lower MTC limit.

#### 2.3.2 The 300 ppm MTC Surveillance Limit is:

The measured 300 PPM ARO, equilibrium RTP MTC shall be less negative than or equal to  $-3.65\text{E-}04 \Delta\text{K/K/}^\circ\text{F}$ .

#### 2.3.3 The 60 PPM MTC Surveillance Limit is:

The 60 PPM ARO, equilibrium RTP MTC shall be less negative than or equal to  $-4.125\text{E-}04 \Delta\text{K/K/}^\circ\text{F}$ .

Where:

- BOC = Beginning of Cycle (burnup corresponding to most positive MTC)
- EOC = End of Cycle
- ARO = All Rods Out
- HZP = Hot Zero Thermal Power
- RTP = Rated Thermal Power
- PPM = Parts per million (Boron)

### 2.4 Shutdown Bank Insertion Limit (TS 3.1.5)

#### 2.4.1 Each shutdown bank shall be withdrawn to at least 222 steps. Shutdown banks are withdrawn in sequence and with no overlap.

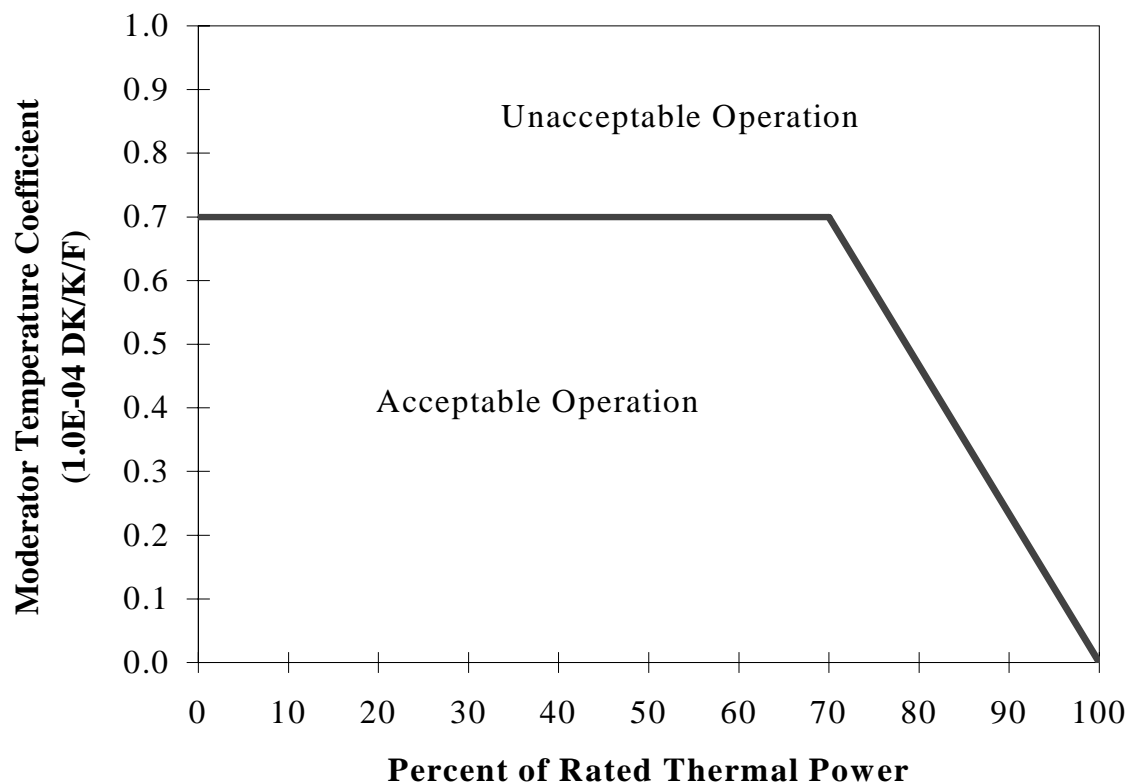
### 2.5 Control Bank Insertion Limits (TS 3.1.6)

#### 2.5.1 Control banks shall be within the insertion, sequence, and overlap limits shown in Figure 3. Specific control bank withdrawal and overlap limits as a function of the fully withdrawn position are shown in Table 1.

## Catawba 1 Cycle 16 Core Operating Limits Report

**Figure 2**

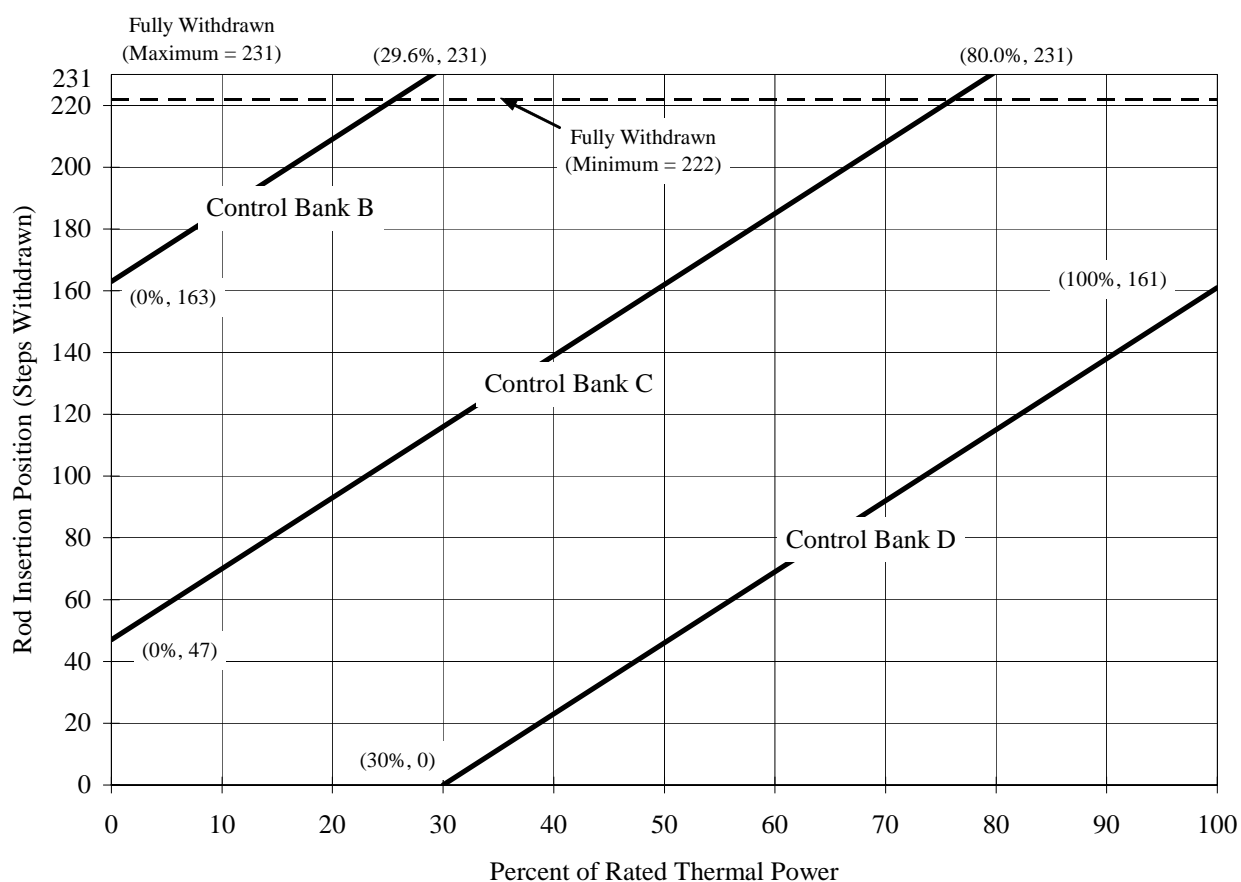
### Moderator Temperature Coefficient Upper Limit Versus Power Level



**NOTE:** Compliance with Technical Specification 3.1.3 may require rod withdrawal limits. Refer to the Unit 1 ROD manual for details.

## Catawba 1 Cycle 16 Core Operating Limits Report

**Figure 3**  
**Control Bank Insertion Limits Versus Percent Rated Thermal Power**



The Rod Insertion Limits (RIL) for Control Bank D (CD), Control Bank C (CC), and Control Bank B (CB) can be calculated by:

$$\text{Bank CD RIL} = 2.3(P) - 69 \quad \{30 \leq P \leq 100\}$$

$$\text{Bank CC RIL} = 2.3(P) + 47 \quad \{0 \leq P \leq 80\}$$

$$\text{Bank CB RIL} = 2.3(P) + 163 \quad \{0 \leq P \leq 29.6\}$$

where  $P = \% \text{ Rated Thermal Power}$

**NOTE:** Compliance with Technical Specification 3.1.3 may require rod withdrawal limits. Refer to the Unit 1 ROD manual for details.

## Catawba 1 Cycle 16 Core Operating Limits Report

**Table 1**  
**Control Bank Withdrawal Steps and Sequence**

Fully Withdrawn at 222 Steps				Fully Withdrawn at 223 Steps			
Control Bank A	Control Bank B	Control Bank C	Control Bank D	Control Bank A	Control Bank B	Control Bank C	Control Bank D
0 Start	0	0	0	0 Start	0	0	0
116	0 Start	0	0	116	0 Start	0	0
222 Stop	106	0	0	223 Stop	107	0	0
222	116	0 Start	0	223	116	0 Start	0
222	222 Stop	106	0	223	223 Stop	107	0
222	222	116	0 Start	223	223	116	0 Start
222	222	222 Stop	106	223	223	223 Stop	107
Fully Withdrawn at 224 Steps				Fully Withdrawn at 225 Steps			
Control Bank A	Control Bank B	Control Bank C	Control Bank D	Control Bank A	Control Bank B	Control Bank C	Control Bank D
0 Start	0	0	0	0 Start	0	0	0
116	0 Start	0	0	116	0 Start	0	0
224 Stop	108	0	0	225 Stop	109	0	0
224	116	0 Start	0	225	116	0 Start	0
224	224 Stop	108	0	225	225 Stop	109	0
224	224	116	0 Start	225	225	116	0 Start
224	224	224 Stop	108	225	225	225 Stop	109
Fully Withdrawn at 226 Steps				Fully Withdrawn at 227 Steps			
Control Bank A	Control Bank B	Control Bank C	Control Bank D	Control Bank A	Control Bank B	Control Bank C	Control Bank D
0 Start	0	0	0	0 Start	0	0	0
116	0 Start	0	0	116	0 Start	0	0
226 Stop	110	0	0	227 Stop	111	0	0
226	116	0 Start	0	227	116	0 Start	0
226	226 Stop	110	0	227	227 Stop	111	0
226	226	116	0 Start	227	227	116	0 Start
226	226	226 Stop	110	227	227	227 Stop	111
Fully Withdrawn at 228 Steps				Fully Withdrawn at 229 Steps			
Control Bank A	Control Bank B	Control Bank C	Control Bank D	Control Bank A	Control Bank B	Control Bank C	Control Bank D
0 Start	0	0	0	0 Start	0	0	0
116	0 Start	0	0	116	0 Start	0	0
228 Stop	112	0	0	229 Stop	113	0	0
228	116	0 Start	0	229	116	0 Start	0
228	228 Stop	112	0	229	229 Stop	113	0
228	228	116	0 Start	229	229	116	0 Start
228	228	228 Stop	112	229	229	229 Stop	113
Fully Withdrawn at 230 Steps				Fully Withdrawn at 231 Steps			
Control Bank A	Control Bank B	Control Bank C	Control Bank D	Control Bank A	Control Bank B	Control Bank C	Control Bank D
0 Start	0	0	0	0 Start	0	0	0
116	0 Start	0	0	116	0 Start	0	0
230 Stop	114	0	0	231 Stop	115	0	0
230	116	0 Start	0	231	116	0 Start	0
230	230 Stop	114	0	231	231 Stop	115	0
230	230	116	0 Start	231	231	116	0 Start
230	230	230 Stop	114	231	231	231 Stop	115

## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.6 Heat Flux Hot Channel Factor - $F_Q(X,Y,Z)$ (TS 3.2.1)

**2.6.1**  $F_Q(X,Y,Z)$  steady-state limits are defined by the following relationships:

$$\begin{aligned} F_Q^{RTP} * K(Z) / P & \quad \text{for } P > 0.5 \\ F_Q^{RTP} * K(Z) / 0.5 & \quad \text{for } P \leq 0.5 \end{aligned}$$

where,

$$P = (\text{Thermal Power}) / (\text{Rated Power})$$

Note: The measured  $F_Q(X,Y,Z)$  shall be increased by 3.1% to account for manufacturing tolerances and 5% to account for measurement uncertainty when comparing against the LCO limit. The more conservative of the manufacturing tolerances for RFA/NGF fuel (3%) or MOX fuel (3.1%) is used when comparing against the LCO limit due to input limitations in monitoring software. The manufacturing tolerance and measurement uncertainty are implicitly included in the  $F_Q$  surveillance limits as defined below for COLR Sections 2.6.5 and 2.6.6.

$$\begin{aligned} \mathbf{2.6.2} \quad F_Q^{RTP} &= 2.60 \times K(\text{BU}) \quad \text{for RFA and NGF fuel} \\ F_Q^{RTP} &= 2.40 \times K(\text{BU}) \quad \text{for MOX fuel} \end{aligned}$$

**2.6.3**  $K(Z)$  is the normalized  $F_Q(X,Y,Z)$  as a function of core height.  $K(Z)$  for Westinghouse RFA and NGF fuel is provided in Figure 4, and the  $K(Z)$  for MOX fuel is provided in Figure 5.

**2.6.4**  $K(\text{BU})$  is the normalized  $F_Q(X,Y,Z)$  as a function of burnup.  $K(\text{BU})$  for Westinghouse RFA and NGF fuel is provided in Figure 6, and the  $K(\text{BU})$  for MOX fuel is provided in Figure 7.

The following parameters are required for core monitoring per the Surveillance Requirements of Technical Specification 3.2.1:

$$\mathbf{2.6.5} \quad [F_Q^L(X,Y,Z)]^{OP} = \frac{F_Q^D(X,Y,Z) * M_Q(X,Y,Z)}{UMT * MT * TILT}$$

## Catawba 1 Cycle 16 Core Operating Limits Report

where:

$[F_Q^L(X,Y,Z)]^{OP}$  = Cycle dependent maximum allowable design peaking factor that ensures that the  $F_Q(X,Y,Z)$  LOCA limit is not exceeded for operation within the AFD, RIL, and QPTR limits.

$F_Q^L(X,Y,Z)^{OP}$  includes allowances for calculational and measurement uncertainties.

$F_Q^D(X,Y,Z)$  = Design power distribution for  $F_Q$ .  $F_Q^D(X,Y,Z)$  is provided in Appendix Table A-1 for normal operating conditions and in Appendix Table A-4 for power escalation testing during initial startup operation.

$M_Q(X,Y,Z)$  = Margin remaining in core location X,Y,Z to the LOCA limit in the transient power distribution.  $M_Q(X,Y,Z)$  is provided in Appendix Table A-1 for normal operating conditions and in Appendix Table A-4 for power escalation testing during initial startup operation.

UMT = Total Peak Measurement Uncertainty. (UMT = 1.05)

MT = Engineering Hot Channel Factor. (MT = 1.031). The more conservative of the manufacturing tolerances for RFA/NGF fuel (3%) or MOX fuel (3.1%) is used when comparing against the  $F_Q$  LOCA surveillance limit due to input limitations in monitoring software. The manufacturing tolerances for RFA/NGF fuel and MOX fuel is implicitly included in the  $F_Q$  LOCA surveillance limits ( $M_Q$ ).

TILT = Peaking penalty that accounts for allowable quadrant power tilt ratio of 1.02. (TILT = 1.035)

$$2.6.6 \quad [F_Q^L(X,Y,Z)]^{RPS} = \frac{F_Q^D(X,Y,Z) * M_Q(X,Y,Z)}{UMT * MT * TILT}$$

where:

$[F_Q^L(X,Y,Z)]^{RPS}$  = Cycle dependent maximum allowable design peaking factor that ensures that the  $F_Q(X,Y,Z)$  Centerline Fuel Melt (CFM) limit is not exceeded for operation within the AFD, RIL, and



## Catawba 1 Cycle 16 Core Operating Limits Report

QPTR limits.  $[F_Q^L(X,Y,Z)]^{RPS}$  includes allowances for calculational and measurement uncertainties.

$F_Q^D(X,Y,Z)$  = Design power distributions for  $F_Q$ .  $F_Q^D(X,Y,Z)$  is provided in Appendix Table A-1 for normal operating conditions and in Appendix Table A-4 for power escalation testing during initial startup operations.

$M_C(X,Y,Z)$  = Margin remaining to the CFM limit in core location X,Y,Z from the transient power distribution.  $M_C(X,Y,Z)$  is provided in Appendix Table A-2 for normal operating conditions and in Appendix Table A-5 for power escalation testing during initial startup operations.

MT = Engineering Hot Channel Factor. (MT = 1.031). The more conservative of the manufacturing tolerances for RFA/NGF fuel (3%) or MOX fuel (3.1%) is used when comparing against the  $F_Q$  RPS surveillance limit due to input limitations in monitoring software. The manufacturing tolerances for RFA/NGF fuel and MOX fuel is implicitly included in the  $F_Q$  RPS surveillance limits ( $M_C$ ).

TILT = Peaking penalty that accounts for allowable quadrant power tilt ratio of 1.02. (TILT = 1.035)

### 2.6.7 KSLOPE = 0.0725

where:

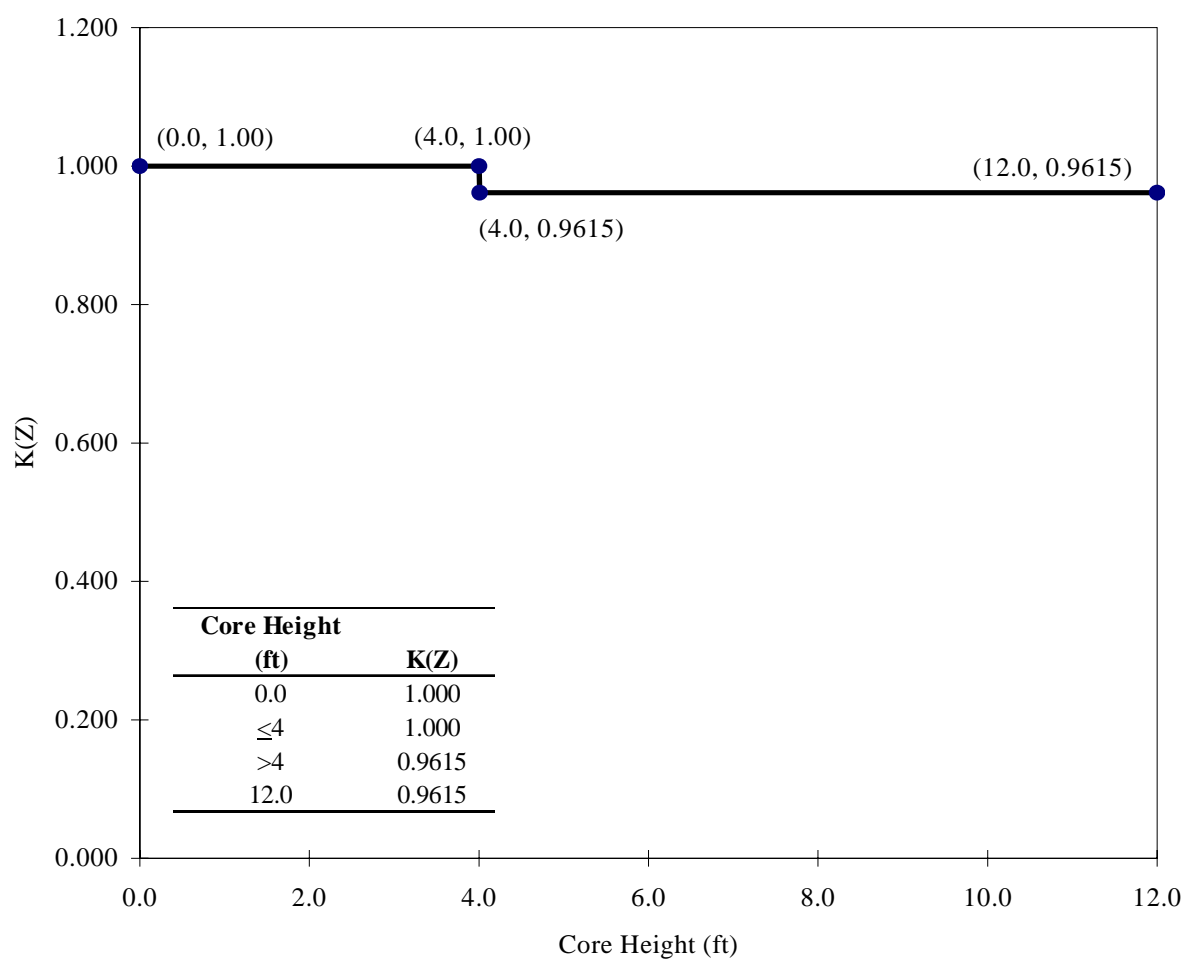
KSLOPE = the adjustment to the  $K_1$  value from OTAT trip setpoint required to compensate for each 1% that  $F_Q^M(X,Y,Z)$  exceeds  $F_Q^L(X,Y,Z)^{RPS}$ .

### 2.6.8 $F_Q(X,Y,Z)$ Penalty Factors for Technical Specification Surveillances 3.2.1.2 and 3.2.1.3 are provided in Table 2.

## Catawba 1 Cycle 16 Core Operating Limits Report

**Figure 4**

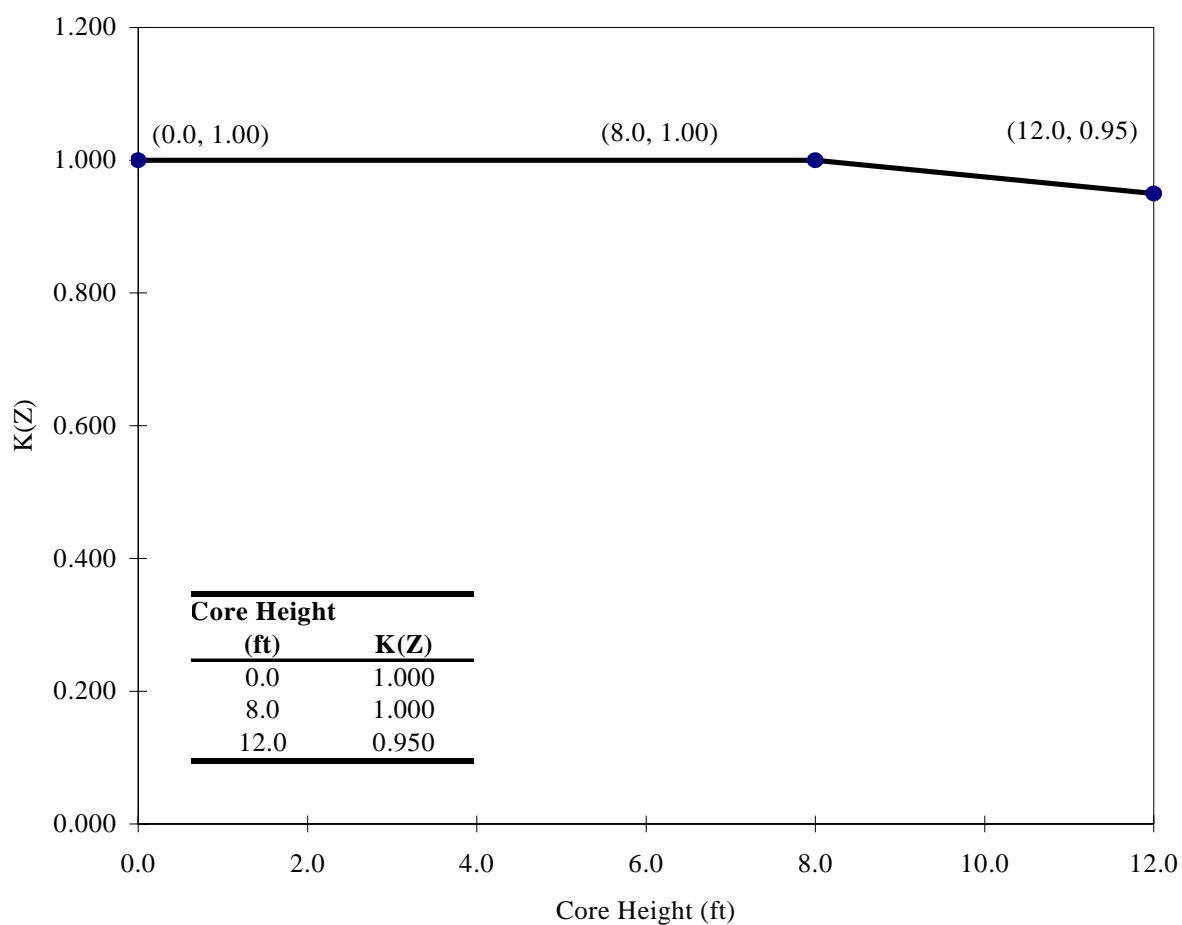
**$K(Z)$ , Normalized  $F_Q(X,Y,Z)$  as a Function of Core Height  
for RFA and NGF Fuel**



## Catawba 1 Cycle 16 Core Operating Limits Report

Figure 5

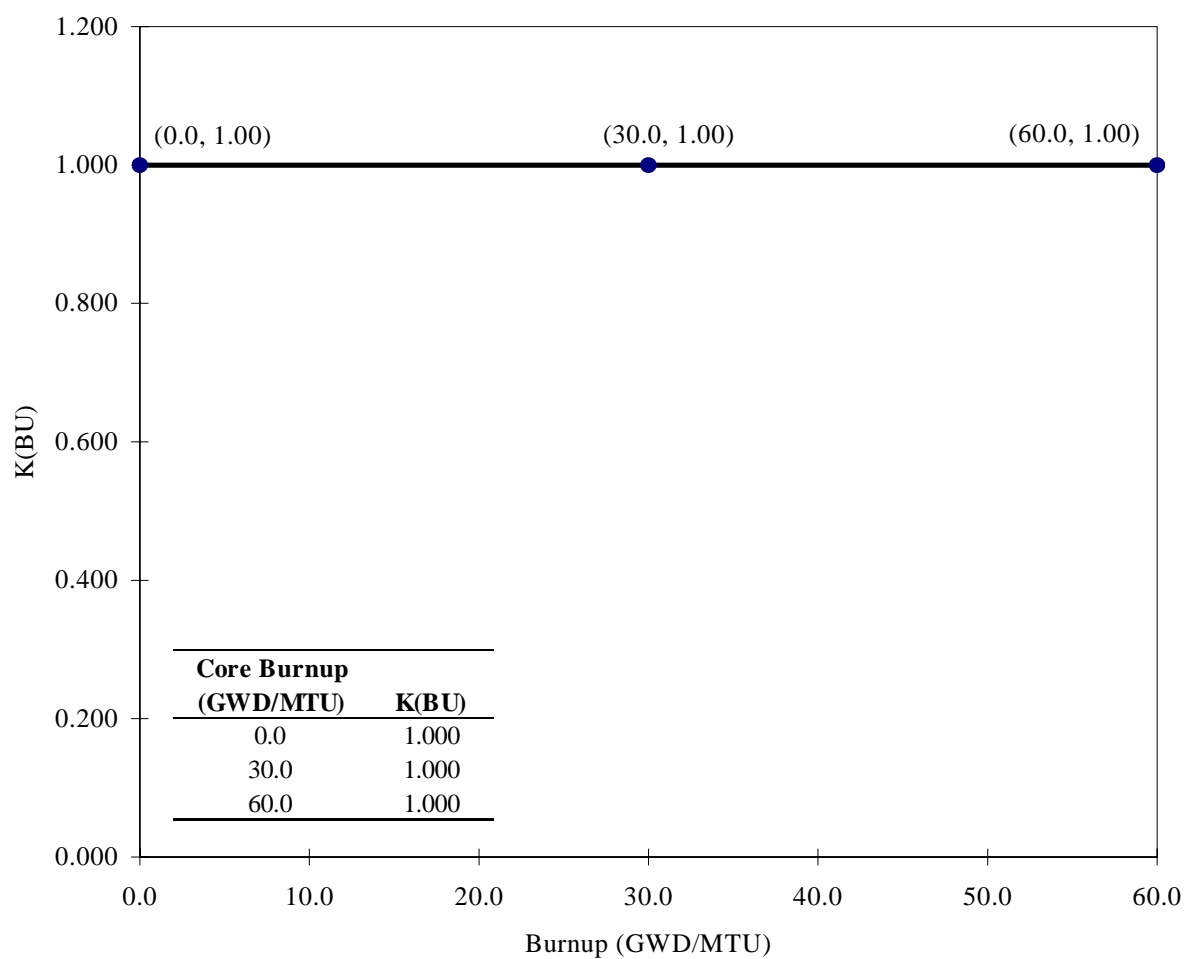
**$K(Z)$ , Normalized  $F_Q(X,Y,Z)$  as a Function of Core Height  
for MOX Fuel**



# Catawba 1 Cycle 16 Core Operating Limits Report

Figure 6

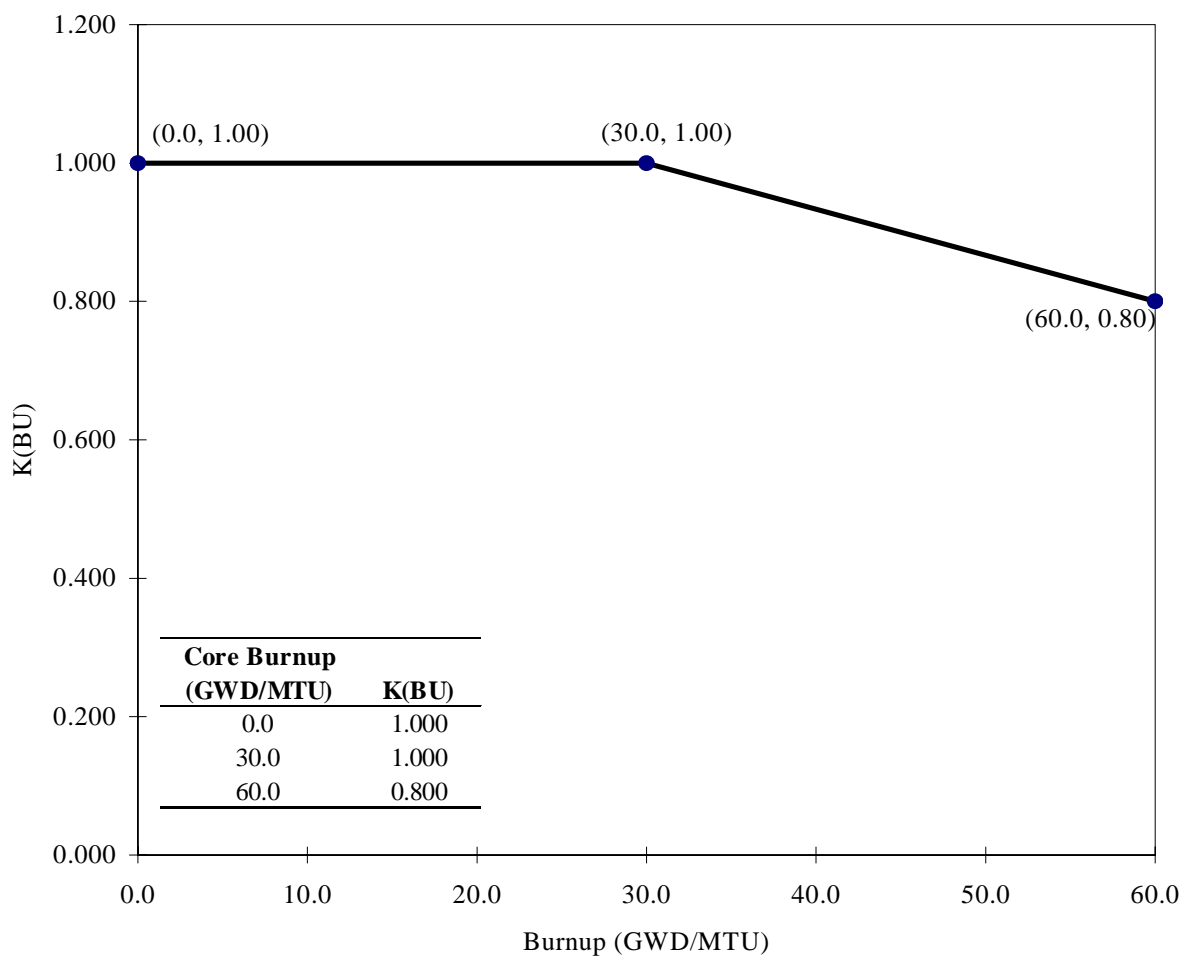
**K(BU), Normalized  $F_Q(X,Y,Z)$  as a Function of Burnup  
for RFA and NGF Fuel**



## Catawba 1 Cycle 16 Core Operating Limits Report

Figure 7

**K(BU), Normalized  $F_Q(X,Y,Z)$  as a Function of Burnup  
for MOX Fuel**



## Catawba 1 Cycle 16 Core Operating Limits Report

**Table 2**

**$F_Q(X,Y,Z)$  and  $F_{\Delta H}(X,Y)$  Penalty Factors  
For Tech Spec Surveillances 3.2.1.2, 3.2.1.3 and 3.2.2.2**

<b>Burnup (EFPD)</b>	<b><math>F_Q(X,Y,Z)</math> Penalty Factor(%)</b>	<b><math>F_{\Delta H}(X,Y)</math> Penalty Factor (%)</b>
4	2.00	2.00
12	2.00	2.00
25	2.00	2.00
50	2.00	2.00
75	2.00	2.00
100	2.00	2.00
125	2.00	2.00
150	2.00	2.00
175	2.00	2.00
200	2.00	2.00
225	2.00	2.00
250	2.00	2.00
275	2.00	2.00
300	2.00	2.00
325	2.00	2.00
350	2.00	2.00
375	2.00	2.00
400	2.00	2.00
425	2.00	2.00
450	2.00	2.00
475	2.00	2.00
480	2.00	2.00
505	2.00	2.00
509	2.00	2.00
524	2.00	2.00

**Note:** Linear interpolation is adequate for intermediate cycle burnups.  
All cycle burnups outside the range of the table shall use a 2% penalty factor for both  $F_Q(X,Y,Z)$  and  $F_{\Delta H}(X,Y)$  for compliance with the Tech Spec Surveillances 3.2.1.2, 3.2.1.3 and 3.2.2.2.

## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.7 Nuclear Enthalpy Rise Hot Channel Factor - $F_{\Delta H}(X,Y)$ (TS 3.2.2)

The  $F_{\Delta H}$  steady-state limits referred to in Technical Specification 3.2.2 are defined by the following relationship.

$$2.7.1 \quad [F_{\Delta H}^L(X,Y)]^{LCO} = \text{MARP}(X,Y) * \left[ 1.0 + \frac{1}{\text{RRH}} * (1.0 - P) \right]$$

where:

$[F_{\Delta H}^L(X,Y)]^{LCO}$  is defined as the steady-state, maximum allowed radial peak and includes allowances for calculation/measurement uncertainty.

$\text{MARP}(X,Y) =$  Cycle-specific operating limit Maximum Allowable Radial Peaks.  $\text{MARP}(X,Y)$  radial peaking limits are provided in Table 3.

$$P = \frac{\text{Thermal Power}}{\text{Rated Thermal Power}}$$

$\text{RRH} =$  Thermal Power reduction required to compensate for each 1% that the measured radial peak,  $F_{\Delta H}^M(X,Y)$ , exceeds the limit.

$$(\text{RRH} = 3.34, \quad 0.0 < P \leq 1.0)$$

The following parameters are required for core monitoring per the Surveillance requirements of Technical Specification 3.2.2.

$$2.7.2 \quad [F_{\Delta H}^L(X,Y)]^{SURV} = \frac{F_{\Delta H}^D(X,Y) * M_{\Delta H}(X,Y)}{\text{UMR} * \text{TILT}}$$

where:

$[F_{\Delta H}^L(X,Y)]^{SURV} =$  Cycle dependent maximum allowable design peaking factor that ensures that the  $F_{\Delta H}(X,Y)$  limit is not exceeded for operation within the AFD, RIL, and QPTR limits.  $F_{\Delta H}^L(X,Y)^{SURV}$  includes allowances for calculational and measurement uncertainty.

$F_{\Delta H}^D(X,Y) =$  Design power distribution for  $F_{\Delta H}$ .  $F_{\Delta H}^D(X,Y)$  is provided in Appendix Table A-3 for normal operation and in Appendix Table A-6 for power escalation testing during initial startup operation.

## Catawba 1 Cycle 16 Core Operating Limits Report

$M_{\Delta H}(X,Y)$  = The margin remaining in core location X,Y relative to the Operational DNB limits in the transient power distribution.  $M_{\Delta H}(X,Y)$  is provided in Appendix Table A-3 for normal operation and in Appendix Table A-6 for power escalation testing during initial startup operation.

UMR = Uncertainty value for measured radial peaks. UMR is set to 1.0 since a factor of 1.04 is implicitly included in the variable  $M_{\Delta H}(X,Y)$ .

TILT = Peaking penalty that accounts for allowable quadrant power tilt ratio of 1.02. (TILT = 1.035)

### 2.7.3 RRH = 3.34

where:

RRH = Thermal Power reduction required to compensate for each 1% that the measured radial peak,  $F_{\Delta H}^M(X,Y)$  exceeds its limit. ( $0 < P \leq 1.0$ )

### 2.7.4 TRH = 0.04

where:

TRH = Reduction in OTΔT  $K_1$  setpoint required to compensate for each 1% that the measured radial peak,  $F_{\Delta H}(X,Y)$  exceeds its limit.

2.7.5  $F_{\Delta H}(X,Y)$  Penalty Factors for Technical Specification Surveillance 3.2.2.2 are provided in Table 2.

## 2.8 Axial Flux Difference – AFD (TS 3.2.3)

2.8.1 The Axial Flux Difference (AFD) Limits are provided in Figure 8.



## Catawba 1 Cycle 16 Core Operating Limits Report

**Table 3**  
**Maximum Allowable Radial Peaks (MARPS)**

RFA Fuel MARPs  
100% Full Power

Core Height (ft)	Axial Peak												
	1.05	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	3.0	3.25
0.12	1.847	1.882	1.947	1.992	1.974	2.107	2.050	2.009	1.933	1.863	1.778	1.315	1.246
1.20	1.843	1.879	1.938	1.992	1.974	2.107	2.019	1.978	1.901	1.831	1.785	1.301	1.224
2.40	1.846	1.876	1.931	1.981	1.974	2.084	1.994	1.952	1.876	1.805	1.732	1.476	1.462
3.60	1.843	1.869	1.920	1.964	1.974	2.065	1.988	1.951	1.874	1.801	1.701	1.467	1.453
4.80	1.838	1.868	1.906	1.945	1.974	2.006	1.945	1.922	1.862	1.800	1.718	1.329	1.288
6.00	1.834	1.856	1.891	1.921	1.946	1.934	1.880	1.863	1.802	1.747	1.673	1.383	1.317
7.20	1.828	1.845	1.871	1.893	1.887	1.872	1.809	1.787	1.732	1.681	1.618	1.318	1.277
8.40	1.823	1.829	1.847	1.857	1.816	1.795	1.739	1.722	1.675	1.630	1.551	1.247	1.209
9.60	1.814	1.812	1.809	1.792	1.738	1.724	1.678	1.665	1.621	1.578	1.492	1.191	1.137
10.80	1.798	1.784	1.761	1.738	1.697	1.682	1.626	1.605	1.558	1.512	1.430	1.149	1.096
11.40	1.789	1.765	1.725	1.684	1.632	1.614	1.569	1.557	1.510	1.466	1.392	1.113	1.060

MOX Fuel MARPs  
100% Full Power

Core Height (ft)	Axial Peak												
	1.05	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	3.0	3.25
0.12	1.746	1.777	1.834	1.884	1.925	1.951	1.860	1.803	1.719	1.643	1.568	1.256	1.195
1.20	1.746	1.774	1.826	1.872	1.912	1.931	1.849	1.806	1.724	1.648	1.546	1.207	1.145
2.40	1.743	1.769	1.816	1.854	1.889	1.906	1.827	1.790	1.719	1.653	1.539	1.171	1.117
3.60	1.740	1.763	1.802	1.836	1.860	1.849	1.797	1.777	1.719	1.653	1.559	1.182	1.107
4.80	1.736	1.755	1.787	1.816	1.802	1.794	1.741	1.724	1.675	1.623	1.574	1.204	1.151
6.00	1.732	1.747	1.770	1.792	1.751	1.737	1.688	1.672	1.624	1.578	1.526	1.287	1.248
7.20	1.727	1.738	1.752	1.741	1.696	1.683	1.634	1.618	1.574	1.531	1.477	1.244	1.206
8.40	1.723	1.725	1.731	1.690	1.641	1.627	1.580	1.567	1.525	1.484	1.429	1.207	1.167
9.60	1.712	1.709	1.685	1.638	1.589	1.574	1.529	1.520	1.481	1.442	1.386	1.170	1.129
10.80	1.701	1.687	1.640	1.590	1.540	1.524	1.482	1.472	1.435	1.401	1.344	1.147	1.109
12.00	1.694	1.670	1.619	1.569	1.518	1.505	1.462	1.453	1.417	1.386	1.334	1.135	1.096

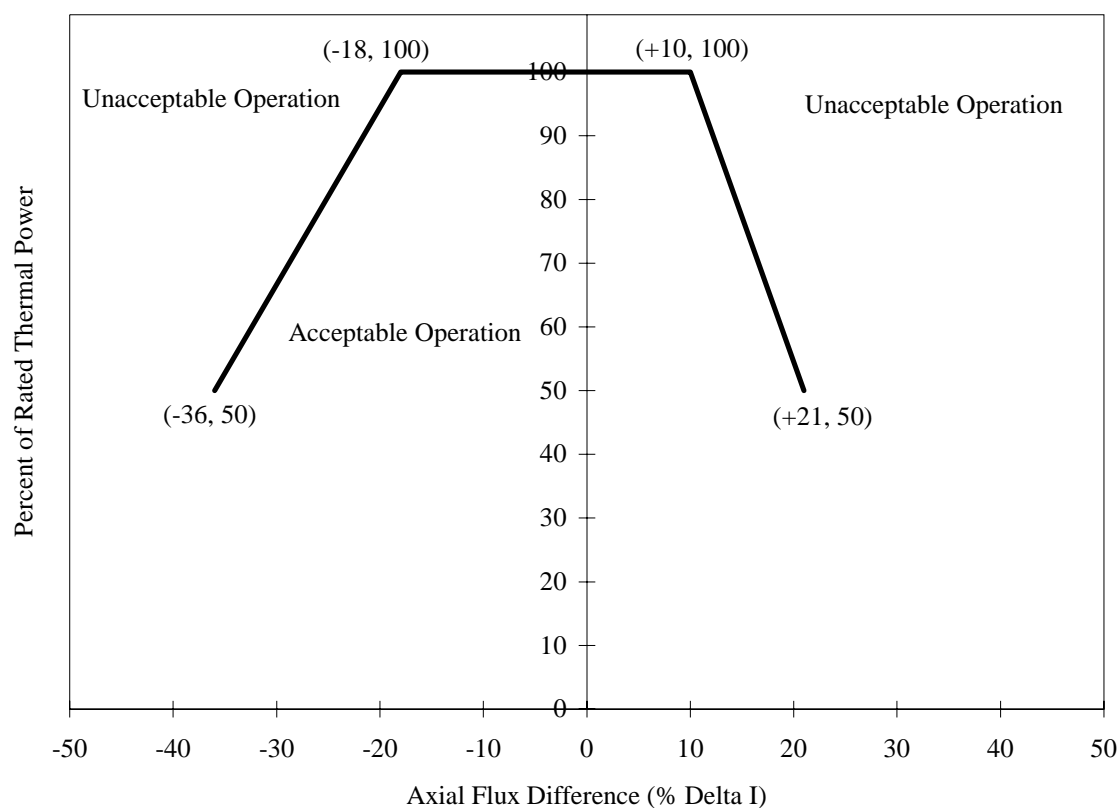
NGF Fuel MARPs  
100% Full Power

Core Height (ft)	Axial Peak						
	1.05	1.2	1.4	1.6	1.8	2.1	3.25
0.12	1.771	1.871	1.805	2.049	1.931	1.786	1.266
2.40	1.760	1.853	1.805	1.993	1.870	1.724	1.442
4.80	1.757	1.824	1.805	1.884	1.809	1.693	1.261
7.20	1.745	1.784	1.805	1.735	1.659	1.553	1.227
9.60	1.729	1.723	1.652	1.587	1.527	1.402	1.059
11.40	1.707	1.642	1.550	1.477	1.416	1.304	1.003

## Catawba 1 Cycle 16 Core Operating Limits Report

**Figure 8**

### Percent of Rated Thermal Power Versus Percent Axial Flux Difference Limits



**NOTE:** Compliance with Technical Specification 3.2.1 may require more restrictive AFD limits. Refer to the Unit 1 ROD manual for operational AFD limits.

## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.9 Reactor Trip System Instrumentation Setpoints (TS 3.3.1) Table 3.3.1-1

#### 2.9.1 Overtemperature $\Delta T$ Setpoint Parameter Values

<u>Parameter</u>	<u>Nominal Value</u>
Nominal $T_{avg}$ at RTP	$T' \leq 585.1 \text{ }^{\circ}\text{F}$
Nominal RCS Operating Pressure	$P' = 2235 \text{ psig}$
Overtemperature $\Delta T$ reactor trip setpoint	$K_1 = 1.1978$
Overtemperature $\Delta T$ reactor trip heatup setpoint penalty coefficient	$K_2 = 0.03340/^{\circ}\text{F}$
Overtemperature $\Delta T$ reactor trip depressurization setpoint penalty coefficient	$K_3 = 0.001601/\text{psi}$
Time constants utilized in the lead-lag compensator for $\Delta T$	$\tau_1 = 8 \text{ sec.}$ $\tau_2 = 3 \text{ sec.}$
Time constant utilized in the lag compensator for $\Delta T$	$\tau_3 = 0 \text{ sec.}$
Time constants utilized in the lead-lag compensator for $T_{avg}$	$\tau_4 = 22 \text{ sec.}$ $\tau_5 = 4 \text{ sec.}$
Time constant utilized in the measured $T_{avg}$ lag compensator	$\tau_6 = 0 \text{ sec.}$
$f_1(\Delta I)$ "positive" breakpoint	$= 19.0 \text{ } \%\Delta I$
$f_1(\Delta I)$ "negative" breakpoint	$= \text{N/A}^*$
$f_1(\Delta I)$ "positive" slope	$= 1.769 \text{ } \%\Delta T_0 / \%\Delta I$
$f_1(\Delta I)$ "negative" slope	$= \text{N/A}^*$

- \* The  $f_1(\Delta I)$  negative breakpoints and slopes for OT $\Delta T$  are less restrictive than the OP $\Delta T$   $f_2(\Delta I)$  negative breakpoint and slope. Therefore, during a transient which challenges the negative imbalance limits the OP $\Delta T$   $f_2(\Delta I)$  limits will result in a reactor trip before the OT $\Delta T$   $f_1(\Delta I)$  limits are reached. This makes implementation of an OT $\Delta T$   $f_1(\Delta I)$  negative breakpoint and slope unnecessary.

## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.9.2 Overpower $\Delta T$ Setpoint Parameter Values

<u>Parameter</u>	<u>Nominal Value</u>
Nominal $T_{avg}$ at RTP	$T'' \leq 585.1 \text{ }^{\circ}\text{F}$
Overpower $\Delta T$ reactor trip setpoint	$K_4 = 1.0864$
Overpower $\Delta T$ reactor trip penalty	$K_5 = 0.02 \text{ }^{\circ}\text{F}$ for increasing $T_{avg}$ $K_5 = 0.00 \text{ }^{\circ}\text{F}$ for decreasing $T_{avg}$
Overpower $\Delta T$ reactor trip heatup setpoint penalty coefficient (for $T > T''$ )	$K_6 = 0.001179/^{\circ}\text{F}$ for $T > T''$ $K_6 = 0.0 \text{ }^{\circ}\text{F}$ for $T \leq T''$
Time constants utilized in the lead-lag compensator for $\Delta T$	$\tau_1 = 8 \text{ sec.}$ $\tau_2 = 3 \text{ sec.}$
Time constant utilized in the lag compensator for $\Delta T$	$\tau_3 = 0 \text{ sec.}$
Time constant utilized in the measured $T_{avg}$ lag compensator	$\tau_6 = 0 \text{ sec.}$
Time constant utilized in the rate-lag controller for $T_{avg}$	$\tau_7 = 10 \text{ sec.}$
$f_2(\Delta I)$ "positive" breakpoint	$= 35.0 \text{ } \%\Delta I$
$f_2(\Delta I)$ "negative" breakpoint	$= -35.0 \text{ } \%\Delta I$
$f_2(\Delta I)$ "positive" slope	$= 7.0 \text{ } \%\Delta T_0 / \%\Delta I$
$f_2(\Delta I)$ "negative" slope	$= 7.0 \text{ } \%\Delta T_0 / \%\Delta I$

## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.10 Boron Dilution Mitigation System (TS 3.3.9)

#### 2.10.1 Reactor Makeup Water Pump flow rate limits:

<u>Applicable Mode</u>	<u>Limit</u>
Mode 3	$\leq 150$ gpm
Mode 4 or 5	$\leq 70$ gpm

### 2.11 RCS Pressure, Temperature and Flow Limits for DNB (TS 3.4.1)

The RCS pressure, temperature and flow limits for DNB are shown in Table 4.

### 2.12 Accumulators (TS 3.5.1)

#### 2.12.1 Boron concentration limits during modes 1 and 2, and mode 3 with RCS pressure >1000 psi:

<u>Parameter</u>	<u>Limit</u>
Cold Leg Accumulator minimum boron concentration.	2,500 ppm
Cold Leg Accumulator maximum boron concentration.	2,975 ppm

### 2.13 Refueling Water Storage Tank - RWST (TS 3.5.4)

#### 2.13.1 Boron concentration limits during modes 1, 2, 3, and 4:

<u>Parameter</u>	<u>Limit</u>
Refueling Water Storage Tank minimum boron concentration.	2,700 ppm
Refueling Water Storage Tank maximum boron concentration.	2,975 ppm

## Catawba 1 Cycle 16 Core Operating Limits Report

**Table 4**

Reactor Coolant System DNB Parameters

PARAMETER	INDICATION	No. Operable CHANNELS	LIMITS
1. Indicated RCS Average Temperature	meter	4	$\leq 587.2$ °F
	meter	3	$\leq 586.9$ °F
	computer	4	$\leq 587.7$ °F
	computer	3	$\leq 587.5$ °F
2. Indicated Pressurizer Pressure	meter	4	$\geq 2219.8$ psig
	meter	3	$\geq 2222.1$ psig
	computer	4	$\geq 2215.8$ psig
	computer	3	$\geq 2217.5$ psig
3. RCS Total Flow Rate			$\geq 388,000$ gpm

## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.14 Spent Fuel Pool Boron Concentration (TS 3.7.15)

**2.14.1** Minimum boron concentration limit for the spent fuel pool. Applicable when fuel assemblies are stored in the spent fuel pool.

<u>Parameter</u>	<u>Limit</u>
Spent fuel pool minimum boron concentration.	2,700 ppm

### 2.15 Refueling Operations - Boron Concentration (TS 3.9.1)

**2.15.1** Minimum boron concentration limit for the filled portions of the Reactor Coolant System, refueling canal, and refueling cavity for mode 6 conditions. The minimum boron concentration limit and plant refueling procedures ensure that the  $K_{eff}$  of the core will remain within the mode 6 reactivity requirement of  $K_{eff} \leq 0.95$ .

<u>Parameter</u>	<u>Limit</u>
Minimum Boron concentration of the Reactor Coolant System, the refueling canal, and the refueling cavity.	2,700 ppm

## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.16 Standby Shutdown System - Standby Makeup Pump Water Supply - (SLC-16.7-9.3)

**2.16.1** Minimum boron concentration limit for the spent fuel pool. Applicable for modes 1, 2, and 3.

<u>Parameter</u>	<u>Limit</u>
Spent fuel pool minimum boron concentration for surveillance SLC-16.7-9.3.	2,700 ppm

### 2.17 Borated Water Source – Shutdown (SLC 16.9-11)

**2.17.1** Volume and boron concentrations for the Boric Acid Tank (BAT) and the Refueling Water Storage Tank (RWST) during Mode 4 with any RCS cold leg temperature  $\leq 210^{\circ}\text{F}$ , and Modes 5 and 6.

<u>Parameter</u>	<u>Limit</u>
Boric Acid Tank minimum boron concentration	7,000 ppm
Volume of 7,000 ppm boric acid solution required to maintain SDM at 68°F	2000 gallons
Boric Acid Tank Minimum Shutdown Volume (Includes the additional volumes listed in SLC 16.9-11)	13,086 gallons (14.9%)

**NOTE: When cycle burnup is > 500 EFPD, Figure 9 may be used to determine the required Boric Acid Tank Minimum Level.**

Refueling Water Storage Tank minimum boron concentration	2,700 ppm
Volume of 2,700 ppm boric acid solution required to maintain SDM at 68 °F	7,000 gallons
Refueling Water Storage Tank Minimum Shutdown Volume (Includes the additional volumes listed in SLC 16.9-11)	48,500 gallons (8.7%)



## Catawba 1 Cycle 16 Core Operating Limits Report

### 2.18 Borated Water Source - Operating (SLC 16.9-12)

**2.18.1** Volume and boron concentrations for the Boric Acid Tank (BAT) and the Refueling Water Storage Tank (RWST) during Modes 1, 2, and 3 and Mode 4 with all RCS cold leg temperatures > 210°F.

<u>Parameter</u>	<u>Limit</u>
Boric Acid Tank minimum boron concentration	7,000 ppm
Volume of 7,000 ppm boric acid solution required to maintain SDM at 210°F	13,500 gallons
Boric Acid Tank Minimum Shutdown Volume (Includes the additional volumes listed in SLC 16.9-12)	25,200 gallons (45.8%)

**NOTE: When cycle burnup is > 500 EFPD, Figure 9 may be used to determine the required Boric Acid Tank Minimum Level.**

Refueling Water Storage Tank minimum boron concentration	2,700 ppm
Volume of 2,700 ppm boric acid solution required to maintain SDM at 210°F	57,107 gallons
Refueling Water Storage Tank Minimum Shutdown Volume (Includes the additional volumes listed in SLC 16.9-12)	98,607 gallons (22.0%)

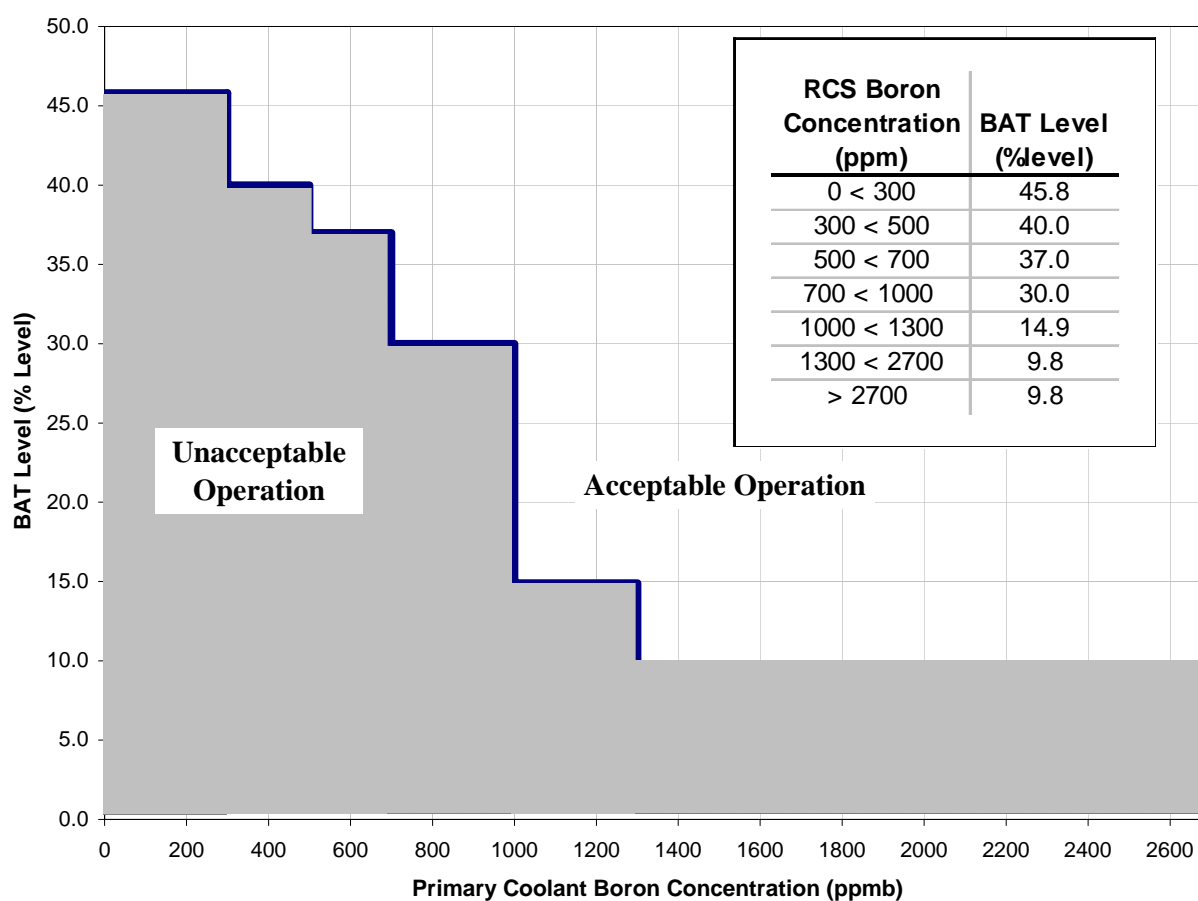
## Catawba 1 Cycle 16 Core Operating Limits Report

**Figure 9**

### Boric Acid Storage Tank Indicated Level Versus Primary Coolant Boron Concentration

(Valid When Cycle Burnup is > 500 EFPD)

This figure includes additional volumes listed in SLC 16.9-11 and 16.9-12



## **Catawba 1 Cycle 16 Core Operating Limits Report**

### **Appendix A**

#### **Power Distribution Monitoring Factors**

Appendix A contains power distribution monitoring factors used in Technical Specification Surveillance. Due to the size of the monitoring factor data, Appendix A is controlled electronically within Duke and is not included in the Duke internal copies of the COLR. The Catawba Reactor and Electrical Systems Engineering Section controls this information via computer files and should be contacted if there is a need to access this information.

Appendix A is included in the COLR copy transmitted to the NRC.