Westinghouse Electric Corporation
Energy Systems

Box 355
Pittsburgh Pennsylvania 15230-0355

August 28, 1997
AW-97-1159

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Attention: J. E. Lyons, Acting Chief, Reactor Systems Branch
Division of Systems Safety and Analysis

Reference: Letter from N. J. Liparulo to J. E. Lyons, NSD-NRC-97-5290, dated August 28, 1997

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: Westinghouse Axial Offset Anomaly Presentations to NRC - July 31, 1997 [Proprietary]

Dear Mr. Lyons:

The application for withholding is submitted by Westinghouse Electric Corporation ("Westinghouse") pursuant to the provisions of paragraph (b) (1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.790, Affidavit AW-97-1159 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-97-1159 and should be addressed to the undersigned.

Very truly yours,

Nicholas J. Liparulo, Manager
Equipment Design and Regulatory Engineering

cc: Kevin Bohrer , NRR/DISP/PADB (12E20)

## Proprietary Information Notice

Transmitted herewith are proprietary and non-proprietary versions of documents furnished to the NRC. In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

## Copyright Notice

# AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Henry A. Sepp, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Corporation ("Westinghouse") and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Henry A. Sepp

Henry A. Sepp, Manager
Regulatory and Licensing Engineering

Sworn to and subscribed
before me this 28 day
of August, 1997.

Janet A. Schwab

Notary Public

Notarial Seal
Janet A. Schwab, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires May 22, 2000
Member, Pennsylvania Association of Notaries

(1) I am Manager, Regulatory and Licensing Engineering, in the Nuclear Services Division, of the Westinghouse Electric Corporation and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Energy Systems Business Units.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Energy Systems Business Units in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in the letter, "Westinghouse Axial Offset Anomaly Presentations to NRC - July 31, 1997," on August 28, 1997 for submittal to the Commission, being transmitted by Westinghouse Electric Corporation (W) letter (NSD-NRC-97-5290) and Application for Withholding Proprietary Information from Public Disclosure, Nicholas J. Liparulo, W, Manager Equipment Design and Regulatory Engineering to the attention of J. E. Lyons, Acting Chief, Reactor Systems Branch. The proprietary information as submitted by Westinghouse Electric Corporation is to provide the material as presented to the NRC staff at the Axial Offset Anomaly meeting on July 31, 1997.

This information is part of that which will enable Westinghouse to:

(a) Minimize extent of Axial Offset Anomaly

(b) Assist customers to obtain license

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of designing reactor cores

(b) Westinghouse can use this information to further enhance their licensing position with their competitors

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar licensing services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing the enclosed information.

Further the deponent sayeth not.

# NRC AOA Meeting Agenda

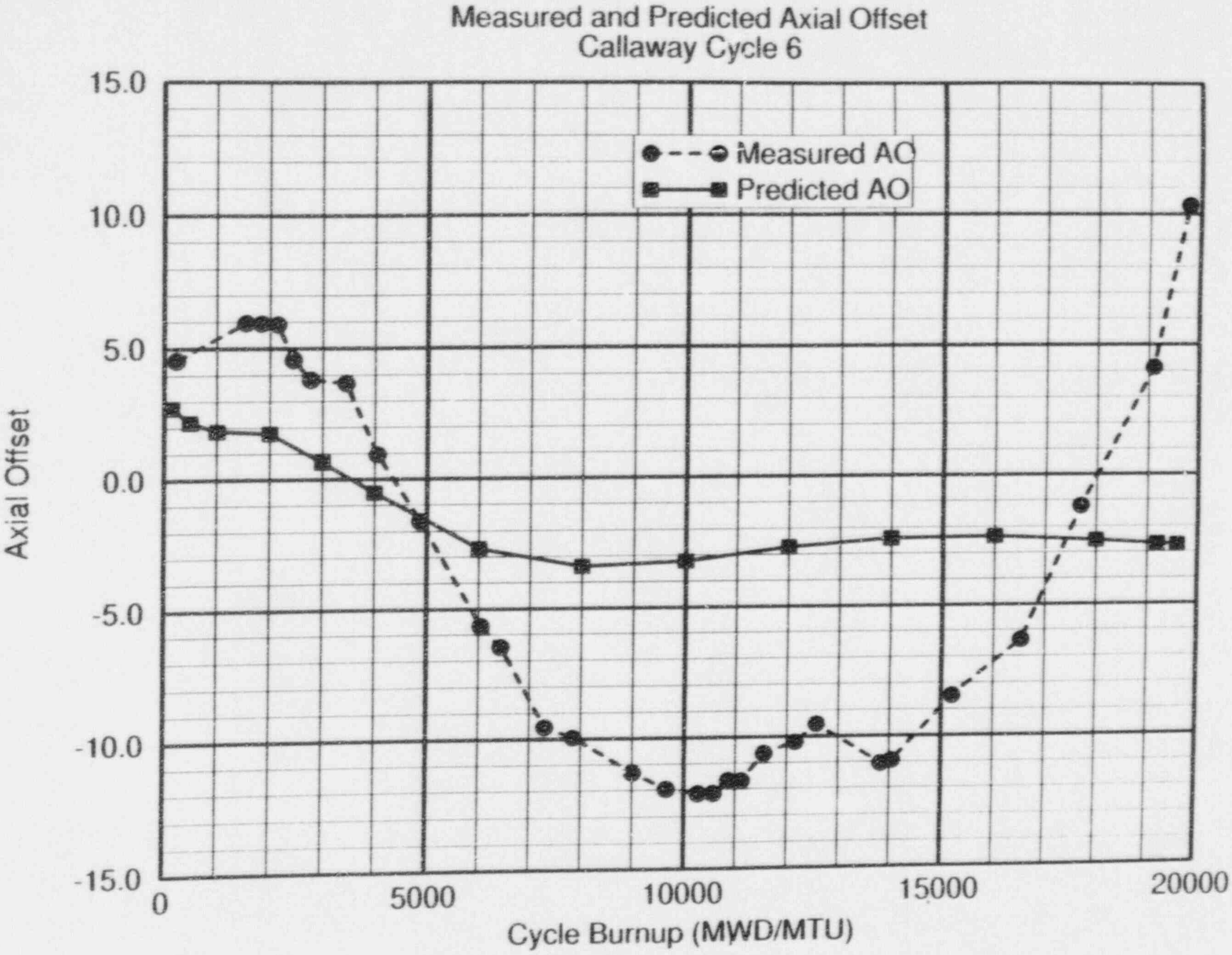
- Introduction - Westinghouse
  - Axial Offset Anomaly Characteristics
  - History of Affected Plants
  - Brief Root Cause Discussion
- TU Presentation
- UE Presentation
- W Root Cause Presentation
- W Safety Analysis Presentation
- Discussion

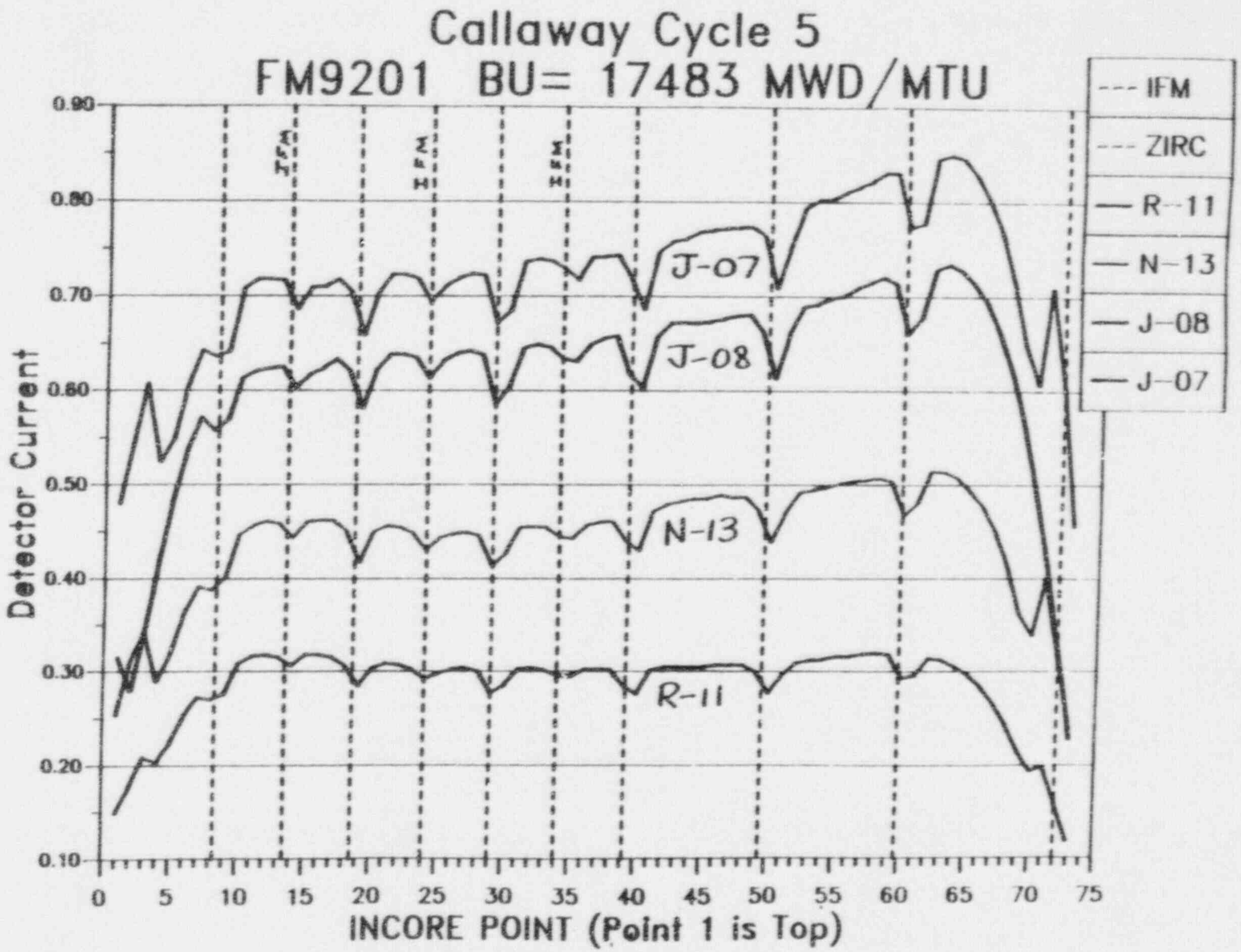
# Introduction

Sumit Ray
Westinghouse

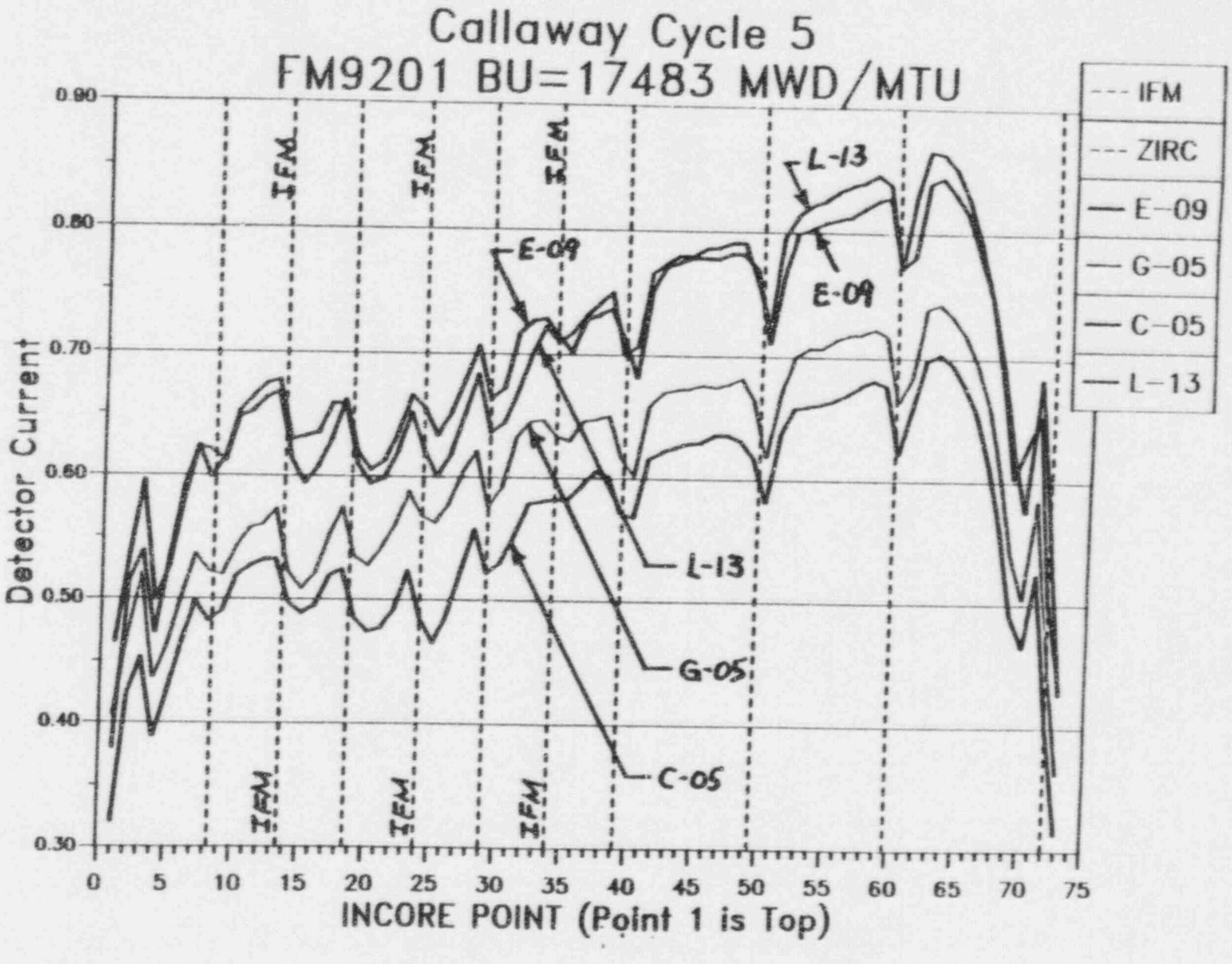
# AOA - Key Characteristics

- Core Axial Offset becomes more negative than predicted , typically at burnups of 5,000-10,000 MWD/MTU
- Incore maps show higher AO deviations for higher power feed assemblies
- Flux depressions in upper half of core are maximum below grids


Measured and Predicted Axial Offset
Callaway Cycle 6
Measured AO
Predicted AO
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
Axial Offset
0
5000
10000
15000
20000
Cycle Burnup (MWD/MTU)



Callaway Cycle 5
FM9201 BU= 17483 MWD/MTU
Detector Current
INCORE POINT (Point 1 is Top)
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
IFM
IFM
IFM
J-07
J-08
N-13
R-11
IFM
ZIRC
R-11
N-13
J-08
J-07



Callaway Cycle 5
FM9201 BU=17483 MWD/MTU
IFM
ZIRC
E-09
G-05
C-05
L-13
Detector Current
INCORE POINT (Point 1 is Top)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

# Axial Offset Anomaly History of Affected Westinghouse Plants

| Plant | Cycle With AOA | Cycle Without AOA | Maximum AO Deviation |
|---|---|---|---|
| Callaway | | 1,2,3,7 | |
| | 4 | | -5 |
| | 5 | | -7 |
| | 6 | | -9 |
| | 8 | | -7 |
| | 9 (op) | | -13 |
| Millstone 3 | | 1,2,3,5,6 (op) | |
| | 4 | | -5 |
| Vogtle 1 | | 1,2,3,5 | |
| | 4 | | -3.5 |
| | 6 | | -6 |
| | 7 (op) | | -3 |
| Vogtle 2 | | 1,2,6 (op) | |
| | 3 | | -3 |
| | 4 | | -3 |
| | 5 | | -3 |
| Wolf Creek | | 1-8 | |
| | 9 (op) | | -6 |
| Catawba 1 | | 1-7, 9 | |
| | 8 | | -4.5 |
| Comanche Peak 2 | 3 | 1,2 | -3.5 |
| Seabrook | | 1-4 | |
| | 5 | | -3 |

# Axial Offset Anomaly
# History of Affected Plants

| Plant | Cycle With AOA | Fuel Type | Peaking Factor (FDH Limit) / kw/ft |
|---|---|---|---|
| Callaway | 4 | 17X17, .360, IFM | 1.65 / 5.69 |
| | 5 | 17X17, .360, IFM | 1.65 / 5.69 |
| | 6 | 17X17, .360, IFM | 1.65 / 5.69 |
| | 8 | 17X17, .360, IFM | 1.65 / 5.69 |
| | 9 (op) | 17X17, .360, IFM | 1.65 / 5.69 |
| Millstone 3 | 4 | 17X17, .374, IFM | 1.70 / 5.44 |
| Vogtle 1 | 4 | 17X17, .360, IFM | 1.65 / 5.44 |
| | 6 | 17X17, .360, IFM | 1.65 / 5.69 |
| | 7 (op) | 17X17, .360, IFM | 1.65 / 5.69 |
| Vogtle 2 | 3 | 17X17, .360, IFM | 1.65 / 5.69 |
| | 4 | 17X17, .360, IFM | 1.65 / 5.69 |
| | 5 | 17X17, .360, IFM | 1.65 / 5.69 |
| Wolf Creek | 9 (op) | 17X17, .374, IFM | 1.65 / 5.69 |
| Catawba 1 | 8 | Non-Westinghouse | ?/5.44 |
| Comanche Peak 2 | 3 | Non-Westinghouse | 1.55 / 5.44 |
| Seabrook | 5 | 17X17, .374 | 1.65 / 5.44 |

# Axial Offset Anomaly
# History of Affected Plants

| Plant | Cycle With AOA | Design Cycle Length (EFPD) | Maximum HFP Boron Concentration (ppm) |
|---|---|---|---|
| Callaway | 4 | 440 | 1300 |
| | 5 | 440 | 1300 |
| | 6 | 450 | 1400 |
| | 8 | 480 | 1400 |
| | 9 (op) | 470 | 1400 |
| Millstone 3 | 4 | 510 | 1700 |
| Vogtle 1 | 4 | 430 | 1650 |
| | 6 | 480 | 1500 |
| | 7 (op) | 490 | 1500 |
| Vogtle 2 | 3 | 470 | 1600 |
| | 4 | 460 | 1400 |
| | 5 | 460 | 1400 |
| Wolf Creek | 9 (op) | 520 | 1550 |
| Catawba 1 | 8 | 390 | 1200 |
| Comanche Peak 2 | 3 | 500 | 1400 |
| Seabrook | 5 | 530 | 1400 |

# AOA Root Cause

- Crud builds up on upper spans of high power fuel assemblies
- Boron absorbs into the crud, concentrating a localized neutron poison
- Flux depressed in upper regions of the core, causing AO to move down (negative)

# AOA Root Cause (Continued)

- Some feed assemblies have sub-cooled nucleate boiling to an extent that enhances crud buildup in the upper spans
- Sub-cooled boiling causes boron to concentrate in porous crud layer
- Boron can be released from the crud layer when subcooled boiling is reduced

# Susceptibility Factors

- Significant sub-cooled boiling
  - High coolant temperatures
  - Higher peaking factors
  - High power density
- Crud buildup on fuel
  - Some crud on fuel is not unusual
  - Individual plant differences can affect crud buildup
- Long cycles
  - High soluble boron

# Safety Significance

- Impact of AOA on Fuel And Accident Analysis Thoroughly Considered
- Key Impacts Are Shutdown Margin And Power Distribution Surveillance Factors
  - These Are Updated For Plants With AOA
- All Fuel/Non-LOCA/LOCA Design And Safety Criteria Continue to Be Met
- No Adverse Impact on Safe Plant Operation

# AOA Industry Communications

- Westinghouse Fuel Users' Group presentations
- Westinghouse Reactor Engineers' Seminars
- Westinghouse Technology User's Group presentations
- EPRI Programs
- INPO SOER 96-2

# Presentation to NRC
# Root Cause Analysis of Axial Offset Anomaly

July 31, 1997

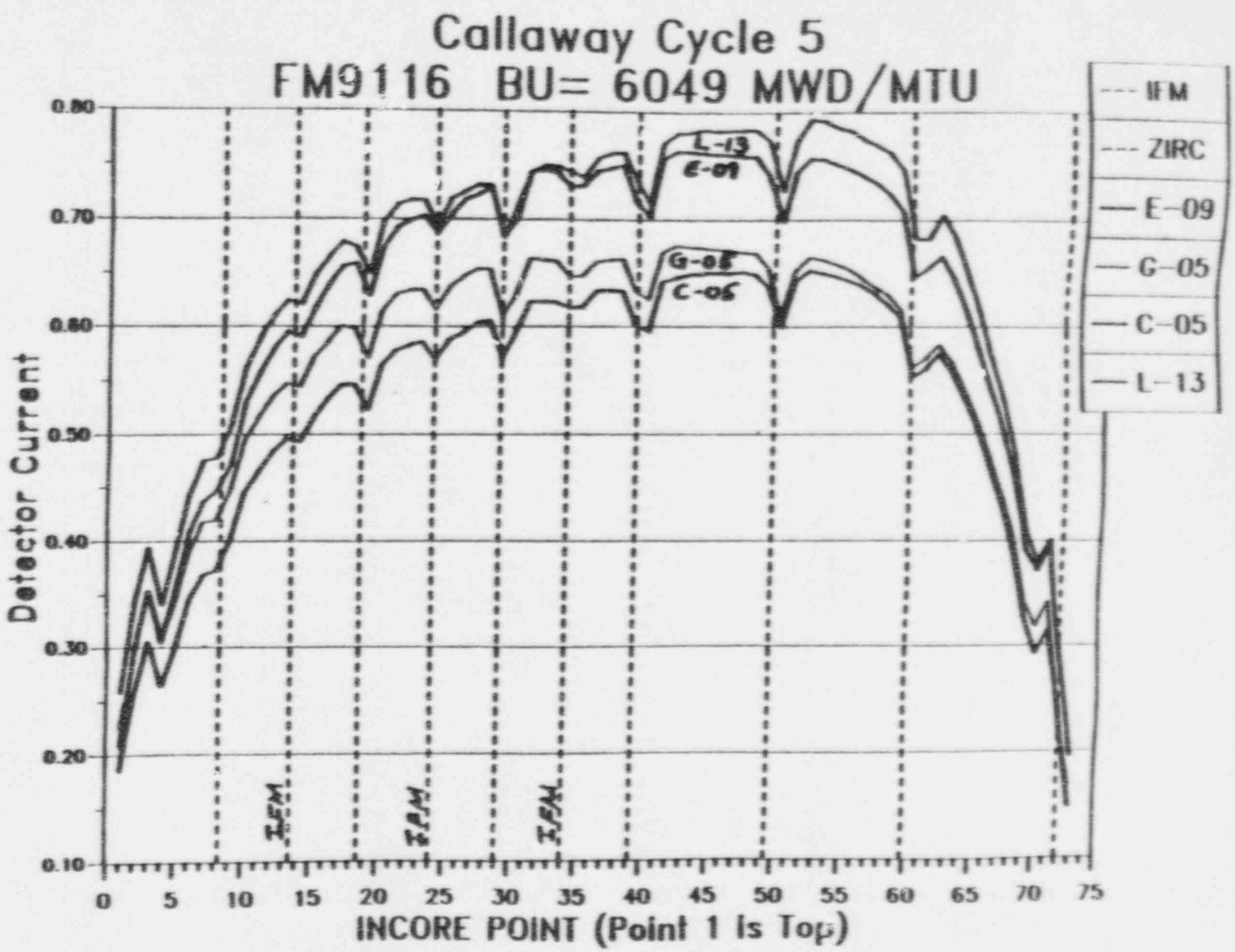
Dr. George P. Sabol, Manager

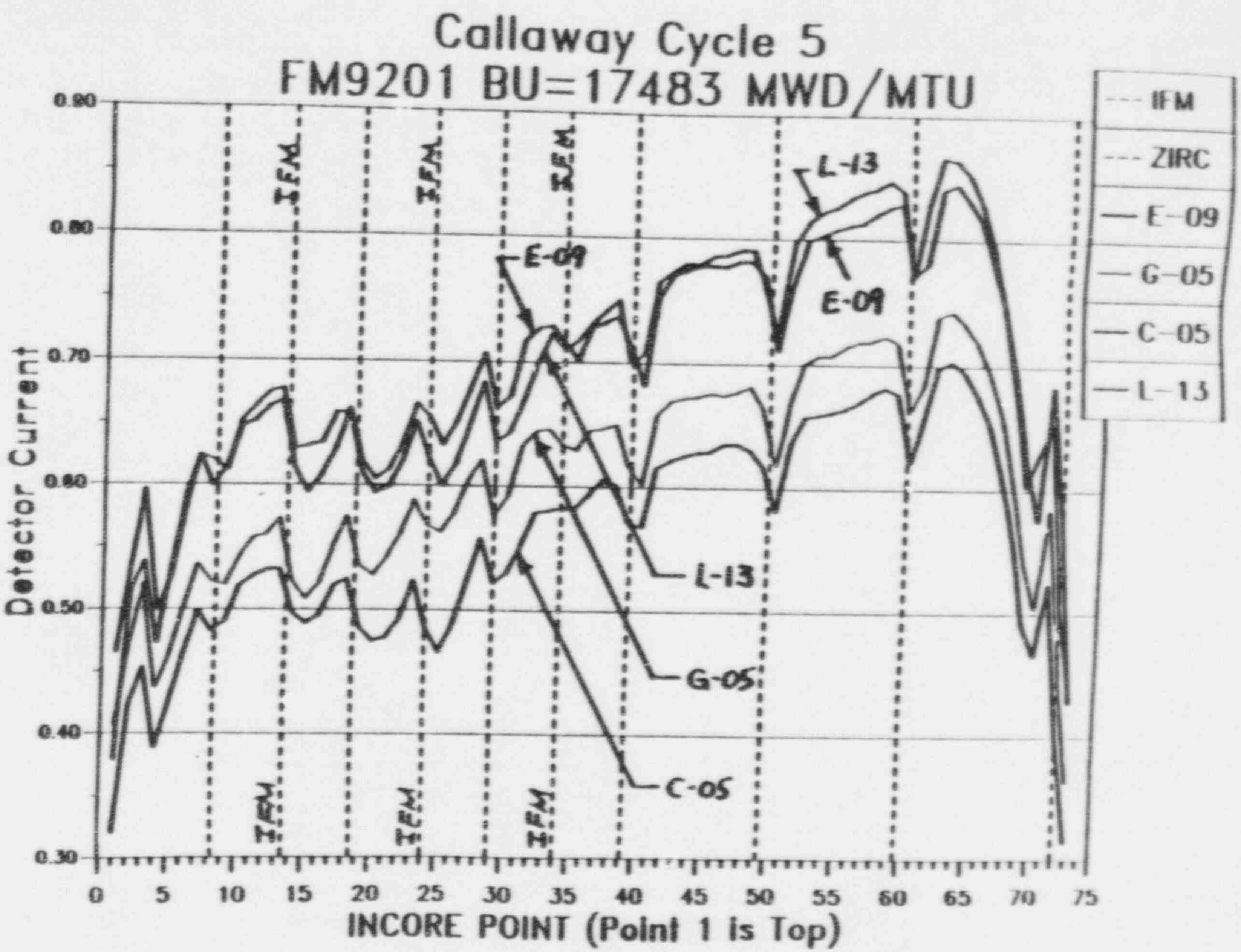
Westinghouse Electric Corporation

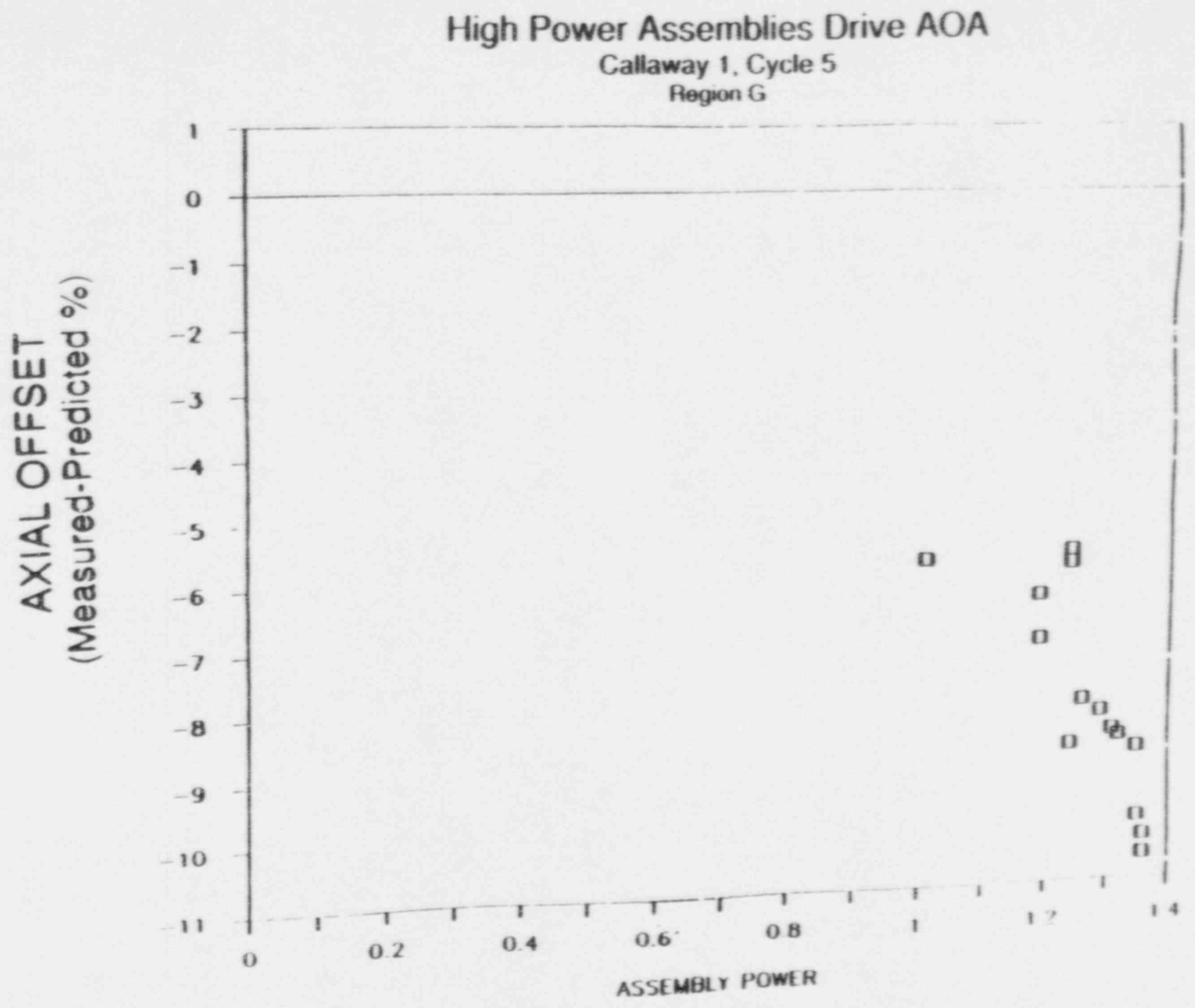
CNFD Development Programs

# Presentation Outline

- Data from plant instrumentation
- Similarities of affected plants
- Fuel visual examinations for crud deposition
- Mechanism of AOA
- Crud chemical analyses
- Coolant chemistry influence and recommendations


Callaway Cycle 5
FM9116 BU= 6049 MWD/MTU
IFM
ZIRC
E-09
G-05
C-05
L-13
Detector Current
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
INCORE POINT (Point 1 Is Top)
L-13
E-09
G-05
C-05
IFM
IFM
IFM


Callaway Cycle 5
FM9201 BU=17483 MWD/MTU
IFM
ZIRC
E-09
G-05
C-05
L-13
Detector Current
INCORE POINT (Point 1 is Top)
0.30
0.40
0.50
0.60
0.70
0.80
0.90
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

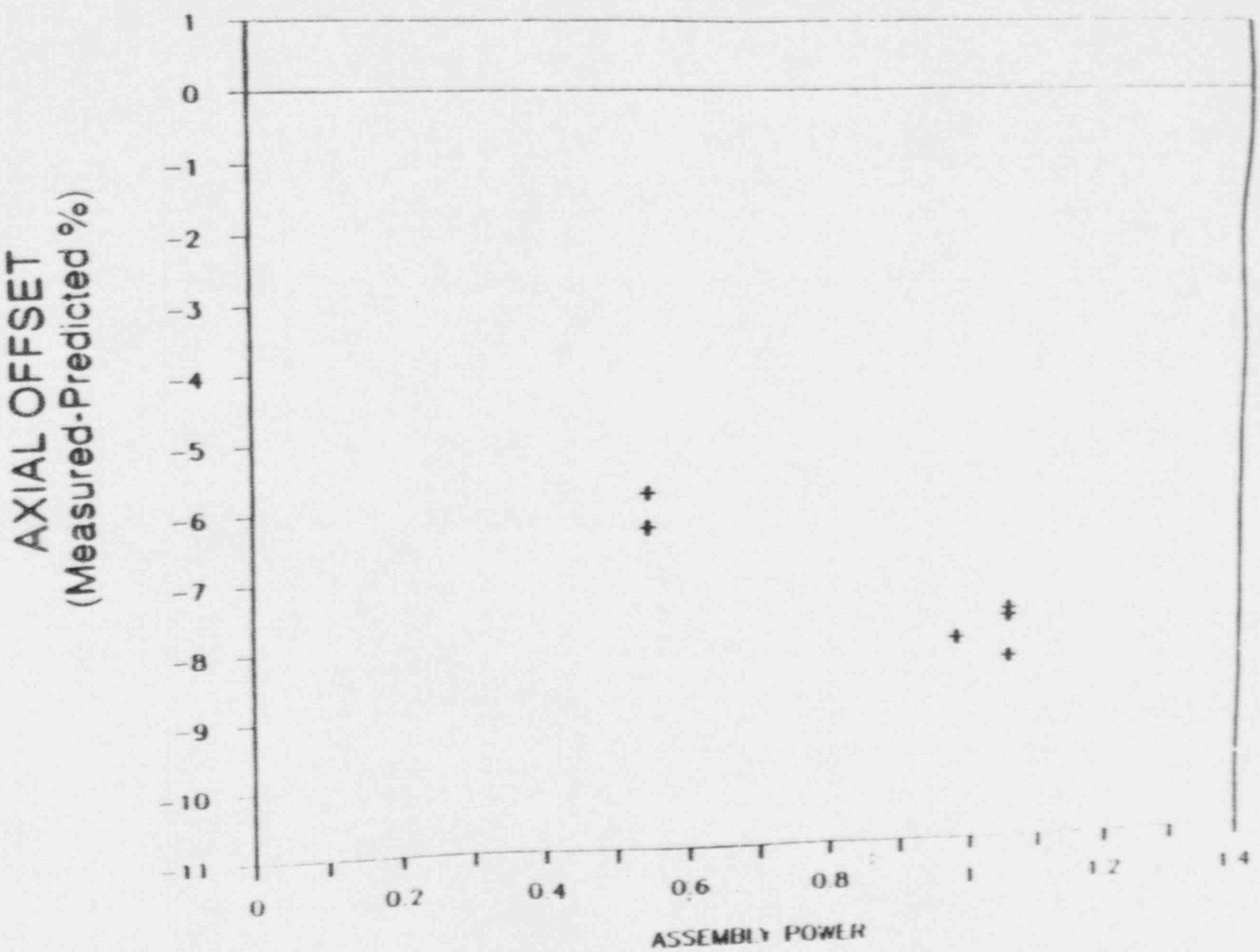


High Power Assemblies Drive AOA
Callaway 1, Cycle 5
Region G
AXIAL OFFSET
(Measured-Predicted %)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
0
0.2
0.4
0.6
0.8
1
1.2
1.4
ASSEMBLY POWER

## Power Dependence of AO for 2 CY Fuel

Callaway 1, Cycle 5

Region F



# Axial Offset Anomaly Characteristics

- Flux depressed in top-half of core
- Depression similar at structural and mixing grids
- Maximum depression just upstream of grid
- ΔAO driven by feed fuel - largest offset in high-power assemblies
- AO deviation starts at 4-10 GWD/MTU

# Similarities of AO-Affected Plants

- Predicted sub-cooled boiling
  - High coolant temperature
  - High surface heat flux
- Boiling is necessary, but not sufficient
  - V. C. Summer is prime exception

a,c

# Hot Channel Sub-Cooled Boiling Duty

Plant/Cycle

(Solid bars had indications of AO anomaly)

(Shaded bar - possible AO anomaly)

Assumptions

1. Single Channel, no mixed core effects
2. Axial blanket power shape used if fresh fuel has axial blankets

MECOMP38.2 7/25/97

# Visual Observations on Fuel

- Plants/Cycles
  - Callaway EOC 5[1], 6, 7
  - Millstone 3 EOC 4
- Observed more crud than expected

[1] First and largest visual exam campaign

# Visual Observations on Crud

- Crud only in top half of fuel. No crud below span 4. Consistent with negative AO.
- Most crud in hottest span 6
- Feed fuel has more crud than 2CY or 3CY fuel
- More crud on high power assemblies, faces
- Little or no crud above grid, but increases up span, consistent with flux depression

# Axial Offset Proportional to Crud Index on Feed Fuel

## Callaway Cycle 5 Region G Crud Evaluation

a,c

## Axial Offset Proportional to Crud on 2 CY Fuel

### Callaway Cycle 4 Region E and Cycle 5 Region F Crud Evaluation

+(a,c)

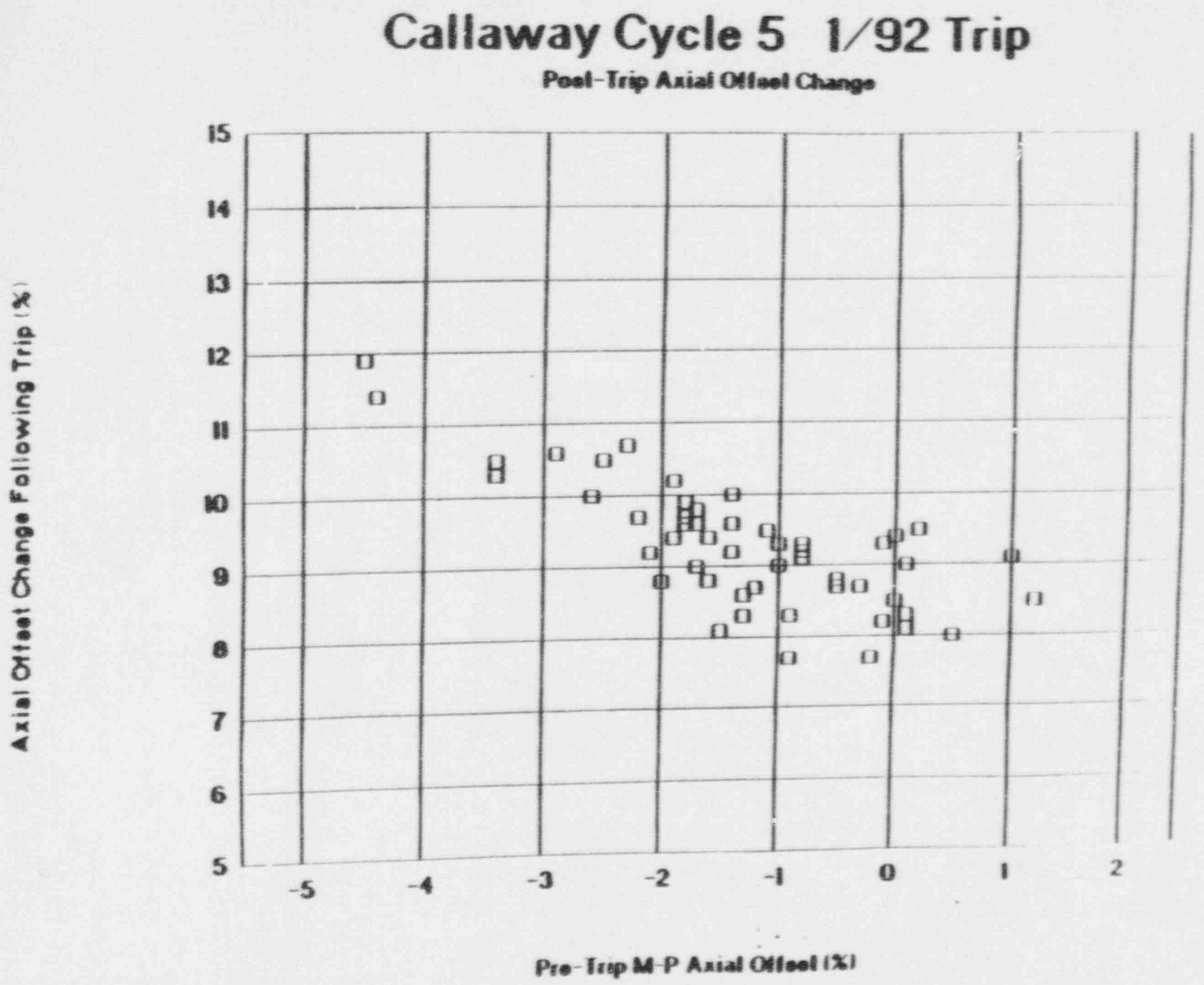
## More Crud on High Power Faces

Callaway Region G Crud Index versus Average Power at Assembly Face

+(a,c)

# Callaway CY5 AO change associated with crud release

- Trip occurred near EOC 5
- AO shift from -4 to +6%
- Significant crud release followed trip and restart



Callaway Cycle 5 1/92 Trip
Post-Trip Axial Offset Change
Axial Offset Change Following Trip (%)
15
14
13
12
11
10
9
8
7
6
5
-5
-4
-3
-2
-1
0
1
2
Pre-Trip M-P Axial Offset (%)

# AO Anomaly is Crud Induced

- Crud only in top half of fuel consistent with negative offset
- Crud highest just below grids agrees with flux depression
- More crud on assemblies with high ΔAO
- Crud release near EOC-5 Callaway associated with rapid AO Shift - 4% to + 6%
- Assemblies with largest ΔAO prior to trip were most affected by the trip

# Effects of Crud on AOA Evaluated

- Physical presence of $Ni_xFe_{3-x}O_4$ is insufficient to depress flux
- Increase in extent of sub-cooled boiling
  - Rougher surface
  - More nucleation sites
  - Slight increase in surface temperature
- Boron concentration within crud
  - Liquid within crud enriched by boiling
  - Boron compound precipitation within crud

# Plant Data Evaluation

- Plant data analyzed
  - Pressure increases
  - Power reductions
  - Temperature reductions
- Data indicate boiling insufficient to explain AO deviation
  - Pressure coefficient of reactivity similar to core model without voiding
  - Anomalous reactivity decreases with power, but still present at 70% power
- Low voiding indicates instantaneous release of reactivity not possible
- Boron concentration in crud is most likely cause of AO deviation

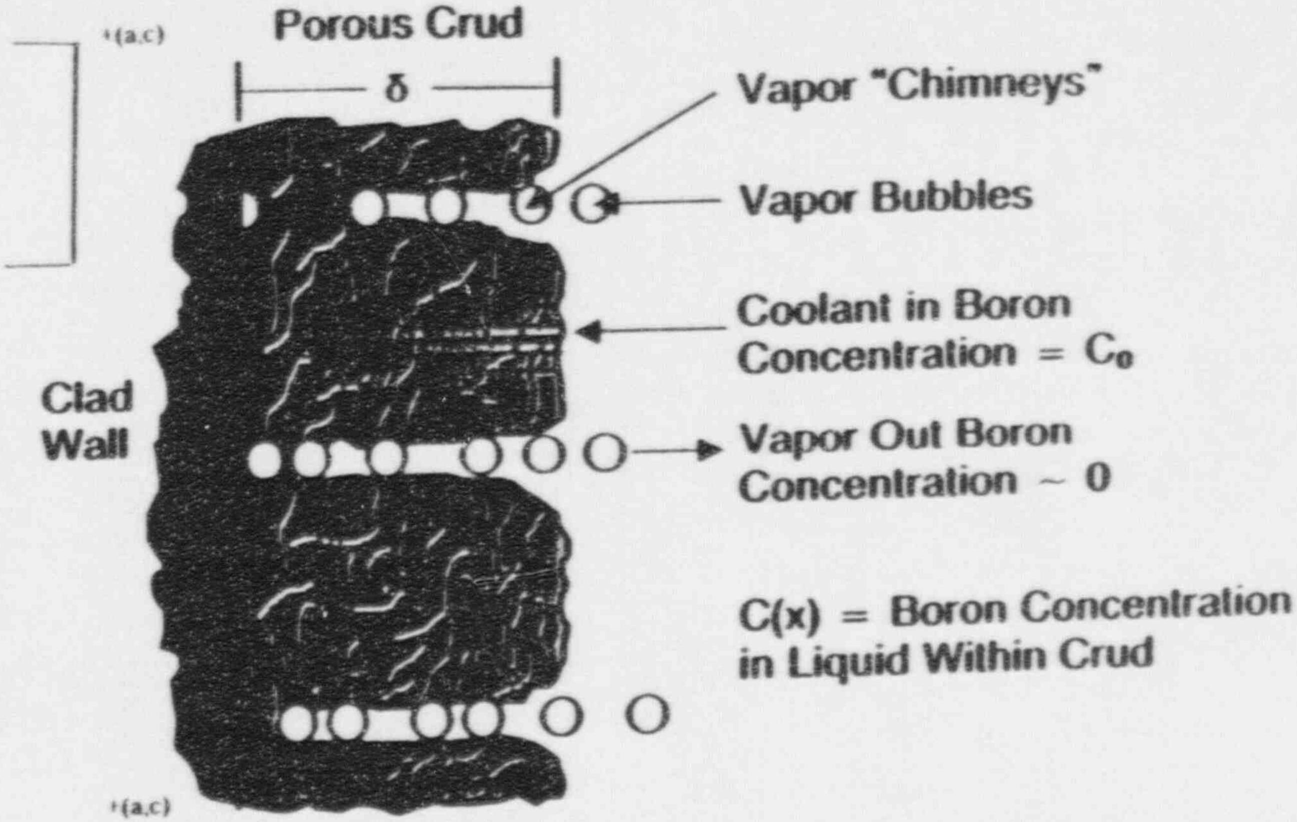
# Model for Boron Concentration in Crud

- Sub-cooled boiling in porous deposit results in concentration of soluble boron in liquid within the deposit

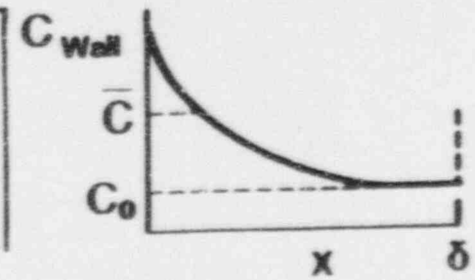
- Boron-enriched liquid leads to formation of boron-rich "solids"

# Crud Is Medium for Boron Concentration

+(a,c)




+(a,c)



# Critical Aspects of Model

- Formation of B "solids" in crud requires B-concentration in liquid within crud to solubility limit
- Most of B retained in "solid" form
- [B] in crud sensitive to boiling, thickness
  - [B] varies as [ ] +(a,c)
- Crud properties important
  - Thickness - coolant chem, impurities
  - Composition - reaction, adsorption of B
- Boron concentration, release is reversible

## Boron Release and Uptake with Power at Callaway

- Power reduction to 30% April 7, 8, 1993
  - Li release of 644g
  - Boron Equivalent (e.g., as $LiBO_2$) = 1012g
- Power increase to 100%
  - Li uptake = 450g
  - Boron equivalent = 707g
- Boron to cause observed Axial offset difference
  - Assumes no $B^{10}$ depletion
  - B release on power reduction = [ ] +(a,c)
  - B pickup on power increase = [ ] +(a,c)
- Good agreement with boron model

# Crud Scraping and Analysis

| | |
|---|---|
| AOA Cycles | |
| Callaway | EOC 6 |
| Millstone 3 | EOC 4 |
| Non-AOA Cycle | |
| Callaway | EOC 7 |

## Callaway EOC 6

## Assemblies Scraped for Crud

| Assy. No. | Region | Core Location | Assy. Power | Crud Index | Axial Offset M-P(Negative) |
|---|---|---|---|---|---|
| H88 | 8B | C8 | 1.34 | +(a,c) | -11.6 |
| H12 | 8A | L13 | 1.30 | | -8.4 |
| H03 | 8A | N13 | 0.95 | | -6.9 |
| G32 | 7B | J9 | 1.16 | | -9.6* |
| G87 | 7B | M9 | 0.98 | | 8.4* |
| E81 | 5C | H8 | 0.99 | | |

* Assemblies not instrumented in cycle 6. AO values based on those of instrumented assemblies symmetrical positions.

# CALLAWAY EOCs 5&6 CRUD EVALUATION

+(a,c)

ASSEMBLY AVERAGE CRUD INDEX

AXIAL OFFSET DIFFERENCE (NEGATIVE)

# Callaway EOC 6 Crud
# Average Surface Concentration and Thickness of Sample Deposits

## 1. Once-Burnt Fuel

| | High Power (H-88, H-12) | | Ave. Power (H-03) | |
|---|---|---|---|---|
| | Surf. Conc | Thickness | Surf. Conc | Thickness |
| Span | $mg/dm^2$ | microns | $mg/dm^2$ | microns |

+(a,c)

## 2. Twice-Burnt Fuel

| | High Power (G-32) | | Ave. Power (G-87) | |
|---|---|---|---|---|
| | Surf. Conc | Thickness | Surf. Conc | Thickness |
| Span | $mg/dm^2$ | microns | $mg/dm^2$ | microns |

+(a,c)

# Callaway EOC 6 Crud
# Average Surface Concentration and Thickness of Sample Deposits (cont'd)

## 3. Thrice-Burnt Fuel

| Average Power (E-81) | | |
|---|---|---|
| Span | Surface Conc mg/dm$^2$ | Thickness microns |

+(a,c)

*Analysis suspect due to small amount of crud.

Correction to #95 89, #95 209, (6/15/97)

## Callaway EOC 6 Crud Composition (Preliminary)
## Concentrations in Weight Percent (Span 6)

+(a,c)

## Millstone 3 EOC 4 Crud Data

| Assembly Number | Relative Power | Crud Index | Axial Offset (M-P) % |
|---|---|---|---|
| F-88 | 1.29 | [ ] +(a,c) | -7.2 |
| F-09 | 1.29 | | -8.3 |

## Average Surface Concentration and Thickness of Crud

| Span | Surface Conc. (mg/dm$^2$) | Thickness (microns) |
|---|---|---|
| [ | | ] |

+(a,c)

*Only one sample from span 4B

Correction to #96 115 (6/15/97)

## MILLSTONE 3 EOC 4 CRUD ANALYSIS
## AVERAGE COMPOSITION ON F-ASSEMBLIES (WT. %)

+(a,c)

*Only one sample from span 4B.

# Millstone 3 Feed Fuel Crud EOC 2 vs. EOC 4

| | Average Surface Concentration mg/dm$^2$ | | |
|---|---|---|---|
| Span | EOC 2 | EOC 4 | Ratio C4/C2 |

+(a,c)

Correction to #96 116 (6/15/97)

# Callaway EOC 7

# Assemblies Scraped for Crud

## SUMMARY OF CALLAWAY CYCLE 6 AND 7 OPERATIONAL DATA

| F/A | Cycle 7 | | | Cycle 6 | | |
|---|---|---|---|---|---|---|
| | Power at 12004 MWD/MTU | AO Value (%) | Assembly Crud Index | Power at 11596 WMD/MTU | AO Value (%) | Assembly Crud Index |
| H - 12 | 0.468 | -1.3 | [ ]+(a,c) | 1.300 | -8.4 | [ ]+(a,c) |
| H - 88 | 1.044 | -2.1 | | 1.340 | -11.6 | |
| J -38 | 1.321 | -1.8 | | - | - | - |
| J - 40 | 1.305 | -1.9 | | - | - | - |
| J - 93 | 1.31 | -1.6 | | - | - | - |

# Callaway CY 6, CY 7 Crud Comparisons

## Average Surface Concentration and Thickness - Span 6

| Feed Fuel | | | | Twice Burned Fuel | | | |
|---|---|---|---|---|---|---|---|
| CY 6 | | CY 7 | | CY 6 | | CY 7 | |
| H-12, H-88 | | J-38, J-40, J-39 | | G-32, G-87 | | H-12, H-88 | |
| $mg/dm^2$ | μ | $mg/dm^2$ | μ | $mg/dm^2$ | μ | $mg/dm^2$ | μ |

[ ] +(a,c)

Correction to #95-213
(6/15/97)

# Callaway Crud Chemical Composition

**Average Compositions of Crud from Span 6**
**from High Power Feed Fuel from Cycles 6 and 7**

+(a,c)

# Summary of Crud Scrape Data

- Crud thickness in proportion to extent of AOA
- Crud concentrations as expected, except Ni/Fe ratios > [ ] [+(a,c)]
- Crud removal observed when driving forces for crud deposition decreased

# Mechanism of AOA

- Some level of sub cooled boiling on feed fuel
- Sub-cooled boiling exacerbates crud deposition
- Boron concentrates within porous crud deposit
- Under some conditions, solubility limit of B-rich solid, e.g., $LiBO_2$, exceeded
- Power suppression due to B-rich solid within crud in top spans of high-power fuel

# Approaches for AOA Mitigation

- Minimize extent of sub-cooled boiling through core design optimization
- Minimize crud deposition through coolant chemistry control
  - Li/B pH control strategy
  - Elevated pH at BOC
  - Coolant corrosion product management

# Axial Offset Anomaly Safety Evaluation

## Nuclear Regulatory Commission

7/31/97

J. R. Secker

Westinghouse

Commercial Nuclear Fuel Division

# Safety Evaluation

- Fuel
- Non-LOCA
- LOCA

# Plant Experience

- Reactivity Changes Associated With Axial Offset Anomaly Occur Slowly
- Boron Compounds No Longer Present in Crud On Return to Critical Following Plant Trip (~12-24 hours)
- Boron Compound Returns to Crud During Power Ascent

# Plant Experience

- Effect of Small AO Deviations Are Much Smaller Than Uncertainties/Conservatism Applied to Safety Analysis Inputs
- AOA Does Not Increase Control Rod Drop Time
- AOA Has Not Caused Any Plant Trips

# Conservative Assumptions for Safety Evaluation

- Small Rapid Reactivity Release From Liquid Boric Acid Concentrated in Crud
  - [ ] +(a,c) of Total Reactivity Associated With AOA
  - [ ] +(a,c) Release Rate
- Observed Plant Behavior Indicates This Assumption is Very Conservative
- Dissolution of Boron Compound Occurs Slowly Enough (Hours) to Not Affect Safety Analysis Assumptions

# Conservative Assumption for Shutdown Margin

- Assumes Instantaneous Reactivity Addition Following Plant Trip
- Very Conservative Assumption Relative to Plant Behavior - Dissolution of Boron Compound Does Not Occur Instantaneously

# Fuel/Core Analysis

## Fuel Related Inputs to Safety Analysis

- Most Parameters Are Not Affected and Remain Bounded By FSAR Safety Analysis
  - Reactivity Coefficients, Kinetics Parameters, Power Distributions
- Parameters Affected:
  - Shutdown Margin
  - Relaxed Axial Offset Control (RAOC) Peaking Factor Surveillance Factors, W(z)

# Fuel/Core Analysis

- DNBR
  - Crud Has Negligible Affect on DNBR
  - Core Limits Remain Applicable for DNB Protection
- Fuel Rod Design
  - Most Design Criteria Unaffected
  - Corrosion Model Database Includes Plants With Crud/AOA - Callaway and Millstone 3
  - Results in [ ] +(a,c) Fuel Temperature Increase at Intermediate Burnups. BOC Temperatures are Still the Highest

# Non-LOCA Accident Analysis

- All Non-LOCA Events Reviewed
- Most Accidents Not Affected
  - Input Parameters Remain Bounded
  - HZP Events Not Effected Since Boron Compound Not Present at HZP
  - Beginning of Cycle Events Not Affected Since Crud is Not Present
  - Limiting DNB Events Result in Increased Subcooled Boiling - No Additional Reactivity Insertion
- Accidents Sensitive to Transient Reactivity Release Maintain Margins To Safety Analysis Limits

# Non-LOCA Accidents
# Crud Release

- Rod Withdrawal At Power
- Rod Ejection At Power

# Non-LOCA Accidents
# Crud Release

- Rod Withdrawal At Power
  - Core Analysis Shows Substantial Margin To Maximum Reactivity Insertion Rate Without Crud
  - Limiting Case is Not Maximum Reactivity Insertion Rates - Intermediate Rates Show Minimum DNBR
  - Increased Reactivity Insertion Rate Results in Earlier Plant Trip

# Non-LOCA Accidents
# Crud Release

- Rod Ejection At Power
  - Very Fast Transient
  - Plant Trip Occurs in 0.1 Sec
  - Control Rod Insertion in Core in 0.5 Sec
  - Nuclear Power Rise Limited By Doppler Feedback - Thermal Power Increase is Small
  - Small Change in Clad Temperature
  - Although There is Little Time for Crud Release to Occur, Event Was Evaluated Assuming Crud Release From Ejected Rod Assembly and Surrounding Assemblies
  - Bounding Reactivity Insertion And Peaking Factor Limits Still Met

# Loss of Coolant Accidents

- Power Shapes Remain Bounded
- Reactivity From Crud Release Offset By Voiding (Large Break) and Trip (Small Break)
- Beginning of Cycle Fuel Temperatures Are Still Highest Since Presence of Crud At Later Burnups Results in Only a Small Fuel Temperature Increase
- Minimal PCT Impact [ ]$^{+(a,c)}$ on Small Break LOCA
- No Affect on Large Break LOCA PCT Since BOC is Limiting (No Crud)

# Safety Evaluation Summary

- Impact of AOA on Fuel And Accident Analysis Thoroughly Considered
- Key Impacts Are Shutdown Margin And Power Distribution Surveillance Factors
  - These Are Updated For Plants With AOA
- All Fuel/Non-LOCA/LOCA Design And Safety Criteria Continue to Be Met
- No Adverse Impact on Safe Plant Operation