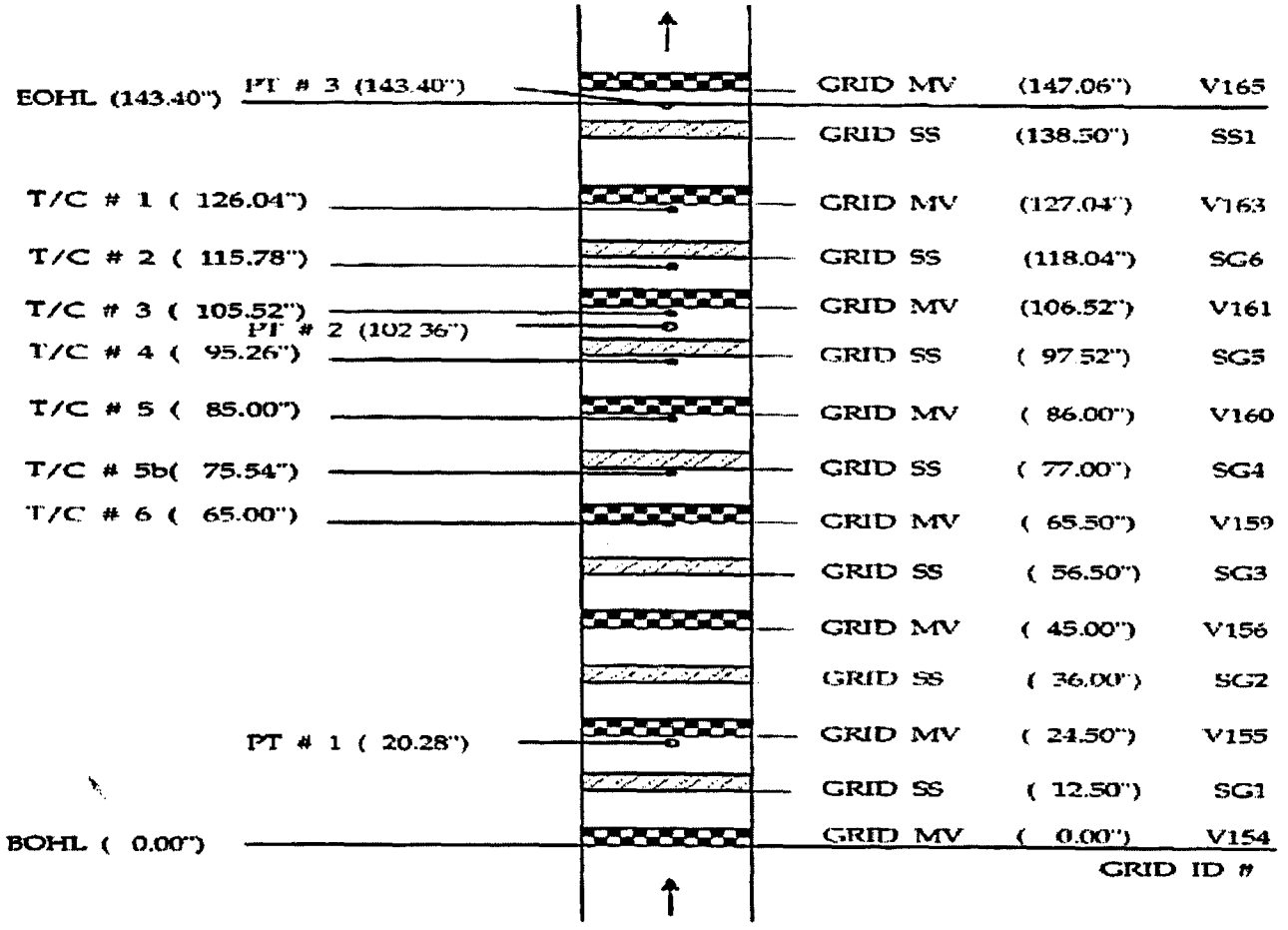
Demonstration and Estimation of Conservatism of the Application of a

Lower Limit Quality Using CHF Test Data

NRC Review Visit, Correlation Application at Qualities Below the Lower Quality Limit

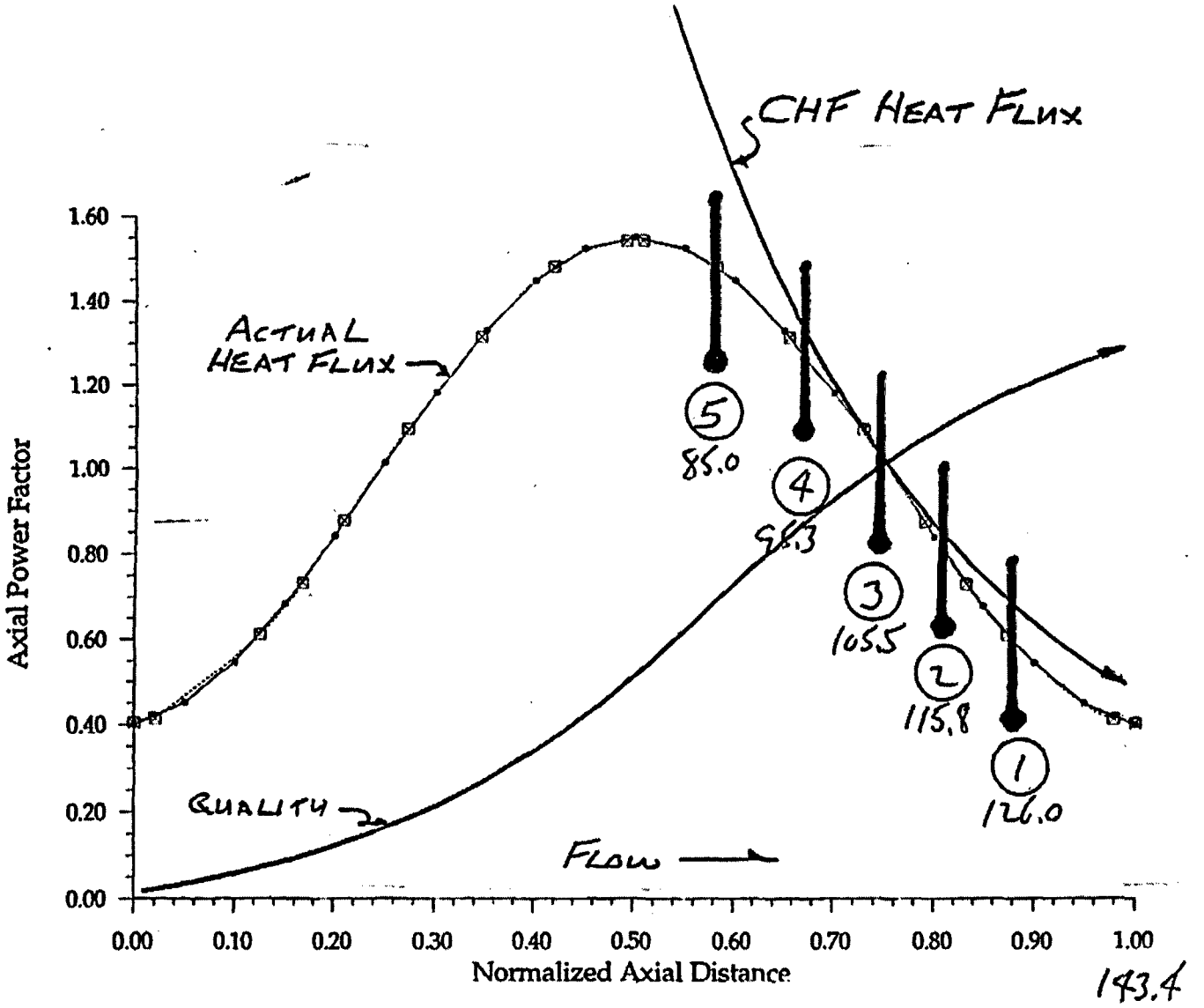
FRAMATOME ANP

Figure 2 Axial Geometry – Framatome ANP Test No 49.0



MV = Mixing Vane
SS = Simple Support

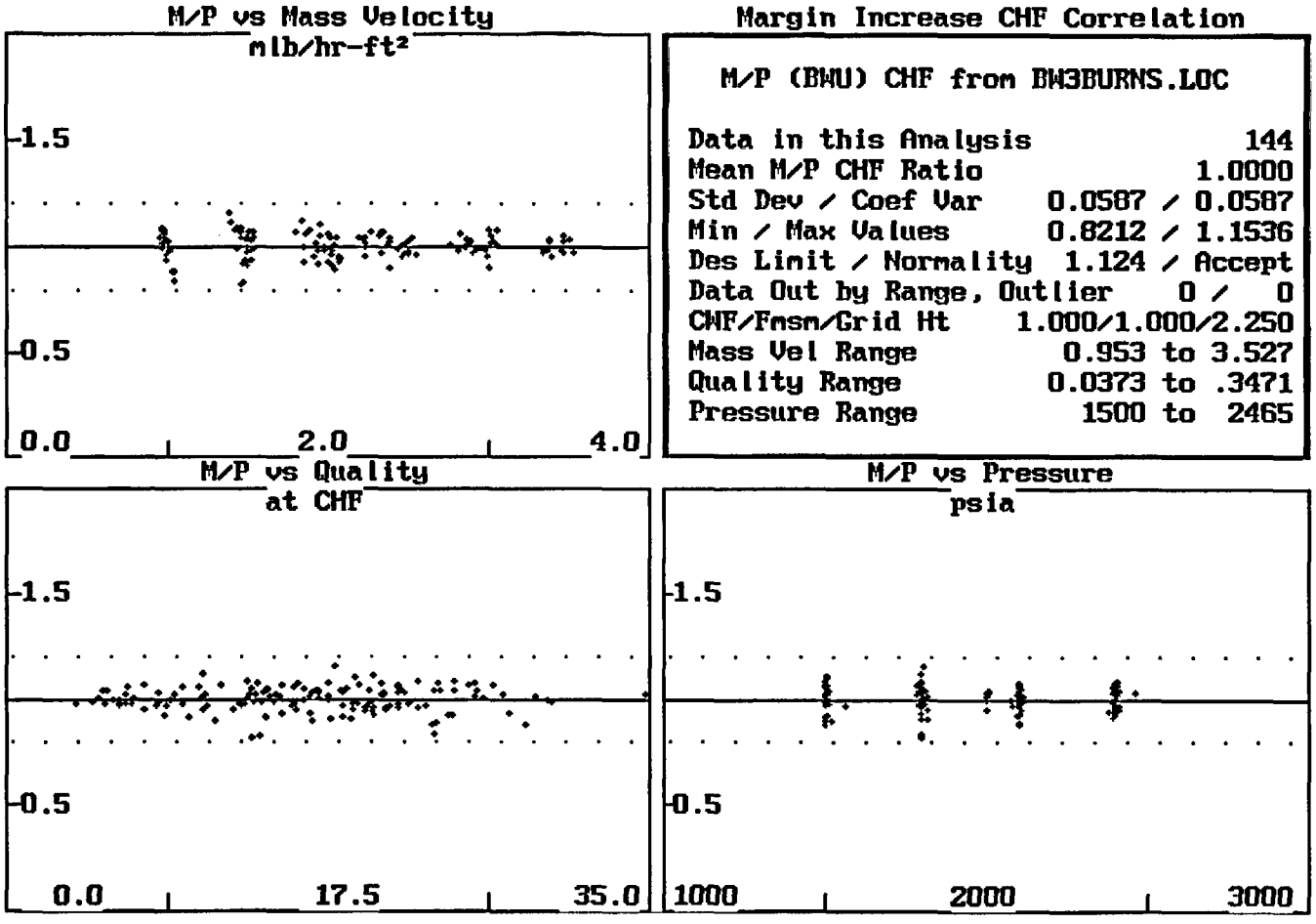
F490AXL.CDR



NRC Review Visit, Correlation Application at Qualities Below the Lower Quality Limit

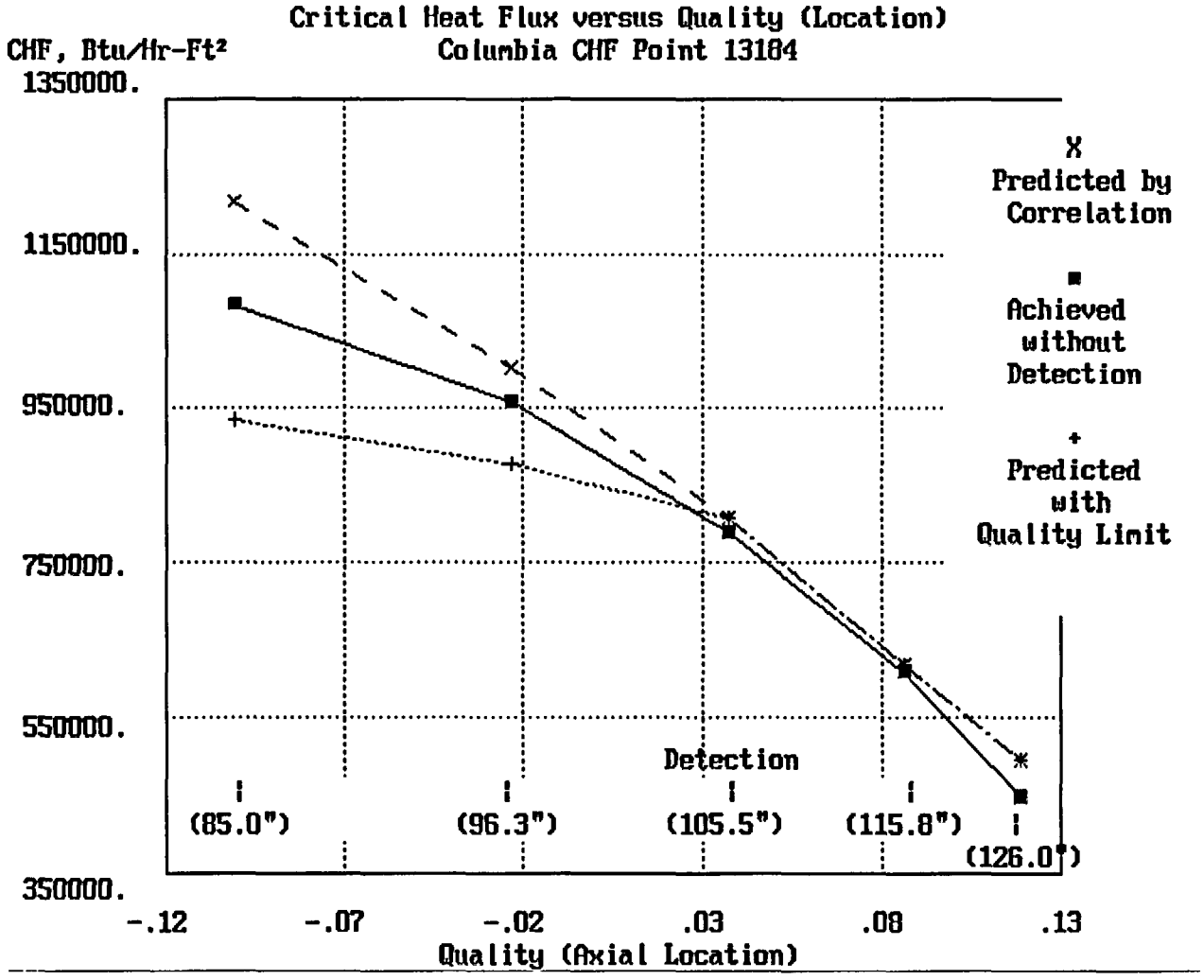
A

FRAMATOME ANP



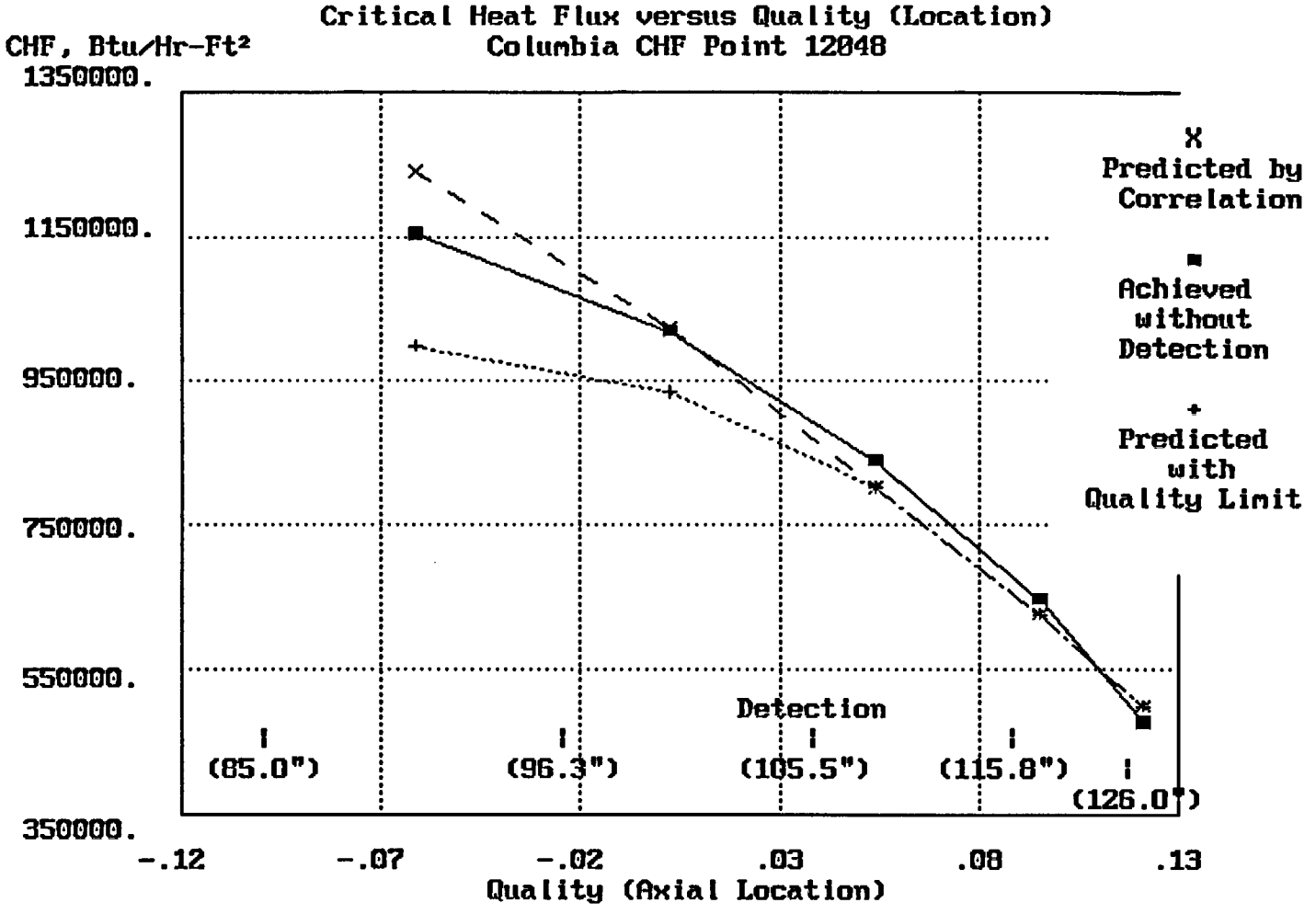
NRC Review Visit, Correlation Application at Qualities Below the Lower Quality Limit

FRAMATOME ANP



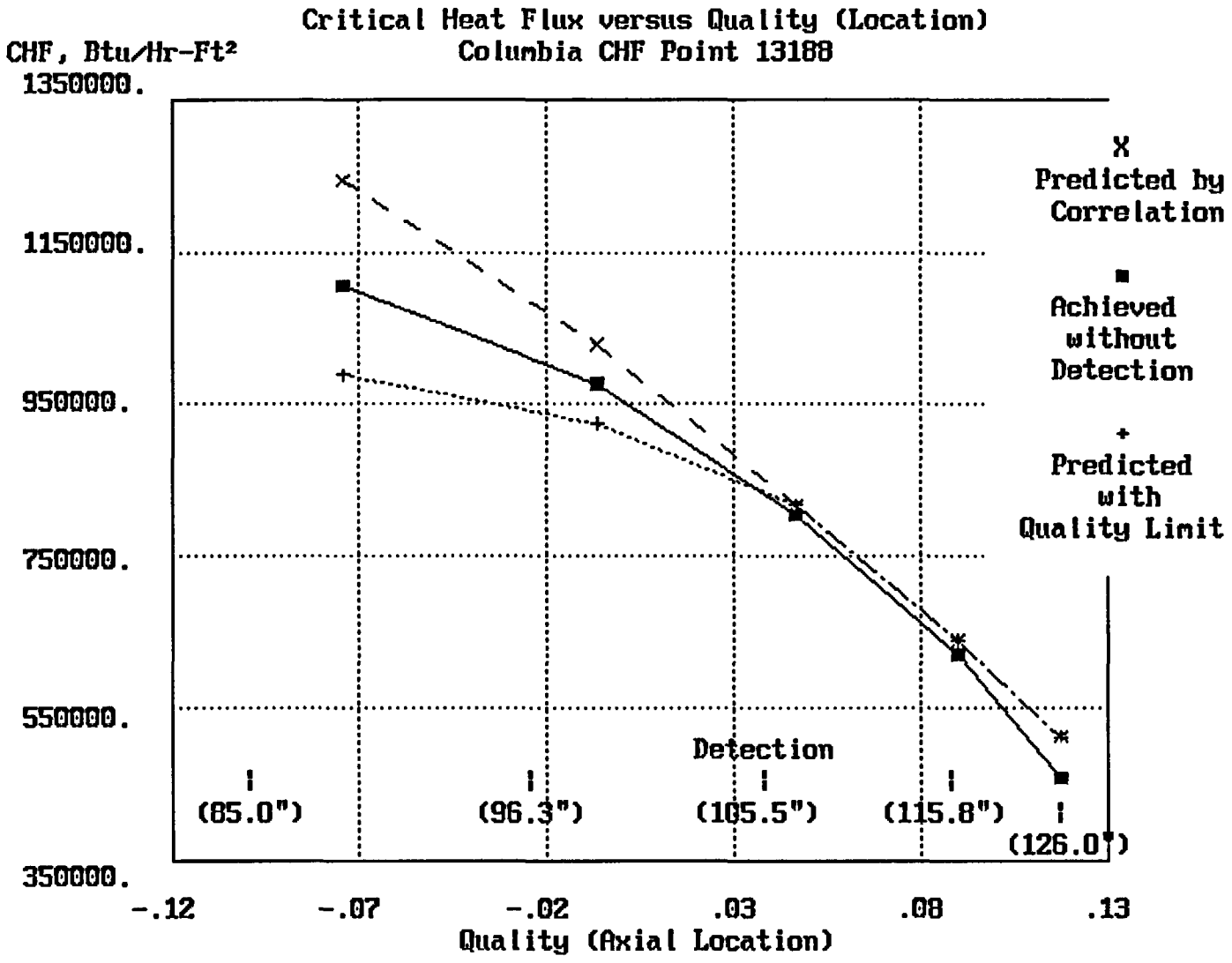
NRC Review Visit, Correlation Application at Qualities Below the Lower Quality Limit

FRAMATOME ANP



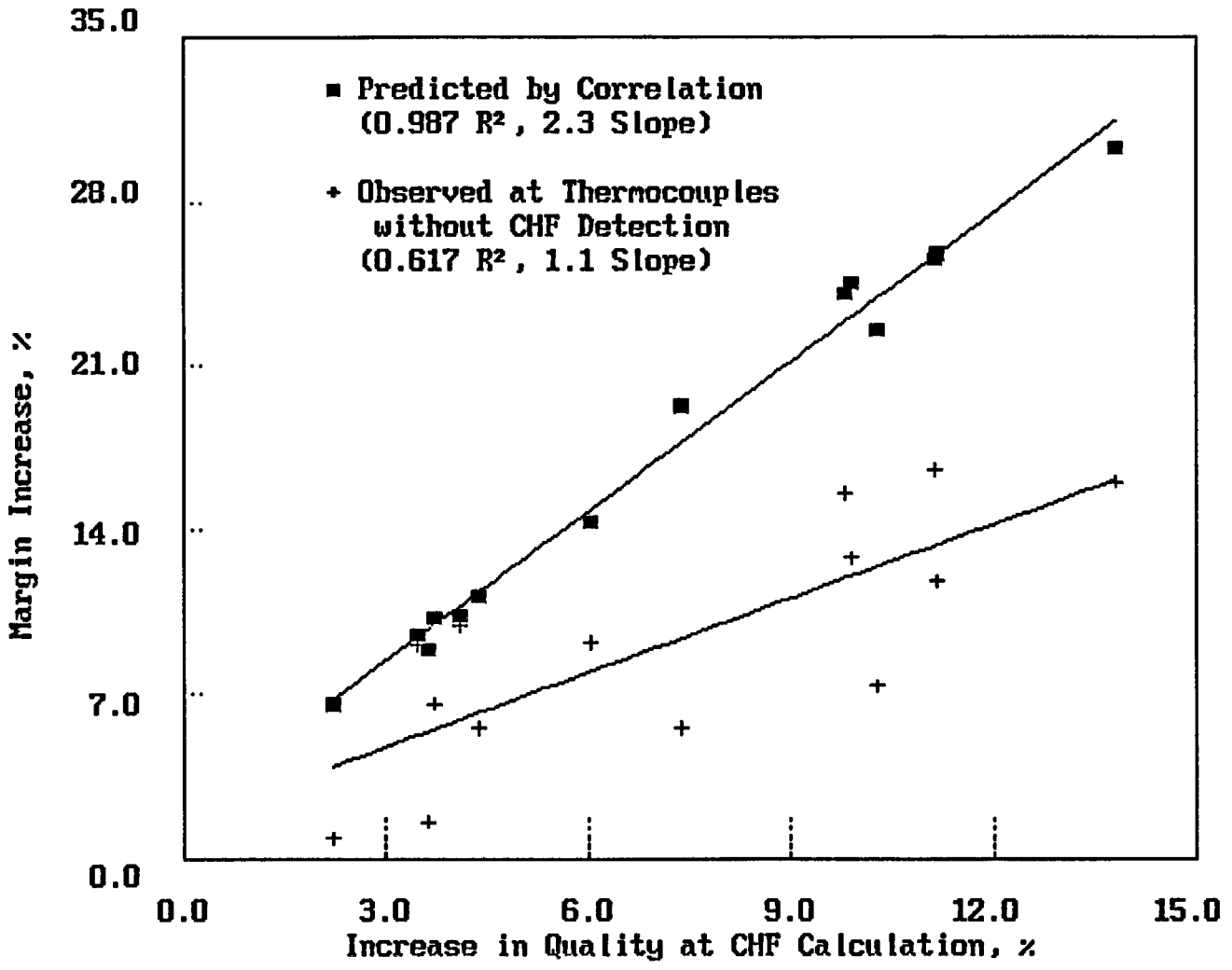
NRC Review Visit, Correlation Application at Qualities Below the Lower Quality Limit

FRAMATOME ANP



NRC Review Visit, Correlation Application at Qualities Below the Lower Quality Limit

FRAMATOME ANP

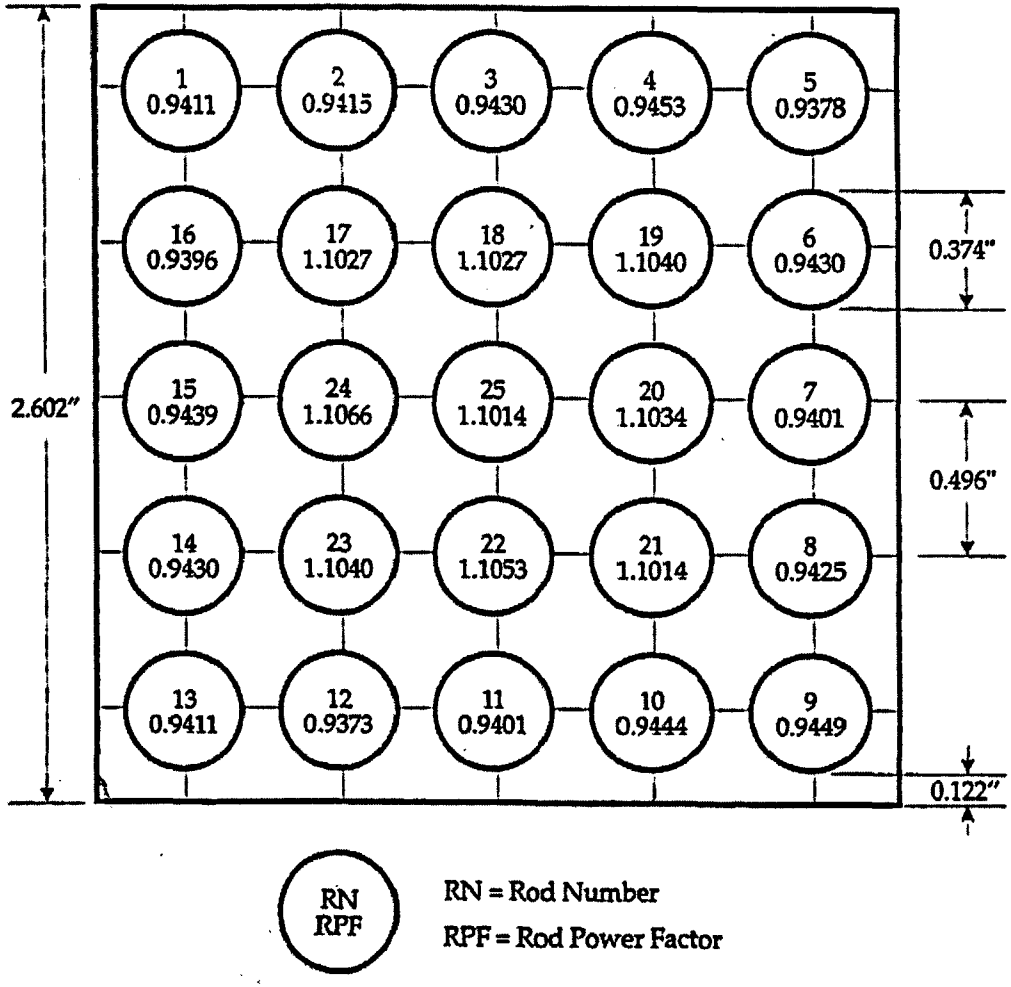


NRC Review Visit, Correlation Application at Qualities Below the Lower Quality Limit

FRAMATOME ANP

Figure 1 Radial Geometry Framatome ANP Test No. 49.0

Flow Area = 0.027944 Sqft
Heated Area = 29.2515 Sqft



F490RAD.CDR

Reload Analyses for CR-3 Cycle 14 Using the BHTP CHF Correlation

General Analysis Process

Impact of Utilizing the Conservative CHF Calculation Adjustment for Local Coolant Qualities Less than the Lower Quality Applicability Range Stated in the BHTP Topical Report

Margin Remaining in the Analyses

NRC Review Visit

October 2003

DNB Analysis Process

- Set Plant Operating Conditions

  -includes Design Peaking (1.800 Radial with a Symmetric 1.65 Axial Peak)

- Set DNBR Criteria Basis

  - CHF Limit (1.132 BHTP)
  - Statistical Design Limit [ ]
  - Thermal Design Limit [ ]

DNB Analysis Process

- Develop DNB-based Pressure-Temperature Safety Limits

  -Steady-state evaluation at the TDL

- Generate Reactor Protection System MAP Limits

  -Combinations of Radial & Axial Peaks with Equivalent MDNBR (TDL)

- Evaluate Limiting DNB Events

  - 1 Pump Coastdown
  - 4 Pump Coastdown
  - Locked Rotor

- Generate Operating Limit MAPs

  - Based on 4 Pump Coastdown (most limiting Condition I/II event)

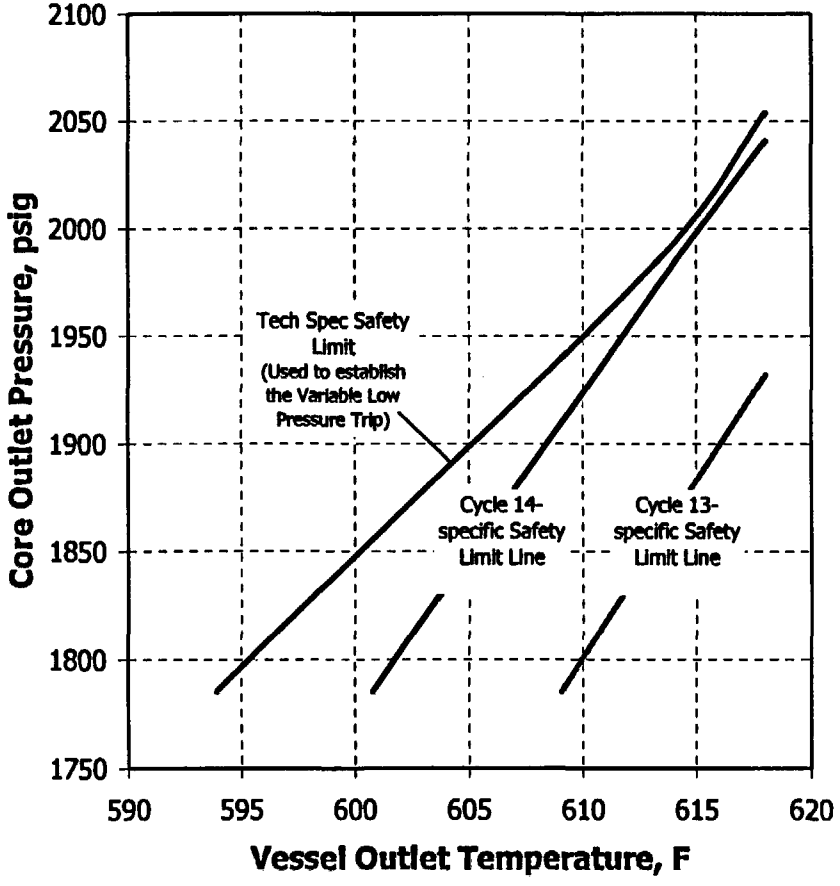
Thermal Design Limit Basis for CR-3 Cycle 14 Using the BHTP Correlation

DNB Margin Within the Thermal Design Limit (TDL) for CR-3 Cycle 14

The DNB-based Pressure Temperature Safety Limit Line has Margin to the Tech Spec Safety Limit

Figure 2

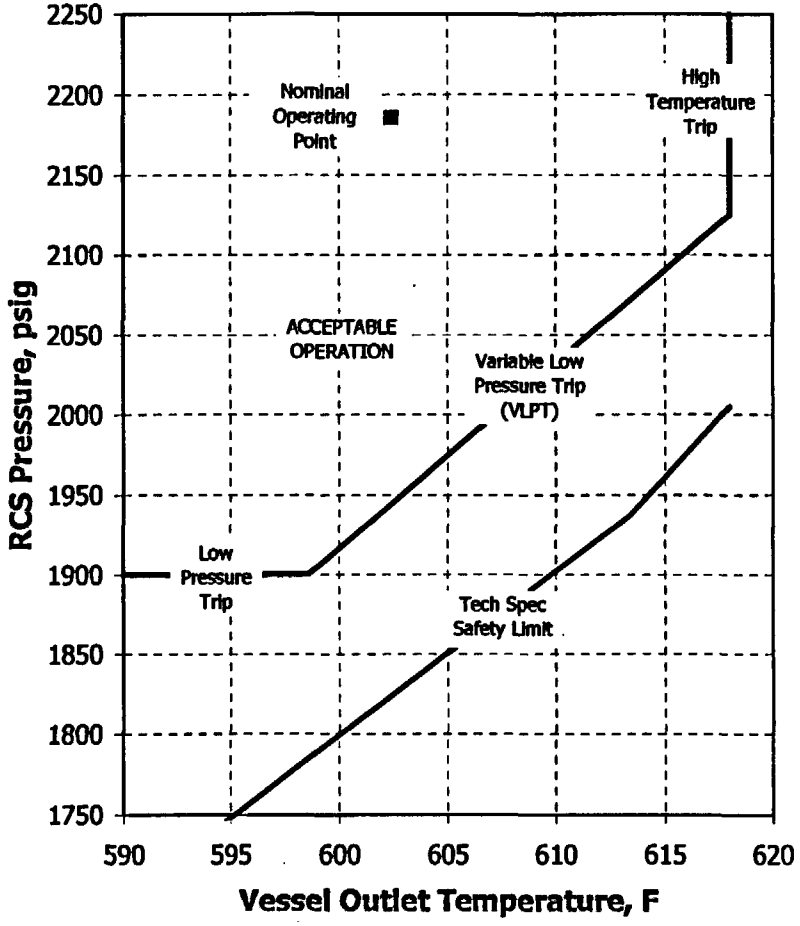
Cycle 13-specific and Cycle 14-specific DNB-Based Safety Limit Lines Compared to the Conservative Tech Spec Safety Limit



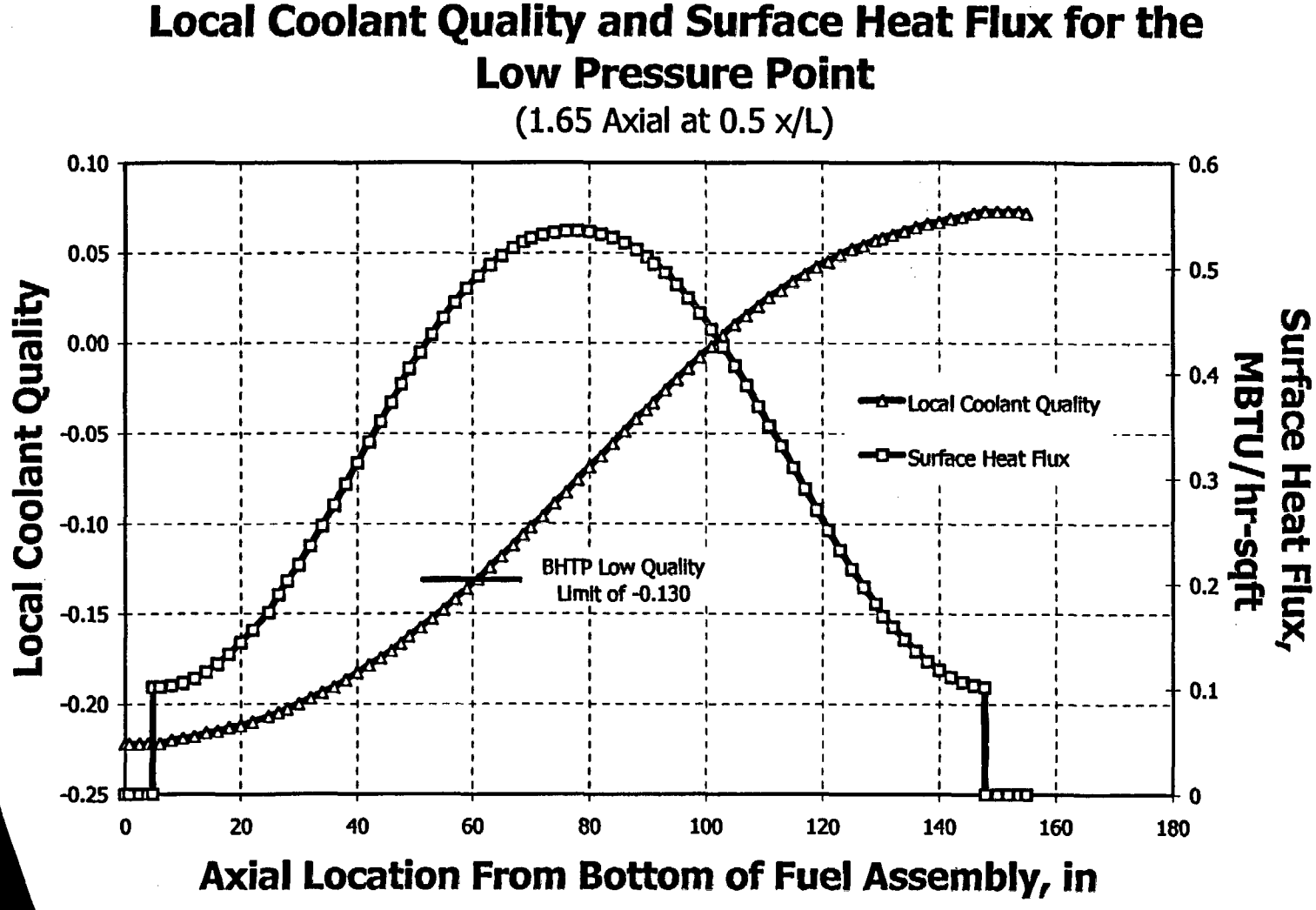
The Variable Low Pressure Trip has Margin to the Tech Spec Safety Limit Cycle 14

Figure 1

Pressure-Temperature Trip Limits and the Tech Spec Safety Limit



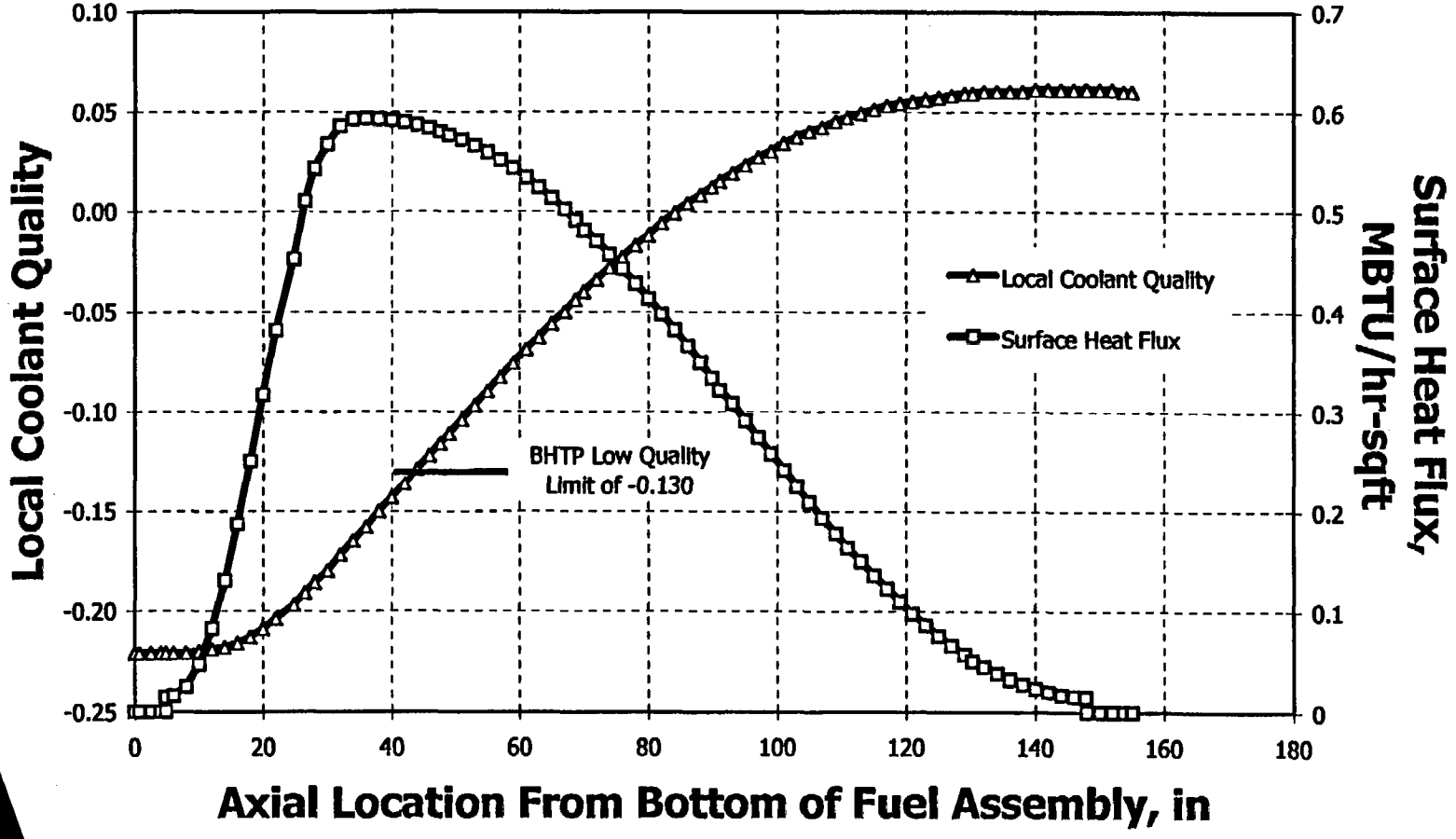
Example of an Axial Power Shape with the MDNBR Above the Elevation of the Lower Quality Limit



Example of an Axial Power Shape with the MDNBR Below the Elevation of the Lower Quality Limit

Local Coolant Quality and Surface Heat Flux for the Low Pressure Point

(1.90 Axial at 0.2 x/L)



Impact of Conservative Adjustment

CR-3 Cycle 14 RPS MAPs for 4 Pump Operation
(BHTP Correlation)

Impact of Conservative Adjustment

CR-3 Cycle 14 Operating Limit MAPs
(BHTP Correlation)

Areas of Margin in the CR-3 Cycle 14 Analysis

- Thermal Design Limit, [ ]
- Final CR-3 Cycle 14 DNB Transition Core Penalty was only [ ]
- Margin between the CR-3 Cycle 14-specific Safety Limit and the Variable Low Pressure Trip [ ]
- Margin by Conservative Treatment of Low Quality Limit in MAP space [ ]

Core Safety And Operating Limits
Core Power Distribution Limit Process

- Maneuvering Analysis defines power distribution dependence on power level, burnup, regulating rod insertion, axial power shaping rod position, & xenon distribution
- Margin to DNB is determined by comparison of augmented total peaking factor to DNB maximum allowable (MAP) limits
- Correlations of peaking margin to axial offset are generated to determine the core safety and operating limits
- Margin to peaking limits based on other criteria are evaluated to determine the limiting power distributions for the core
  - LHR limit based on centerline fuel melt criterion
  - LHR limit based on transient cladding strain criterion
  - LHR limit based on ECCS criteria (LOCA evaluation)
- Reactivity limits are also evaluated to determine regulating rod insertion limits
  - Shutdown margin criteria
  - Ejected rod worth criteria

CORE PROTECTION LIMITS

> RPS Safety Limits

- Centerline Fuel Melt: 22.1 kW/ft (Batch 16 UO_2 fuel rod)
- RPS DNB Maximum Allowable Peaking (MAP) limits
- TCS kW/ft limits: 28.9 @ 20 GWd/mtU & 20.3 @ 65 GWd/mtU

- Core protection is provided by the Limiting Safety System Settings specified in the Tech Specs/COLR (RPS Power-Imbalance Trip)

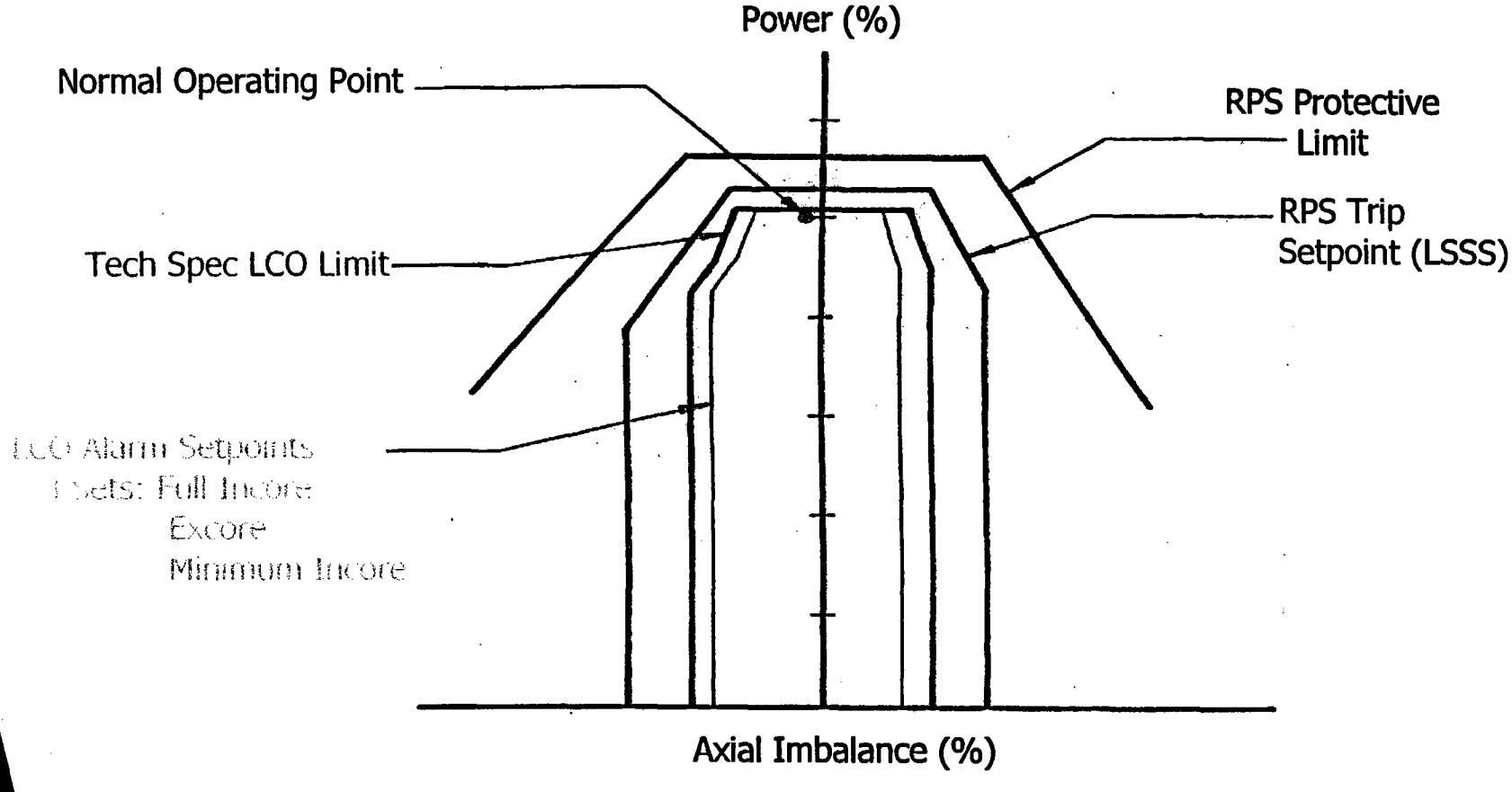
> Core Operational Limits

- LOCA LHR Limits as function of elevation & burnup
- IC DNB Maximum Allowable Peaking (MAP) limits
- 1%Δk/k Shutdown Margin limit
- 1%Δk/k (HZP) / 0.65%Δk/k (HFP) Ejected Rod Worth limit

- Core Protection is provided by the Limiting Conditions for Operation specified in the Tech Specs/COLR (Administrative operating alarms)

CFM, TCS, & LOCA LHR limits specific to Gd rods are also defined and used in the maneuvering analysis

Core Protection Imbalance LSSS & LCO Relationships



LCO Alarm Setpoints, RPS Protective Limit, & RPS Trip Setpoint are specified in the COLR

CR-3 Cy14 Maneuvering Analysis Limit Case Matrix

[ ]

Executing all cases would represent a total of 10,080 NEMO Power Distributions

PEAKING MARGIN

Peaking margin is calculated using the formula:

$$Margin = \left(1 - \frac{NEMO\ Peak * factors}{Limit}\right) * 100\%$$

Depending on the factors, the Limit may be either a Peaking limit or a linear heat rate limit

Peaking Augmentation Factors – DNB Margin

- Most Uncertainties are treated in the SCD Response Surface Model and are reflected in the DNB Maximum Allowable Peaking (MAP) limits

- Augmentation factors applied for specific effects:
  - Spacer Grid allowance
  - Quadrant Power Tilt allowance

Notes:
-Other factors may be applied to accommodate effects of SS replacement rods, increased OTSG tube plugging levels, etc.
-The allowance for Quadrant Power Tilt is selected to provide a COLR limit of approximately 4% for steady-state tilt when thermal power > 60% RTP.

Target Margin

- A non-zero Target Margin is generally used to set the core offset limits
- Target Margin can account for:
  - Expanded shutdown flexibility
  - Allowance for time-in-life effects
  - Flexibility in the EOC Tavg reduction maneuver
  - Allowance for other special operations
  - Conservatism to offset increased peaking if the core is redesigned after the design analysis is completed
- Target Margin may be burnup dependent and may be different for positive and negative offset limits
- Cycle 14 Target Margins

[

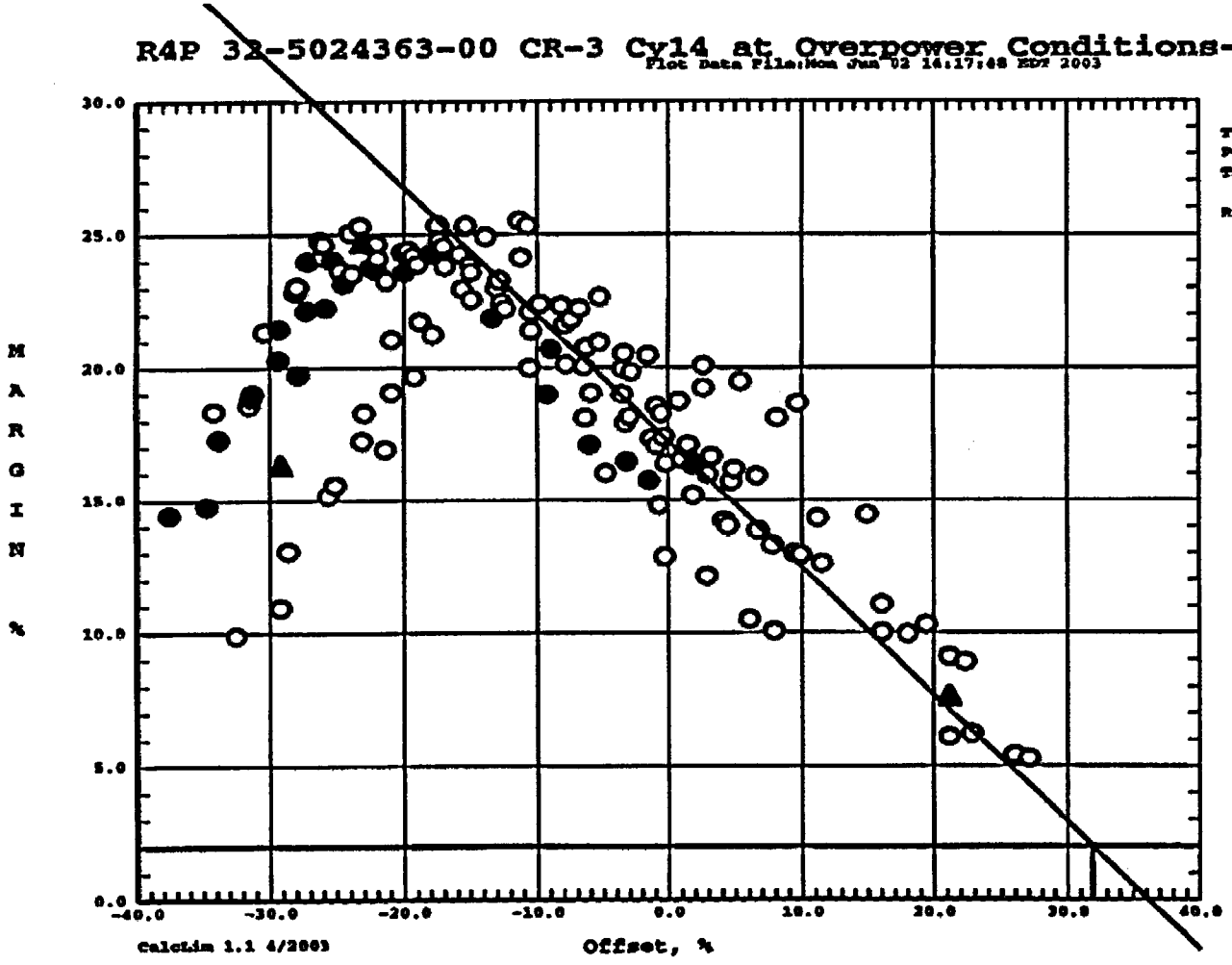
]

CR-3 Cy14 CFM and RPS DNB Peaking Margins

500 EFPD 112%RTP Max Xenon

Rod Index	APSR (%WD)	% Axial Offset	% CFM Margin	% SSDNB Margin
300	0	1.47	43.9 (N11, 27)	17.0 (N11, 27)
300	50	-10.73	38.9 (M10, 5)	25.3 (M10, 5)
290	30	-11.33	37.2 (M10, 5)	25.5 (M10, 5)
275	0	-15.40	37.7 (M10, 5)	25.2 (M10, 5)
275	50	-26.30	28.6 (M10, 5)	24.7 (N11, 5)
250	0	-27.23	27.9 (M10, 5)	23.9 (N11, 5)
250	10	-29.38	24.7 (M10, 5)	20.2 (N11, 5)
250	30	-34.75	19.6 (M10, 5)	14.7 (N11, 5)
250	50	-37.56	19.3 (M10, 5)	14.4 (N11, 5)
250	80	-33.86	22.2 (M10, 5)	17.2 (N11, 5)
250	100	-31.40	23.8 (M10, 5)	18.8 (N11, 5)
225	0	-20.93	25.6 (M10, 5)	21.0 (N11, 5)
225	50	-32.52	16.0 (M10, 5)	9.8 (N11, 5)

CR-3 Cy14 RPS DNB Margin 500 EFPD 112%RTP



TIL = 500.00 EFPD Rods IN
POWER = 100.00 % FP
TARGET MARGIN: Neg. off. = 0.00; Pos. off. = 2.00

Ranges for Included Fit Points:

	efpd	0.00	500.00	A	offset	10.00	30.00	A
	fp	99.00	101.00	A	aper	IN	IN	
OR								
	efpd	501.00	703.00	A	offset	10.00	30.00	A
	fp	99.00	101.00	A	aper	IN	IN	
OR								
	efpd	0.00	703.00	A	offset	6.00	30.00	A
	fp	99.00	101.00	A	aper	OUT	OUT	

RESULTS: Neg. Limit = 0. % Pos. Limit (Manual) = 31.88 %

Neg. offset: y = 0.000 * X + 0.000

Pos. offset: y = -0.477 * X + 17.200

DNB Check Cases

- The limiting DNB peaking margins are confirmed by evaluation of DNB (physics) check cases
- Normalized axial power shapes for limiting power distributions are evaluated with LYNXT to determine actual DNBR and peaking margin
- Ensures that approximations inherent in use of DNB MAP limits are properly accounted for
- Margins determined by DNB check cases are typically within $\pm$ 2% of the MAP based margin

RPS Offset Limits at 112% RTP

EFPD	CFM OS Limit % Negative	CFM OS Limit % Positive	SSDNB OS Limit % Negative, 4RCP	SSDNB OS Limit % Positive, 4RCP
4	-59.6	56.2		33.2
50	-74.6	57.4		41.5
150	-67.2	61.7		37.5
250	-57.3	59.4		38.1
350	-49.5	55.8		30.5
450	-46.3	54.6		31.9
500	-45.0	54.6	-37.7 (-42.9)*	29.3 (31.8)*
550	-45.9	52.3		30.0
600	-47.9	54.6		31.0
653 G8 in	-49.1	56.5		30.7
653 G8 out	-47.6	56.5		33.9
685	-48.9	59.9		32.5
695	-48.5	58.2		33.6
703	-48.6	58.8		34.3

Notes: *Based on DNB Check Case results

RPS Power – Imbalance – Flow Trip Setpoints

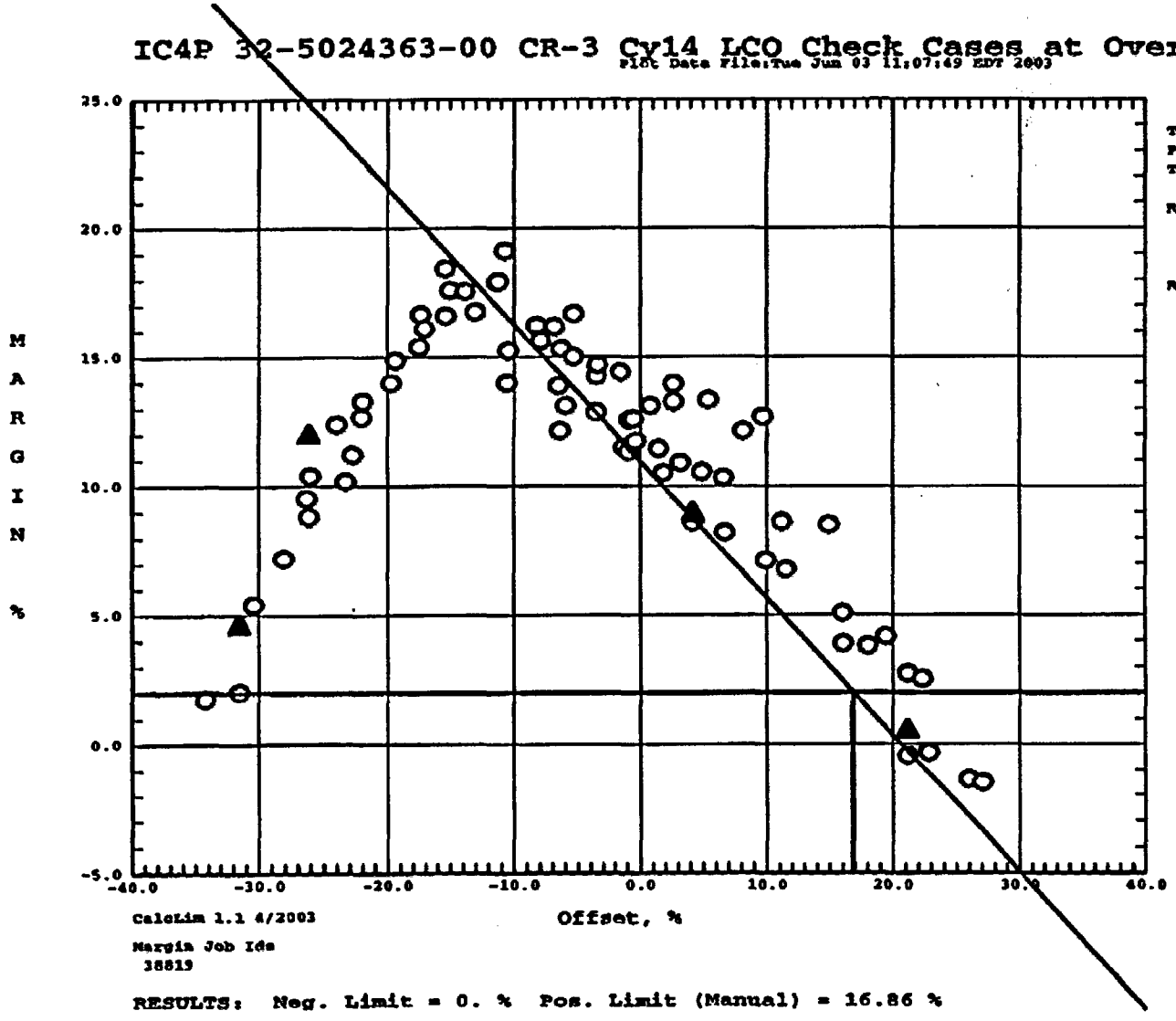
- RPS offset limits are converted to imbalance and adjusted for uncertainty to generate RPS imbalance trip setpoints
- Error adjustment includes the contributions of:
  - Incore detector system measurement error
  - Excore-to-incore detector calibration
  - Instrument string errors
- RPS error equation provides a 95%/95% one-sided statistical tolerance limit for the imbalance error as a function of:
  - Power
  - Imbalance
  - Gain
  - Ucore (accounts for incore detector sensitivity depletion)

CR-3 Cy14 LOCA and ICDNB Peaking Margins

500 EFPD 102%RTP Max Xenon

Rod Index	APSR (%WD)	% Axial Offset	% LOCA Margin	% ICDNB Margin
300	0	1.47	26.8 (N11, 28)	11.4 (N11, 27)
300	50	-10.73	16.6 (M10, 5)	19.1 (M10, 5)
290	30	-11.33	14.2 (M10, 5)	17.8 (M10, 5)
275	0	-15.40	14.9 (M10, 5)	18.4 (M10, 5)
275	50	-26.30	2.5 (M10, 5)	9.5 (N11, 6)
250	0	-27.23	1.5 (M10, 5)	8.5 (N11, 5)
250	10	-29.38	-2.8 (M10, 5)	4.1 (N11, 5)
250	30	-34.75	-9.7 (M10, 5)	-2.6 (N11, 5)
250	50	-37.56	-10.1 (M10, 5)	0.5 (N11, 5)
250	80	-33.86	-6.2 (M10, 5)	2.3 (N11, 5)
250	100	-31.40	-4.0 (M10, 5)	5.0 (N11, 5)

CR-3 Cy14 ICDNB Margin 500 EFPD 102%RTP

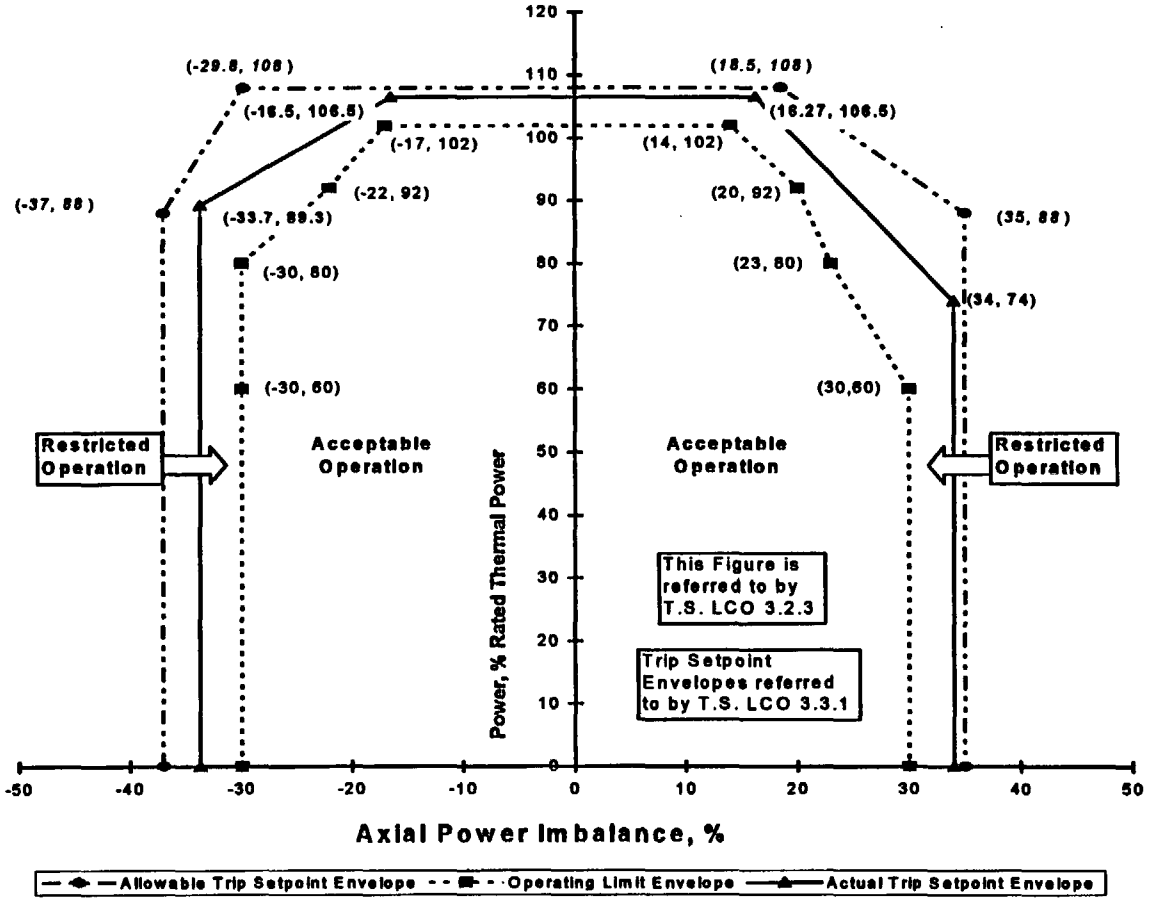


RESULTS: Neg. Limit = 0. % Pos. Limit (Manual) = 16.86 %

Neg. offset: y = 0.000 * X + 0.000

Pos. offset: y = -0.530 * X + 10.940

Axial Power Imbalance Error Adjusted
Operating Limit and Trip Setpoint Envelopes
Four Pump Operation
0 EFPD to EOC



CR-3 Allowable Radial Peaking Limits for COLR

$F_{\Delta H} \leq ARP\ [1 + (1/RH)*(1- P/P_m)]$

ARP = Allowable Radial Peak

P = ratio of Thermal Power / Rated Thermal Power
P_m = 1.0 for 4-RCP operation
P_m = 0.75 for 3-RCP operation

RH = 3.34

Axial Peak	Axial Location* (X/L)	ARP
1.1	0.2	1.9254
1.1	0.4	1.9240
1.1	0.6	1.9229
1.1	0.8	1.9224
1.3	0.2	2.0858
1.3	0.4	2.0827
1.3	0.6	1.9721
1.3	0.8	1.8095
1.5	0.2	1.9034
1.5	0.4	1.9694
1.5	0.6	1.8275
1.5	0.8	1.6786
1.7	0.2	1.6795
1.7	0.4	1.7622
1.7	0.6	1.6947
1.7	0.8	1.5617
1.9	0.2	1.5027
1.9	0.4	1.5812
1.9	0.6	1.5791
1.9	0.8	1.4620

*Based on an active core height of 143.0 inches; Linear interpolation between values is acceptable.

Areas of Margin in the CR-3 Cycle 14 Analysis

- Thermal Design Limit, [ ]
- Final CR-3 Cycle 14 DNB Transition Core Penalty was only [ ]
- Margin between the CR-3 Cycle 14-specific Safety Limit and the Variable Low Pressure Trip [ ]
- Margin by Conservative Treatment of Low Quality Limit in MAP space [ ]
- [ ] Uncommitted Target Margin preserved in Cycle 14-specific Maneuvering Analysis
- RPS Hardware Trip Setpoints are set to more restrictive values than the Cycle 14-specific allowable values [ ]
- Axial Imbalance Operating Limit Setpoints are set to more restrictive values than the Cycle 14-specific allowable values [ ]