WCAP-14783

Final Report

Incomplete RCCA Insertion

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1.0 Introduction/ History of Events

An RCCA insertion anomaly was experienced at Wolf Creek near the end of Cycle 8. During this trip, five RCCAs did not fully insert. Wolf Creek performed rod drop tests at reactor coolant temperature below 200°F after the anomaly and after three additional RCCAs did not fully insert.

Since Wolf Creek was approximately one month from EOC shutdown, the utility decided to remain shutdown and go into their refueling outage.

A similar incident occurred at South Texas Unit 1 on December 18, 1995 when during a reactor trip, four RCCAs did not fully insert. Subsequent to a review of the situation with the NRC, the unit returned to power with an agreement to conduct an RCCA trip/operability test on March 2, 1996. The RCCA tests on March 2 resulted in seven RCCAs which did not fully insert. Subsequent to satisfying technical specifications and safety evaluation limits, the unit returned to power until EOC when it shutdown. In accordance with NRC Bulletin 96-01, RCCAs were tripped and eleven RCCAs did not fully insert. A calendar of events is shown below.

Calendar of Events

South Texas Event	12/95
Wolf Creek Event	01/96
NRC Contacted WOG/WOG Responded to 14 NRC Questions	02/96
Westinghouse/WOG/NRC Meeting	02/96
Bulletin 96-01 Issued	03/96
NRC/Westinghouse/WOG Meeting Susceptible Fuel 06/15/96 Root Cause 08/31/96	03/96
Westinghouse/WOG/NRC Meeting	05/96
Westinghouse Meeting with NRC on Susceptible Fuel	06/96
WOG/NRC Meeting	08/96
Westinghouse Root Cause Meeting with NRC	9/9/96

2.0 Summary of Plant Trip Information

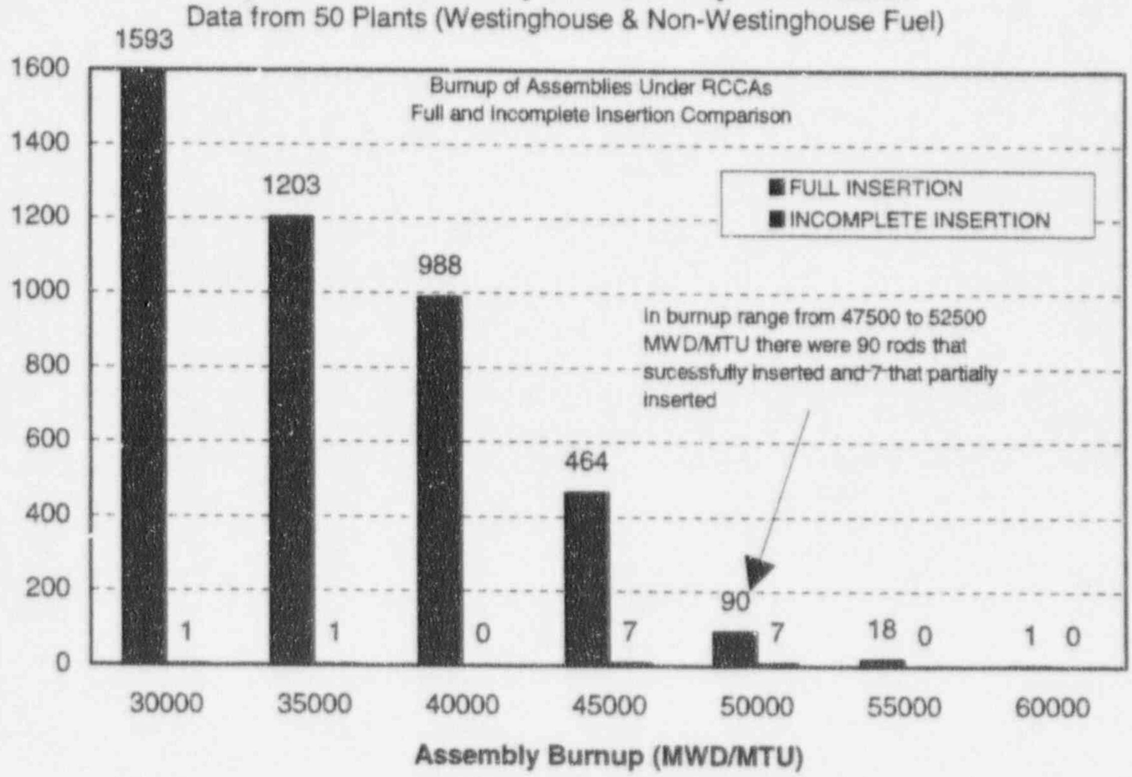
Figure 2.1 provides a graphical representation of plant trip information for full and incomplete RCCA insertion for 50 of the 51 Westinghouse designed domestic plants (the remaining plant, Watts Bar, is not included since its fuel assembly burnup is below 27,500 MWD/MTU). This figure has been developed based on information provided by the utilities in response to a request from the Westinghouse Owners Group (WOG). The data include information from both Westinghouse and non-Westinghouse supplied fuel of 12 foot, 10 foot, and 14 foot designs and

consists of the results of beginning of cycle and end of cycle rod drop tests, mid-cycle rod drop tests, and RCCA insertion observations during reactor trips. The table below provides a summary of this figure with information relative to the fuel assemblies at Wolf Creek and South Texas Unit 1 incomplete RCCA insertions.

BU (GWD/MTU) RANGE UNDER RCCA's	NUMBER FAs SHOWING FULL INSERTION	NUMBER FAs SHOWING INCOMPLETE INSERTION (WOLF CREEK)	NUMBER FAs SHOWING INCOMPLETE INSERTION (SOUTH TEXAS UNIT 1)
27.5 - 32.5	1593	0	1
32.5 - 37.5	1203	0	1
37.5 - 42.5	988	0	0
42.5 - 47.5	464	0	7
47.5 - 52.5	90	5	2
52.5 - 57.5	18	0	0
57.5 - 62.5	1	0	0

Figure 2.1: Summary of Plant Trip Information

Data from 50 Plants (Westinghouse & Non-Westinghouse Fuel)



As indicated above, the only instances of incomplete RCCA insertion below an assembly burnup of 47,500 MWD/MTU are associated with South Texas Unit 1, a plant utilizing a 14 foot fuel design. Additionally, with fuel of the 12 foot and 10 foot designs, there have been no incomplete RCCA insertions in fuel assemblies with an assembly burnup below approximately 49,000 MWD/MTU.

3.0 Root Cause Process

Several activities were planned/initiated to determine the root cause of incomplete RCCA insertion. These activities are shown pictorially in Figure 3.1. The objective/purpose of these activities are as follows (the detailed results will be discussed in later sections):

<u>Plant Trip History Data</u>
Determine the extent of the problem for all domestic plants that have experienced trips in the last 3-5 year period. The results were discussed in the previous section.

<u>Detailed Manufacturing Review</u>
Determine whether the thimble tube materials used in Wolf Creek and South Texas were unusual in any respects with regard to material specifications or process changes. Results showed no abnormalities in process or basic material properties.

<u>Plant Operations and Fuel Management Review</u>
Determine if there were any unique or unusual chemistry, fuel management, or core operating conditions which might suggest a cause. Both plants operated within the chemistry specifications. However, both plants have high operating temperature and Wolf Creek (Region H) appeared to operate with a somewhat unusual power history (3 cycle operation with high power in cycle 2 and 3).

<u>Review of Available Worldwide Experience</u>
Determine in a similar but less detailed fashion whether similar problems have been experienced in non-domestic plants. To date there are six European plants which have experienced incomplete RCCA insertions which appear to have the same symptoms as Wolf Creek and South Texas and therefore probably have the same or similar root cause. Information has and continues to be gathered on these plants and incorporated in the process to determine common root causes.

<u>Westinghouse Testing at Plant Sites</u>
Develop and implement a detailed testing program to gather information at ten plant sites (8, excluding Wolf Creek and South Texas Unit 1). The plants and particular fuel assemblies tested were identified to cover the range of most all Westinghouse designs as well as bracket the time history of thimble tube fabrication for Wolf Creek (see Figure 3.2).

The results suggested that the W[illegible] reek H assemblies were unique in terms of fuel assembly growth. Wolf Creek and South Texas also displayed RCCA drag characteristics which were significantly larger than other plants tested, and also different from each other.

<u>Zircaloy Material Property Review</u>
Performed a comprehensive review of all known Zircaloy properties information including work with outside consultants. This was done because Wolf Creek experienced unusually large fuel assembly growth. In addition, unirradiated material tests were performed to augment existing information on the effects of oxide and hydrogen on fully annealed tubing. This information was used to modify the Westinghouse growth model. This information was also incorporated in our overall mechanical model.

Hot Cell Measurements
Determine the dimensional and material conditions/characteristics in irradiated Wolf Creek fuel assemblies to obtain basic information and insight into detailed thimble tube behavior. Fuel rods from two assemblies (H50 and H38) that had experienced incomplete RCCA insertion were removed, the skeletons sectioned and sent to the Westinghouse Science and Technology Center (STC) hot cell facility for detailed examination. Key information gathered was growth as a function of elevation, oxide/hydrogen as a function of elevation and detailed dimensional characteristics of thimble tubes (ovality, bow, diameter).

Detailed Mechanical Model
Develop a mechanical model based on prior experience and basic knowledge of fuel mechanical design criteria and incorporate all the information developed on growth mechanisms. The purpose of the model is to understand the interactions of various mechanisms, interpret test results and evaluate future design changes. The comparisons between the model and test results are reasonably good considering the complexity of the problems.

Figure 3.1: Root Cause Determination Process

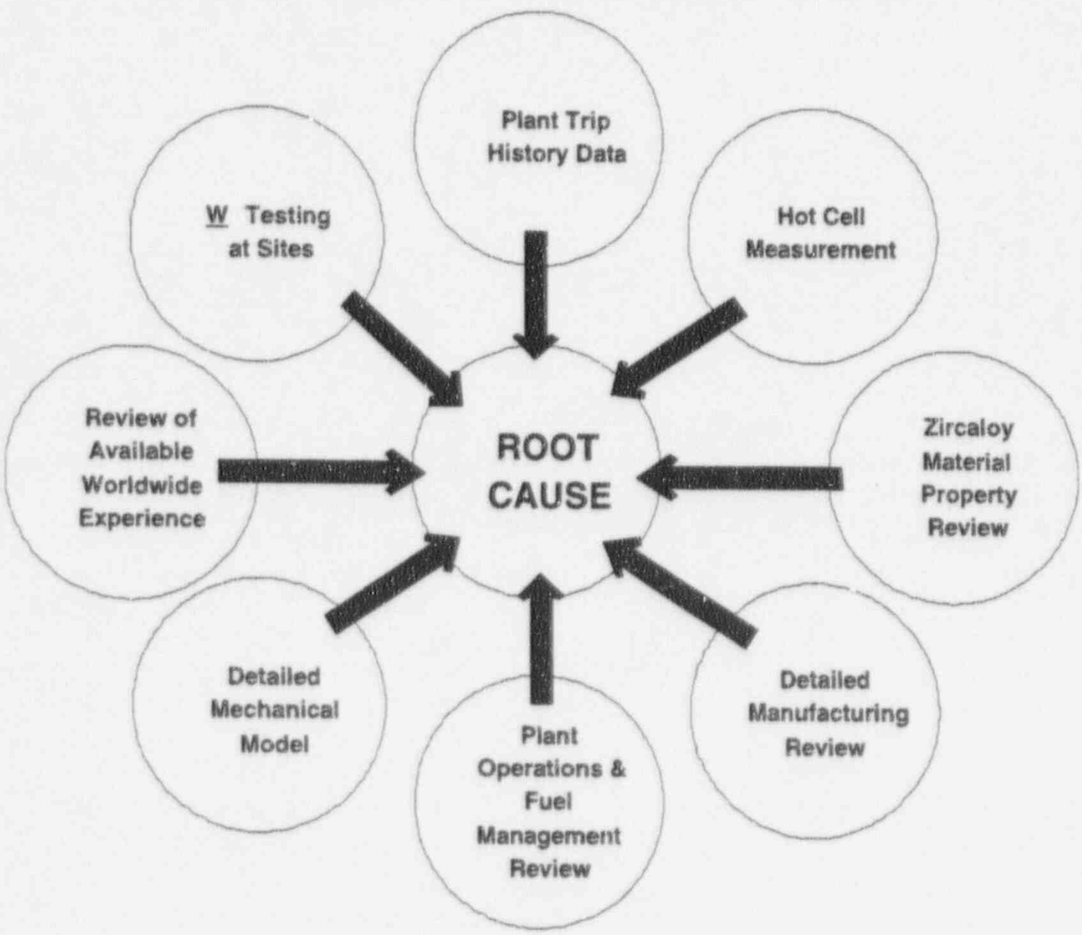


Figure 3.2: Program Status Overview

Isolation of the Population that may be Susceptible

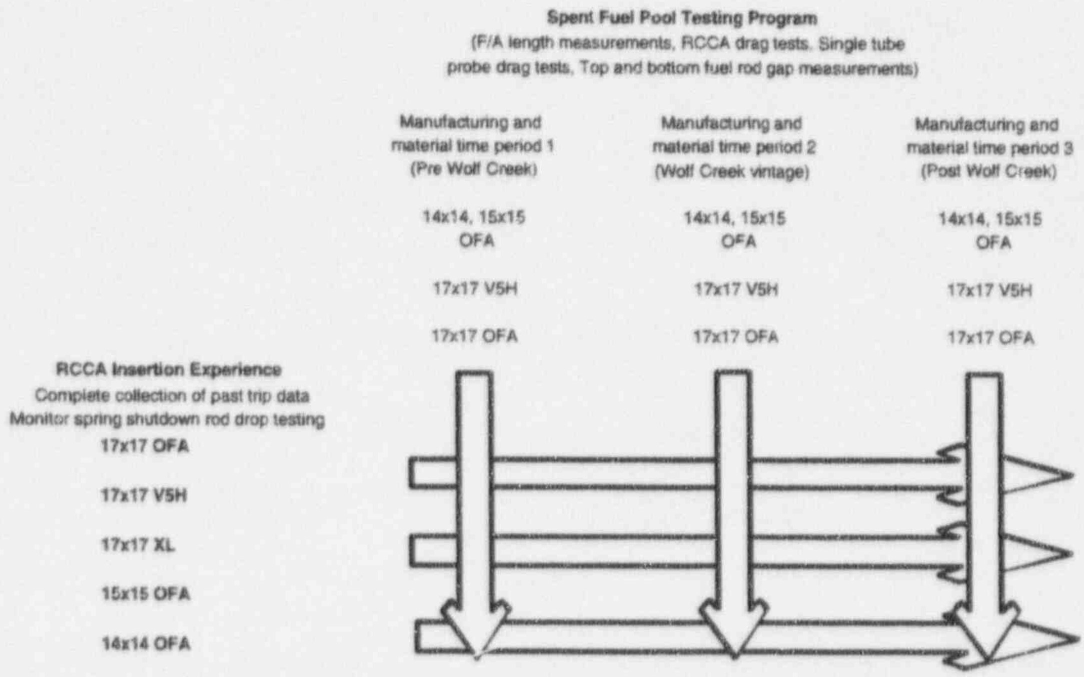


Figure 3.3: Process & testing logic used to determine root cause

Determine extent of problem
- Plant trip history data

Related to design (V5H) or manufacturing?
- Materials and process review
- Testing program at ten sites

Related to plant operations?
- Chemistry
- Temperature/flow/power
- Fuel management

Material property related?
- Unirradiated tests
- Hot cell exams
- Literature review
- Consultant experts including General Electric

Root cause hypothesis
- Data analysis
- Analytical model

4.0 Site Test Program/Logic

As previously discussed, the purpose of the Site Testing Program was to determine the susceptibility of various designs for the incomplete RCCA insertion anomaly. Manufacturing effects/contributions were also investigated by sampling assemblies which had thimble tubes that were manufactured before, during, and after the time period in which the thimble tubes for Wolf Creek were manufactured (Figure 3.2).

Table 4.1 shows the plants included in the program, their fuel design type and the nature of the tests performed. A summary of the results follows with the detailed data for each plant being included in the appendices.

Table 4.1: Completed Site Testing Programs

PLANT	FUEL TYPE	VISUAL	DRAG TESTING	GROWTH	PROBE	BORESCOPE	FA BOW
Wolf Creek	17x17 V5H	√	√	√	√	√	√
	17x17 V5H w/IFM	√	√	√	√	NP	√
	17x17 STD	√	√	√	NP	NP	NP
Millstone 3	17x17 V5H w/ IFM	√	√	√	√	NP	NP
South Texas	17x17 XL	√	√	√	√	√	√
Point Beach	14x14 OFA	√	√	√	√	NP	NP
Surry	15x15 OFA	√	√	√	√	NP	NP
VC Summer	17x17 OFA w/IFM	√	√	√	√	NP	NP
Sequoyah	17x17 V5H	√	√		√	NP	NP
Diablo Canyon	17x17 OFA w/IFM	√	NP	√	√	NP	NP
North Anna	17x17 V5H	NP	√	√	√	NP	NP
Vogtle	17x17 OFA w/IFM	√	√	√	√	NP	NP

NP = Not Planned

5.0 Site Testing

In this section of the report, the visual, drag test, fuel assembly growth, fuel rod growth, single tube probe, borescope and fuel assembly bow results are presented. In Table A.1, the design features for the different types of fuel assemblies that were tested are presented. In Table A.2, the drag, fuel assembly growth, fuel rod growth and single tube probe data is summarized for the assemblies that were tested. In Appendix D, the inspection report for the different programs is presented.

5.1 Guide Thimble Drag Tests

The drag test results for two different programs are presented in this section. The two programs are the NRC Bulletin 96-01 tests and the root cause tests performed by Westinghouse. The NRC Bulletin 96-01 tests were performed after the reactor tripped. The root cause tests were investigative tests on fuel assemblies that were stored in the spent fuel pool. The NRC Bulletin 96-01 tests are referred to as "drag measured after reactor trip" while the root cause tests are referred to as "spent fuel pool tests".

In response to NRC Bulletin 96-01, nuclear plants supplied either "in-core drag data" or "spent fuel pool drag data" for either "withdrawal drag data" or "withdrawal and insertion drag data". The data was analyzed and based on the data trends, the Wolf Creek spent fuel pool withdrawal drag data was compared with the withdrawal drag data from other plants. This analysis revealed the following necessary conditions for incomplete RCCA insertions in 12' fuel assemblies: a) the fast fluence must be greater than 7.5×10^{21} nvt (~40 GWD/MTU) and b) the F-spec screening guideline for the [

.]^{a,b,c}.

The "drag measured after reactor trip" results are presented in Figures 5.1.1, A.1 and A.2. The data in these figures and the questions that were answered in Appendix C support the IFM acceptability conclusions.

The Wolf Creek plant drag data and the root cause drag data are presented in Table A.2 and in Figures 5.1.2, A.3 and A.4. The data in these figures and the questions that were answered in Appendix C support the 14x14 fuel assembly, 15x15 fuel assembly and IFM acceptability conclusions. The drag test results from the different programs are discussed below.

<u>Wolf Creek - Phase 1</u>

1) <u>Drag Test with Upper Internals in Place</u>
A total of 27 RCCA positions were selected for drag testing with the upper internals in place. They included some assemblies which did not fully insert, and a sample of assemblies with various burnups. Fuel assembly H16 (hafnium RCCA) was not selected because of the risk that the RCCA could not be reinserted. Since it was necessary to preserve "evidence" within some of the assemblies for future testing, fuel assemblies H03, H53 and H59 were not selected.

The reactor head was first removed with the RCCA drive shafts remaining attached to the RCCAs. A load cell and strip chart recorder were used in conjunction with the crane to withdraw the RCCA from the fuel assembly while recording total weight as a function of axial position of the RCCA in the fuel assembly.

Each of the thrice burned fuel assemblies (Region "H") showed a high drag in both the dashpot and the upper guide thimble. With only one exception (assembly H69), all "H" assemblies would have exceeded the F-spec guideline. The twice burned assemblies (Region "J") showed an intermediate drag, and the once burned (Region "K") showed low drag.

On the "H" assemblies, although the highest drag was observed in the dashpot, a relatively high drag was observed over the entire length of the upper guide thimble. The "J" and "K" assemblies exhibited negligible drag in the upper guide thimble, and light to moderate drag in the dashpot.

2) <u>Drag Tests in the Spent Fuel Pool</u>
Seventeen fuel assemblies were selected for this test based on the results of the in reactor tests. The selected RCCAs were latched with a handling tool and withdrawn approximately 108 inches, then reinserted back into the fuel assembly.

In general, the highest drag was observed at the bottom of the dashpot (breakaway). The drag would then decrease to a constant (relatively high) value through the rest of the dashpot. There is usually a sharp decrease as the tips of the RCCA rodlets exit the dashpot. The drag typically decreases constantly but slowly through the upper guide thimble until it is stopped at about 108 inches. The drag for the "H" assemblies was still relatively high at the end of withdrawal.

3) <u>Drag Tests of RCCAs in Reference Fuel Assembly</u>
Seventeen RCCAs were drag tested in a new fuel assembly (L54). In all cases, the drag observed was less than [ ]^{a,b,c} and is insignificant. The results indicate that a binding interference exists between the thimble tubes and the RCCAs, causing the high drag. The RCCAs show no indications of damage or deformation; therefore, the problem resides within the fuel assembly.

<u>Wolf Creek - Phase 2</u>
Six additional fuel assemblies were selected for drag testing. Two 'G' region and four 'H' region assemblies were tested. The 'G' region assembly burnup values were 35 and 54 GWD/MTU. The 'H' region assembly burnup values were 34.3, 37.4, 39.7 and 43.7 GWD/MTU.

Both 'G' region assemblies showed low drag in the upper guide thimbles. Assembly G33 (35 GWD/MTU) showed low drag in the dashpot and assembly G68 (54 GWD/MTU) showed high drag in the dashpot. Because of the low upper guide thimble drag values it was judged that neither 'G' region assemblies were at risk for the insertion anomaly problem during operation.

The 'H' region assemblies also showed relatively low drag in the upper guide thimbles and intermediate to high drag in the dashpot. The drag in the four assemblies could not be differentiated by burnup. Based on the low upper guide thimble drag, it was judged that none of these 'H' region assemblies were at risk of an insertion anomaly during operation. It is noteworthy that even though the upper guide thimble drags were low, they were still on average higher than the 'G' region assemblies tested.

<u>Wolf Creek - H50 Skeleton Assembly</u>
After the fuel rods were removed from fuel assembly H50, a drag check measurement was performed with the dummy RCCA. The purpose was to determine what difference, if any, could be measured with the fuel rods removed. The measurements were taken in the new fuel elevator with the skeleton clamped down.

The drag measured in the empty skeleton was somewhat lower than the drag in the fuel assembly, but was still in the high range. The small decrease in drag indicates that the deformations in the fuel assembly skeleton are primarily plastic (i.e., permanent) rather than elastic or associated with fuel rod loading.

North Anna

Fuel assemblies fabricated for six different contracts were drag tested in the spent fuel pool Drag test data was not obtained for assemblies 0A1, 0A2, 0A8 and 2A8 because the RCCA would not insert completely into the assembly. Due to constraints on resources the RCCA was not pushed to full insertion. Therefore, the drag in the dashpot is not available, but it is known this drag exceeds [.][a,b,c]

Fuel assembly 3L4 was the only assembly to exceed the F-spec dashpot and guide thimble drag guideline. Fuel assembly 3L4 (VGIF) displayed high dashpot drag similar to the fuel assemblies that experienced incomplete RCCA insertion at Wolf Creek. However, it should be noted that even the highest upper guide tube drag of [ ][a,b,c] (insertion drag) in North Anna assembly 3L4 is about 80% of the minimum upper guide tube drag load of [ ][a,b,c] (insertion drag) for assemblies that did not fully insert at Wolf Creek.

VC Summer

Fuel assemblies fabricated for two different contracts were drag tested in the spent fuel pool. Fuel assemblies K47, H50 and H46 did exceed the F-spec dashpot drag guideline [ ][a,b,c] but none of the assemblies exceeded the F-spec upper guide thimble drag guideline [ ][a,b,c]. The upper guide thimble drag loads were [ ][a,b,c] for all assemblies tested. The low upper guide thimble drag has been attributed to the IFMs within these assemblies.

The VC Summer fuel assemblies that were tested had fast fluence values less than or equal to 8.001 x 10^{21} nvt. The VC Summer assemblies did not display drag characteristics similar to the Wolf Creek assemblies that experienced incomplete RCCA insertion for comparable fluences.

Point Beach

Fuel assemblies fabricated for four different contracts were drag tested in the spent fuel pool. Fuel assemblies Y11, V75, V77, V78, Z11 and Z12 exceeded the F-spec upper guide thimble drag guideline of [ ][a,b,c], but none of the assemblies exceeded the F-spec dashpot drag guideline of [.][a,b,c]

Vogtle

Fuel assemblies fabricated for four different contracts were drag tested in the spent fuel pool. Fuel assemblies 5G68 and 5G84 were not tested because the [.][a,b,c] Due to constraints on resources the RCCA was not pushed to full insertion. Therefore, the drag in the dashpot is not available, but it is known this drag exceeds [.][a,b,c] None of the assemblies exceeded the F-spec upper guide thimble drag guideline of [.][a,b,c] Eight assemblies exceeded the F-spec dashpot drag guideline of [.][a,b,c] The low upper guide thimble drag has been attributed to the IFMs within these assemblies.

Surry

Fuel assemblies fabricated for five different contracts were drag tested in the spent fuel pool. Two assemblies from region VPIF (0F3 and 0F6), standard design, were drag tested as part of the inspection plan. These assemblies had burnups greater than 49,000 MWD/MTU and showed negligible upper guide tube and dashpot drag.

Fuel assemblies 3H8, 5H1, 4G1 and 0V2 exceeded the F-spec guidelines. Assemblies 3H8, 5H1 and 0V2 were in control rod locations during their last cycle of operation and tripped properly. A review of the drag traces shows that the assemblies generally exhibit a gradual increase in the upper guide tube drag with increasing insertion, consistent with a gradual bowing of the tube. The drag increases slightly when entering the dashpot and continues to gradually increase up to the maximum value recorded. This behavior is more benign than that experienced by Wolf Creek assemblies with comparable burnups. The comparable Wolf Creek assemblies exhibited [ ]^{a,b,c} increased drag steps and [ ]^{a,b,c} in the upper guide tube sections and dashpots in assemblies which did not allow complete RCCA insertion.

South Texas

Fuel assemblies fabricated for four different contracts were drag tested in the spent fuel pool.. In contrast to the Wolf Creek fuel, none of the South Texas Unit 1 fuel assemblies exceeded the F-spec upper guide thimble drag guideline. All the significant drag is attributable to the dashpot interference.

A review of the drag traces [ ]^{a,b,c} shows that the assemblies generally exhibit a small, steady upper guide tube drag with increasing insertion. This is consistent with traces from the dummy fuel assembly. The drag then shows a [ ]^{a,b,c} as it enters the upper dashpot. The load generally levels off in the transition piece between the upper and lower dashpots. The load increases again in another [ ]^{a,b,c} upon entering the lower dashpot. The process concludes with one final rapid increase to its peak as the RCCA approaches full insertion.

Sequoyah

Fuel assemblies fabricated for eight (8) different contracts were drag tested in the spent fuel pool. The fast fluence value for assemblies S74 and F61 is greater than 9 x 10^{21} nvt (47.7 GWD/MTU). However, insertion did occur in these assemblies because their guide thimble drag values are low [.]^{a,b,c}

Assembly E22 was tested three (3) times and at each time the RCCA [.]^{a,b,c} This assembly probably would not have experienced an insertion anomaly because of the low upper guide thimble drag value [ ]^{a,b,c}

Millstone

Fuel assemblies fabricated for two different contracts were drag tested in the spent fuel pool. Nine of the ten fuel assemblies that were tested were fabricated with Vantage 5H fuel features and have burnups of approximately 47 GWD/MTU. All of the Millstone 3 drag data is within the guideline limits.

Figure 5.1.1: Dashpot and Upper Guide Thimble Drag Data
(Drag Measured after Reactor Trip)

a,b,c

Figure 5.1.2: Dashpot and Upper Guide Thimble Drag Data
(Spent Fuel Pool Testing)

a,b,c

5.2 Fuel Assembly and Fuel Rod Growth

Fuel assembly growth data is obtained by using a measuring device that has a dial indicator and comparing the measurement to a standard of known length. The data is corrected for the spent fuel pool water temperature.

Fuel rod growth data is obtained from the axial gaps between each peripheral rod and the assembly nozzles that were measured from the low magnification TV tapes. The measurements were performed using a divider and steel scale. The actual gaps were determined from conversion factors. Conversion factors were obtained by measuring the TV image of several grid spring heights on the outer straps in the top and bottom grids. The factors were obtained by comparing the measured spring height to the as-built dimension. [.]^{a,b,c} The rod growth data is summarized in Table A.1.

Fuel rod growth was derived from pre- and post- gap data and the measured fuel assembly growth using the following equation:

[ ]^{a,b,c}

For selected F/As, the axial gap between each peripheral rod and the F/A top nozzle was manually measured from the low magnification TV tapes obtained during the fuel examination. When combined with the F/A growth information previously obtained, a value for fuel rod growth can subsequently be derived. Conversion factors were also used as outlined above.

In Figures 5.2.1 and 5.2.2, the recent assembly growth data is shown for [,]^{a,b,c} respectively. The data in Figure 5.2.1 shows that the problem assemblies at Wolf Creek are [.]^{a,b,c} The data also shows the higher fuel assembly growth trend in the Wolf Creek "H" assemblies and some of the VC Summer demonstration fuel assemblies. In Figure 5.2.2, all of the assemblies that were measured are[.]^{a,b,c} The assembly and rod growth data summaries are provided below.

<u>Wolf Creek - Phase 1</u>
Twenty-six fuel assemblies were measured for fuel assembly growth. The thimble tube material of the "H", "J" and "K" [;]^{a,b,c} all "G" assemblies utilized [.]^{a,b,c} The fuel assembly growth was [ ]^{a,b,c} for the "G" assemblies, [ ]^{a,b,c} for the "H" assemblies (excluding H81), [ ]^{a,b,c} for the "J" assemblies and [ ]^{a,b,c} for the "K" assemblies.

It should be noted that assembly H81 showed relatively low growth since the assembly was irradiated for only two cycles and had been stored in the Spent Fuel Pool. The growth data from the "H" assemblies appears to be higher than the existing data, possibly due to the initiation of breakaway growth at the higher temperatures and burnups.

Rod growth data was obtained on eleven (11) assemblies. [.][a,b,c] It was also observed that the top gaps in most of the assemblies were fairly even, except that some interior rods in assemblies J29, H62, and H43 appeared higher than the exterior rods.

The calculated fuel rod growth was [ ][a,b,c] for the "G" assemblies, [ ][a,b,c] for the "H" assemblies, [ ][a,b,c] for the "J" assemblies and [ ][a,b,c] for the "K" assemblies. The Wolf Creek rod growth data are [ ][a,b,c] at higher burnup levels.

<u>Wolf Creek - Phase 2</u>

The fuel assembly length measurements were performed on 8 assemblies. The 'G' assemblies use [.][a,b,c]

The measured assembly growth was [ ][a,b,c] for the G assemblies (G33 was twice burnt and G68 was three times burnt), [ ][a,b,c] for J assemblies and [ ][a,b,c] for H assemblies. It should be noted that, of the 4 'H' assemblies, only H61 was irradiated for three cycles. Assemblies H35, H67 and H83 were irradiated for two cycles. The assembly growth of [.][a,b,c]

Rod growth data was obtained for 10 additional assemblies. [.][a,b,c] The data range was [ ][a,b,c] for the G assemblies (G33 was twice burnt and G68 was three times burnt), [ ][a,b,c] for the J assemblies, and [ ][a,b,c] for the H assemblies (H35, H67, and H83 were twice burnt). The data shows that the Wolf Creek rod growth values are within the expected limits at comparable burnup levels.

<u>North Anna</u>

Fuel assembly length measurements were performed on 16 assemblies (14 assemblies were drag tested during root cause testing). The thimble tube material for assemblies 2A8, K17, K32, Y08, and X09 is [ ][a,b,c]; the remaining assemblies have thimbles made from [.][a,b,c]

The measured assembly growth was from [.][a,b,c] The assembly growth data is within the expected range and does not show any evidence of breakaway growth.

VC Summer

Fuel assembly length measurements were performed on a total of 8 assemblies. The thimble tube material in assemblies H46 & H51 is [ ]^{a,b,c}; assemblies H47 & H50 have [;]^{a,b,c} assemblies J09, J10, J13, and J22 have [.]^{a,b,c}

The measured growth was [ ]^{a,b,c} for the "H" assemblies and [ ]^{a,b,c} for "J" assemblies. The data is within the expected range and does not show any evidence of breakaway growth. The "J" assembly growth data confirms that [ ]^{a,b,c} growth is significantly less than [.]^{a,b,c}

Point Beach

Assembly length and rod growth measurements were performed on a total of 10 assemblies. The thimble tube material of assemblies V75, V76, V77, V78, Y11, and Z11 is [ ]^{a,b,c} is the thimble tube material for assemblies V17, V20, V22, and V26.

The measured assembly growth was [.]^{a,b,c} The data is within the expected range and does not show any evidence of breakaway growth. The rod growth data was [ ]^{a,b,c} for the V assemblies, [ ]^{a,b,c} for the Y assembly, and [ ]^{a,b,c} for the Z assembly.

Vogtle

Fuel assembly length and rod growth measurements were performed on a total of 14 assemblies. The thimble tube material of assembly 5D28 is [ ]^{a,b,c}; all thimbles in the "F", "G" and "R" assemblies contain [.]^{a,b,c}

The assembly growth was [ ]^{a,b,c} for assembly 5D28, [ ]^{a,b,c} for F assemblies, [ ]^{a,b,c} for G assemblies, and [ ]^{a,b,c} for R assemblies. The data is within the expected range and does not show any evidence of breakaway growth. Fuel assemblies 5F27, 5F41, 5F65, 5F43 and 5F47 were fabricated with the same thimble tube lots as Wolf Creek assemblies H59 and H53.

In the rod growth measurements, most of the rods in all of the assemblies .]^{a,b,c} The data was [ ]^{a,b,c} for the "D" assembly, [ ]^{a,b,c} for the "F" assemblies, [ ]^{a,b,c} for the "R" assemblies, and [ ]^{a,b,c} for the "G" assemblies. The Vogtle rod growth values are slightly lower than the expected results at the higher burnup levels.

Surry

Fuel assembly length measurements were performed on a total of 10 assemblies. Assemblies 0F3, 0F6, 1G0, and 4G1 use [ ]^{a,b,c} thimble material, while all of the "H", "J", and "V" F/A thimbles use [.]^{a,b,c}

The measured growth was [ ]a,b,c for the "F" assemblies, [ ]a,b,c for the "G" assemblies, [ ]a,b,c for the "H" assemblies, [ ]a,b,c for the "J" assemblies and [ ]a,b,c for the "V" assemblies. The data is within the expected range and does not show any evidence of breakaway growth.

Fuel assemblies 0F3, 1G0, 4G1, 5H1, and 3J1 were measured for rod growth. [ ]a,b,c The rod growth data was [.]a,b,c The rod growth data is consistent within the expected range.

South Texas

Fuel assembly length measurements were performed on a total of 24 assemblies. The measured growth range was [ ]a,b,c for the C assemblies, [ ]a,b,c for F assemblies, [ ]a,b,c for R assemblies and [ ]a,b,c for E assemblies. The South Texas growth data is normal and within the expected range. The data does not show any evidence of breakaway growth.

Rod growth measurements were made for 9 South Texas Unit 1 assemblies to determine fuel rod growth. The data range was [ ]a,b,c for the C assembly, [ ]a,b,c for the E assemblies, [ ]a,b,c for the F assemblies, and [ ]a,b,c for the R assemblies. The data shows that the South Texas rod growth values are within the expected limits at comparable burnup levels.

Millstone

Fuel assembly length and rod growth measurements were performed on 10 assemblies. The measured assembly growth was [ ]a,b,c for the assembly E40 and [ ]a,b,c for the F assemblies. The data is within the expected range and does not show any evidence of breakaway growth.

The rod growth data range was [ ]a,b,c for assembly E40 and [ ]a,b,c for the F assemblies. The data shows that the Millstone rod growth values are within the expected limits at comparable burnup levels.

Diablo Canyon

Fuel assembly length and rod growth measurements were performed on 16 assemblies. The measured assembly growth was [ ]a,b,c for the T assemblies, [ ]a,b,c for the U assemblies and [ ]a,b,c for the S assemblies. The data does not show any evidence of breakaway growth.

The rod growth data range was [ ]a,b,c for the S assemblies, [ ]a,b,c for the T assemblies and [ ]a,b,c for the U assemblies. The data shows that the Diablo Canyon 2 rod growth values are within the expected limits at comparable burnup levels.

Figure 5.2.1: Recent Fuel Assembly Growth Data - Zr-4 Grids

a,b,c

Figure 5.2.2: Recent Fuel Assembly Growth Data - Inconel Grids

a,b,c

5.3 Guide Thimble Single Tube Probe

Fuel assemblies that show relatively high drag in the RCCA test have been selected for this test. Therefore, it is known that there is an interference between the RCCA rodlets and thimble tubes. The objective of this test was to determine the condition of the thimbles with respect to the following:

- -Are the dashpots and/or major diameters distorted?
- -Are the distortions "bows" or "kinks"?
- -Are the distortions localized at a particular elevation?
- -Are all the thimble tubes within an assembly distorted?

Probes were fabricated in a progression of lengths and diameters to test both the dashpot and major diameters. The probes were then lowered into each thimble tube and allowed to insert by their own weight. If the probe was inserted the entire length of the thimble tube (for dashpot probes) a "GO" was recorded. If the probe stopped before bottom, the elevation was recorded and the tube was designated to be "NO-GO". For the guide thimble probes, the top of the dashpot was "bottom".

Some "NO-GO" tubes were selected for drag testing with one of the guide thimble probes and [ ]^{a,b,c} probe. For these tests, the probe was allowed to drop by its own weight until it stopped, then was pushed to bottom. The probe was then withdrawn at slow speed, and the total load (drag and weight) was recorded as a function of elevation on a strip chart recorder. The probe "GO and NO-GO" results are summarized in Table A.2 and are discussed below. The single tube probe drag test results are provided in Appendix D.

<u>Wolf Creek - Phase 1</u>

The "GO" results were clustered in an assembly area consisting of peripheral thimble tubes, or located at random locations in the fuel assembly. At least one of the thimble tubes that surround the instrument tube was a NO-GO indication in the tests with NO-GO results.

The thimble tube drag tests results usually peaked at the thimble tube entrance and at the bottom of the dashpot. In the dashpot, the peaking could be attributed to [.]^{a,b,c}

The single tube probe tests demonstrate that distortion exists in varying degrees in the fuel assembly guide thimble tubes. These distortions were observed in both the dashpots and major diameters of the guide tubes. The highest degree of guide tube distortion was observed [.]^{a,b,c}

<u>Wolf Creek - Phase 2</u>

The single tube probing was performed on the dashpot of fuel assembly G68. This assembly was selected because of [.]^{a,b,c} The drag above the dashpot was negligible; therefore, single tube probing was not done in the upper guide thimble. The data shows that significant bowing in the dashpot is primarily responsible for the high observed drag forces.

North Anna

The two assemblies in which the RCCAs [

][a,b,c] it appears that all of the assemblies tested have experienced dashpot distortion which affects both dashpot apparent diameter (ovality) and bow over the entire dashpot length. This observation is supported by the data from the [

.][a,b,c]

The test data indicates that [

.][a,b,c]

It is noteworthy that these assemblies had been placed in the spent fuel pool some 18 months prior to the test. No problems were reported in removing RCCAs from these assemblies when they were removed from the core 18 months earlier. It has been experienced from other testing work that assemblies can increase in bow as a function of cooling time. It has been proposed that this is caused by differences in cooling rates between the fuel rod and thimble tubes.

Point Beach

Assemblies Z11 and Y11 have upper guide thimble distortion. The distortion in the dashpot in these assemblies is small when compared to 17x17 fuel designs at similar burnups.

Vogtle

The probe data shows that the fuel assembly upper guide thimbles are only mildly distorted, and that high fuel assembly dashpot drags can be attributed primarily to gradual dashpot area bowing to varying degrees. The extent of dashpot drag is [

.][a,b,c]

Surry

Single tube probing was conducted on four fuel assemblies at Surry. Assembly 5H1 showed the greatest amount of upper guide tube and dashpot distortion, consistent with its relatively high drag force. Even though this assembly had [ ][a,b,c] in the dashpot, the actual contribution to drag from entering the dashpot was only an increase of [

.][a,b,c] A large portion of the total drag is attributed to gradual bowing in the upper guide tubes. It is also significant that the burnup of this assembly is as high as any assembly at Wolf Creek which experienced the insertion anomaly. This assembly shows similar dashpot probing behavior as assembly 1G0. Both assemblies would [

.][a,b,c] In contrast, assembly 1G0 would [

][a,b,c] while assembly 5H1 would not. These differences help illustrate why the upper guide tube drag forces in assembly 1G0 are less than assembly 5H1 while both assemblies have comparable increases in drag when entering their dashpots.

Assembly 3J1 showed the least amount of upper thimble tube and dashpot distortion of the four assemblies tested. The assembly dashpots and upper guide tubes show mild distortion in both areas, consistent with the low drag force readings.

Assembly 0V7 has approximately the same burnup as assembly 3J1, but the drag recorded is much higher in assembly 0V7 than assembly 3J1. The probe results show that the dashpots in assembly 0V7 are somewhat better than those in assembly 1G0, while the upper guide tubes are nearly identical. This observation suggests that [. $]^{a,b,c}$

The probe data shows that the fuel assembly upper guide thimbles and dashpots are only mildly distorted. The observed fuel assembly drags can be attributed to a combination of gradual guide tube and dashpot area bowing to varying degrees. The peak dashpot and thimble tube drag is consistent with the higher number of [. $]^{a,b,c}$ There is no clear evidence of preferential distortion between the dashpots and the upper guide tubes. There is evidence however, that the drag force and guide thimble distortions are increasing with increasing burnup.

South Texas

Assembly F26 showed the greatest amount of upper guide tube and dashpot distortion. This is consistent with it [.$]^{a,b,c}$ Assemblies F01, F25, F26, F53 and F64 were not drag tested [. $]^{a,b,c}$

Assemblies R31 and R27 have nearly identical burnups and power histories. These assemblies are particularly interesting since assembly R31 exhibited the least amount of dashpot and thimble tube distortion, while assembly R27 exhibited some of the worst dashpot and thimble tube distortion. For example, assembly R31 dashpots [.$]^{a,b,c}$

It is noteworthy that nearly all the upper guide tubes successfully passed [. $]^{a,b,c}$ This observation supports the conclusion that the degree of distortion is much less severe in upper guide tubes than the dashpot areas and is bounded (in terms of insertion anomalies) by that experienced in the dashpots.

The single tube probing indicates that the insertion anomalies can be attributed to dashpot distortion within the fuel assembly thimble tubes. The degree of distortion appears to be dependent upon burnup. The probe data also indicates that the distortion is progressing upwards into the upper guide tubes and that dashpot distortions are clearly limiting in terms of susceptibility for RCCA insertion problems. None of the upper guide tubes probed indicate severe restrictions or localized distortion as seen at Wolf Creek. The drag test data and probe results indicate that the insertion problems (if it occurs) will occur at an elevation near the entry point into the lower dashpot.

Sequoyah

Single tube probing was conducted on three fuel assemblies at Sequoyah Unit 2. Assembly E22 [

,]^{a,b,c} consistent with its observed drag forces. This assembly had a drag force of only [ ]^{a,b,c} in the upper guide tube area with a large increase in load as the RCCA was inserted into dashpot. This [ ]^{a,b,c} was not probed in the upper guide tube, but is expected to have only mild upper guide tube distortion as evidenced by it very low drag readings of [.]^{a,b,c} It is likely that this assembly would have tripped properly, since the upper guide tube would not have decelerated the RCCA prior to entering the dashpot.

Assembly E22 is behaving like other [

]^{a,b,c} cannot be characterized as anomalous.

Assemblies H47 and H55 show the majority of the thimble tube distortion is concentrated in the dashpot areas. Both assemblies show that the dashpot is contributing the highest percentage of RCCA drag. This behavior was also noted in assembly E22 as mentioned above. The upper thimble tubes show mild distortion as evidenced by the ability of assembly H47 to accept the [.]^{a,b,c} This tendency for concentrated distortion in the dashpot areas is consistent with behavior noted at North Anna, VC Summer and Vogtle.

Millstone

Single tube probing was conducted on fuel assembly F02 at Millstone 3. Based on the RCCA drag testing it was judged the tested assemblies at Millstone 3 do not have a significant amount of thimble tube distortion. None of the tested assemblies exceeded the Westinghouse F.5.1 guidelines for RCCA drag.

The baseline probe [

.]^{a,b,c}

Diablo Canyon

Single tube probing was conducted on two fuel assemblies at Diablo Canyon Unit 1. The assemblies (T78H and T80H) were selected based on their containing the same thimble tube material lot as the assemblies at Wolf Creek which experienced the RCCA insertion anomaly.

Assembly T78H has slightly higher burnup than T80H, but its thimble tubes are less bowed. Neither assembly demonstrates sufficient bow to exceed either of the F-spec guideline numbers for drag. [

.]^{a,b,c} In fact, assembly T78H is demonstrating extremely good dashpot and upper guide tube dimensional stability. Both assemblies can be characterized as containing only mild distortion of a very gradual nature biased to the dashpot areas. Neither assembly would be expected to inhibit RCCA insertion in any way.

5.4 Guide Thimble Borescope Examinations

Borescope examinations were conducted on all guide thimbles based upon the results of their RCCA drag force measurements and their burnup. Every guide thimble in the selected assemblies was examined to determine:

- -The presence of obvious physical anomalies and the general condition of the tube;
- -The presence of debris or debris-related scarring on the thimbles; and
- -The quantity and severity of wear marks believed to be present in the guide thimbles based upon their drag force results.

Wolf Creek

The wear marks seem to suggest that individual RCCA rodlets were forced to assume a shape similar to the distorted guide thimble tubes, thereby causing increased RCCA drag loads. This indicates that the thimbles may be [.]a,b,c Individual borescope observations for each fuel assembly are given below.

H38 All 24 thimble tubes showed wear marks near the top nozzle, and the marks continued along almost the entire length of each tube. The marks appeared [.]a,b,c The marks were wider and more continuous in the upper half of the tube (between grids 5 through 8). In the lower portion of the tube, the rub marks became more intermittent and narrow. They often disappeared immediately above and below the grid locations. Similar marks were also observed in the dashpot region. All marks appeared to be superficial.

J03 All 24 thimble tubes displayed wear marks near the top nozzle, but they appeared less pronounced than those seen in H38. The marks continued along almost the entire length of each thimble tube. The marks appeared straighter than those seen in H38, although a [ ]a,b,c was evident.

H16 Only one tube had a wear mark near the top nozzle. [,]a,b,c and all tubes showed wear marks beyond that point. The marks were less pronounced than those on F/A H38, and showed a [.]a,b,c The marks became narrow and intermittent over the bottom half of the tubes. The marks often disappeared immediately above and below the grid locations. Several tubes showed a [.]a,b,c

H81 [ ]a,b,c had no wear marks near the top nozzle, while all but [.]a,b,c All had marks thereafter. The marks were significantly less pronounced than the previous H and J assemblies. The marks showed a [ ]a,b,c nature. The bottom half of the tubes showed narrow and intermittent marks that often disappeared immediately above and below the grid locations.

K06 Near the top nozzle, [ ]^{a,b,c} tubes showed wear marks. At [ ]^{a,b,c} were marked. After passing [,]^{a,b,c} but the marks were significantly less pronounced than those on F/As H38 and J03. The marks were relatively straight and were also very intermittent in the lower half of the tube.

South Texas

Assembly F26 was chosen for borescope examination based on its incomplete RCCA insertion history. The inspection was aimed at establishing the extent of wear or other evidence of interference visible on the inner diameter of the thimble tubes. The Wolf Creek guide thimble tubes exhibited [.]^{a,b,c} These marks were visible on the upper guide tube areas and dashpot areas.

The borescope examination showed [ ]^{a,b,c} of the guide tube. This is consistent with anticipated light fretting wear normally associated with RCCA stepping. There was **no evidence** of significant wear [ ]^{a,b,c} in the upper guide tube like that seen at Wolf Creek. The dashpot [

.]^{a,b,c}

In summary, the borescope inspection at South Texas Unit 1 showed evidence of dashpot interference. The [ ]^{a,b,c} going from upper to lower areas of the dashpot. There was [ ]^{a,b,c} at Wolf Creek.

5.5 Assembly Bow

The bow measurements were performed at Wolf Creek and South Texas 1. At Wolf Creek during phase 1, the plumb bob method was used to measure assembly bow. During the Wolf Creek phase 2 and the South Texas 1 campaigns, alternative methods were used to obtain an indication of the distortion within the assemblies.

Wolf Creek - Phase 1

Seventeen fuel assemblies were measured for bow in the spent fuel pit. The bow was measured by suspending a plumb bob against the fuel assembly's top nozzle and measuring the distance between the string and the edge of the assembly. This method does not provide a "true" indication of shape because the assembly prevents the plumb bob from moving in the negative direction.

[ ]a,b,c

Wolf Creek - Phase 2

The bow for assemblies H50 and H38 was re-measured by two additional methods (direct view & profile view). This was done to correct for the inaccuracies in the "plumb bob" method. The plumb bob, profile view and direct view methods are not 100% comparable.

The string is fixed at the top and bottom nozzles for the profile view and direct view methods. In both methods, the corrected bow is also obtained from the measured distance between the string and the grid's edge. The profile view and the plumb bob methods are similar since the bow is measured parallel to the assembly face. In the direct view method the bow is measured normal to the assembly face.

As shown in the following table and in Figures 5.5.1 and 5.5.2, the bow in assembly H50 changed little when the fuel rods were removed because the bow increased on one assembly face while it decreased on the adjacent assembly face.

[ ]a,b,c

Figure 5.5.1: Fuel Assembly H50, Face 3 Bow Data - Direct View

a,b,c

Figure 5.5.2: Fuel Assembly H50, Face 4 Bow Data - Direct View

a,b,c

The bow for assemblies F26, F32, F37 and F41 was measured by two methods (direct view & profile view). Care must be used when interpreting the data because the data inaccuracy is approximately 0.1 inches.

In Figure 5.5.3 and in the table below, the fuel assembly "direct view" bow data is provided. The data in Figure 5.5.3 was determined from the vector addition of the bow data from adjacent faces. [

.]a,b,c

At South Texas, the assemblies tested which have RCCA insertion problems [

.]a,b,c

[ ] a,b,c

a,b,c

Figure 5.5.3: South Texas 1 Assembly Bow Data - (Vector Added)

6.0 Empirical Observations of Growth Data

A statistical analysis was performed on the assembly growth and thimble tube and dashpot drag data. The correlations were made to power history data for each assembly, which is found in Appendix B. This history data is for 121 assemblies from 12 different plants. The data includes growth and individual cycle properties for each assembly such as relative power, EFPY, burnup, coolant inlet temperature, delta temperature across the core, and the core average power density.

It is difficult to draw any unequivocal conclusions in a "statistical sense" primarily since the data base was based on information gathered from the site tests. In the site tests the focus was on high burnup, design variety and manufacturing chronology. The focus was not on "designing an experiment" which would yield statistically significant results.

In Figure 7.1, the relationship between growth and fluence as a function of core average outlet temperature (T_{HOT}) for three cycle fuel is shown. The data is separated into two populations, T_{HOT} greater than and less than 615°F. Figure 7.2 shows similar information for two cycle fuel.

The following trends were observed:

(1) There is higher growth associated with higher drag force in the thimble tubes.

(2) Accelerated growth begins at a fluence [.][a,b,c]

(3) This accelerated growth occurred only at Wolf Creek and predominantly in H assemblies.

(4) G assemblies also showed accelerated growth, but this began at a higher fluence.

(5) The accelerated growth can be associated with high coolant outlet temperature plants. However, there are other factors which influence growth besides temperature, since high temperature plants exist that do not have high growth.

(6) This outlet temperature effect seems to be a plant effect and not an individual assembly effect.

(7) This accelerated growth is associated with three cycle operation. However, there are factors which influence growth besides the number of cycles, since many three cycle assemblies do not have high growth.

(8) Low first cycle and nigh second cycle power is associated with high growth, but only at Wolf Creek.

(9) Low first cycle and high second cycle power is associated with high drag values.

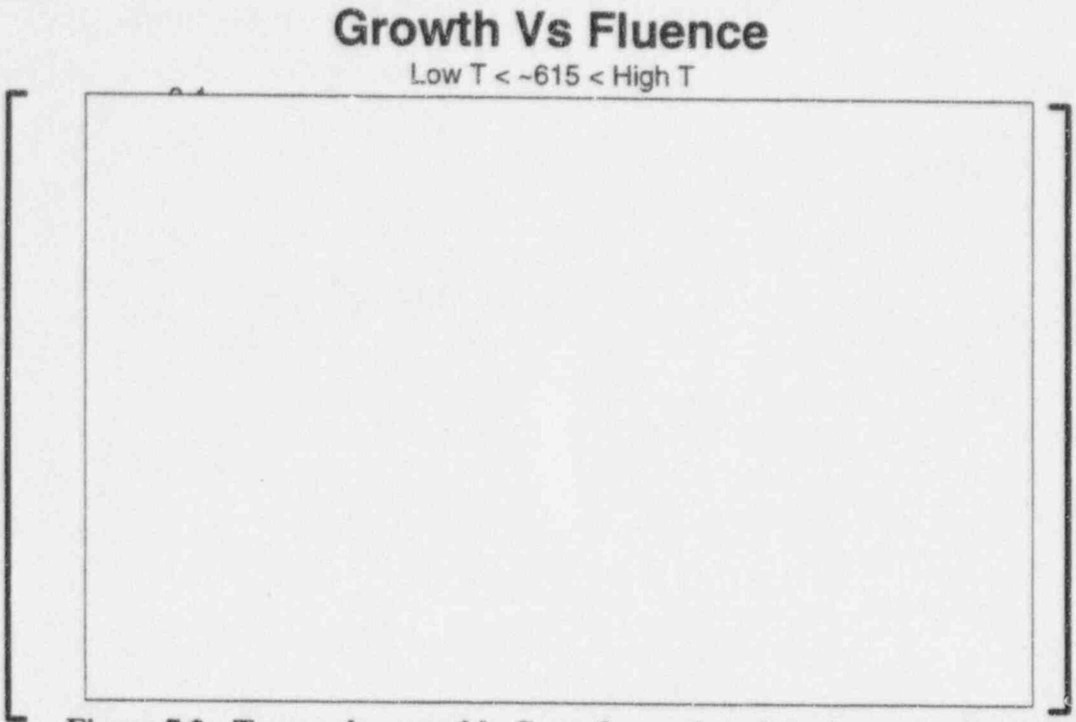
Growth Vs Fluence

Low T < ~615 < High T

a,b,c

[ ]

Figure 7.1: Three cycle assembly Growth as a function of average fluence that the assembly has seen. The plant average coolant outlet temperature is either greater or less than 615°F.



a,b,c

Figure 7.2: Two cycle assembly Growth as a function of average fluence that the assembly has seen. The plant average coolant outlet temperature is either greater or less than 615°F.

7.0 Susceptibility Conclusion

Based on plant trip information, site test results and observations of growth data, Westinghouse presented the following susceptibility conclusions to the NRC on June 27, 1996:

- Based on the data and analysis to date, fuel with IFMs are not susceptible to incomplete insertion.
- The manufacturing period does not affect the susceptibility to incomplete insertion.
- Twelve foot Westinghouse fuel is not susceptible below a burnup of 40,000 MWD/MTU.
- Based on the data to date, while it does appear that 14x14 and 15x15 fuel are less susceptible, it is difficult at this time to make a definitive conclusion.

8.0 Materials Investigations

8.1 Unirradiated Materials Testing

The objective of these tests were to characterize archived samples of tubes from the same lots used in the fabrication of the Wolf Creek "H" assemblies. After the materials properties were characterized it could be determined if the thimble tubing was typical or if there were some anomalous tube conditions.

Dimensions
The dimensions of the thimble tubes used in the Wolf Creek assemblies had been inspected prior to their release for use in skeleton fabrication. To verify that the dimensions did not have significant deviations, the 36 inch long archive samples from eleven thimble tube lots were retrieved and dimensionally inspected using the standard production ultrasonic inspection units. The outer diameter, inner diameter, and the wall thickness of the tubes were measured and recorded on charts. All dimensions were found to be well within the drawing limits and close to nominal. The wall thickness variations were less than 50% of the in-house limits and the diameters were typically within 50% of the allowable tolerance range around the nominal drawing dimension.

It is concluded that there are no dimensional anomalies in the tubes and that there would be no abnormal impact on the tube performance from a dimensional perspective.

Tensile Testing
Sections were taken from six of the archive tubes and a room temperature tensile test was performed on the samples. The 0.2% yield strength and ultimate strength were recorded and compared to the average of 104 production lot tests. The mechanical properties of the archive tubes were near the average for the production lots and within the normal range of values obtained from past and current tube lots. Samples from the thimble tube lots are tensile tested prior to the lot release and the original lot values were reviewed and found to be typical.

It is concluded that there are no anomalous conditions in the tensile properties of the Wolf Creek thimble tubes and that the material was typical of recrystallized annealed tubing.

Crystallographic Texture
It is generally agreed that the crystallographic texture can influence the degree of irradiation growth. The irradiation growth is related to texture by the (1-3F) term where "F" is the texture factor or Kearns number for a specific tube direction; axial, radial, or circumferential. The axial texture influences the irradiation growth along the thimble tube length. The texture was measured on 2 samples from the Wolf Creek archive tubes and compared to results from three samples taken from tubes produced in the same time frame, three lots made over two years prior to the Wolf Creek production and one current lot. The direct pole method was used to determine the tubing texture. The Wolf Creek results were equivalent to and within the range of the other samples.

It is concluded that the texture in the Wolf Creek thimble tubes is typical of normal production and that texture differences are not present or a factor in the observed high growth of the Wolf Creek "H" assemblies.

Material Chemistry

The chemistry or alloying and impurity element levels are measured at the ingot stage. The ingot chemistry certifications were reviewed and no deviant chemistry conditions were observed. To further verify the material chemistry, samples were taken from eleven archive tubes and tested for alloy element levels. The tin, iron, and chrome levels in all the samples were well within the specification limits and at nominal levels.

It was concluded that there were no deviant chemistry conditions associated with the thimble tube lots.

Conclusion

The unirradiated material testing performed on the archive tube samples representing the thimble tube lots used in the fabrication of the Wolf Creek "H" assemblies indicates that there are no anomalous conditions present that would contribute to increased irradiation growth or thimble tube distortion.

8.2 Manufacturing Process

The thimble tube manufacturing process was reviewed to determine if there was any changes made that would contribute to an increase in the thimble tube irradiation growth rate.

Timeline

a,b,c

Ingot Processing

The "H" assemblies thimble tubes were fabricated from material produced from twelve ingots. These twelve ingots were melted over an eight month time span; thus, there is no single ingot source or small production time window in which an anomalous condition could have occurred and contributed to the observed thimble tube growth. The data reported for each ingot was reviewed and all met the specification requirements and no deviations were observed.

Tube Lot Processing

There are 23 thimble tube lots associated with the "H" assemblies. The lots were produced over a six month time frame and two separate production runs were involved. There was no single or small group of lots or a small production window in which an anomalous condition could have occurred and contributed to the observed thimble tube growth.

A thimble tube lot nominally contains 240 tubes. About 40% of the tubes in the 23 lots were used in the Wolf Creek assemblies and the remaining were used to fabricate fuel for other reactors. Table 8.2.1 lists the thimble tube lots made in the same time frame and that are of equivalent design to the "H" assembly thimble tubes. About 85% of the thimble tubes produced in the 54 lots from the two thimble tube runs were used in skeleton fabrication for other, non-Wolf Creek fuel.

During recent reactor site examinations, the assemblies at two sites which had thimble tubes from the same lots as Wolf Creek were evaluated. The irradiation growth of the assemblies at Diablo Canyon and Vogtle have normal growth and do not show the accelerated growth observed at Wolf Creek. Figure 5.2.1 shows a plot of the assembly growth of the various reactors and the specific assemblies at Vogtle and Diablo Canyon with the same thimble tube lots as Wolf Creek are noted in Table A.2 with an asterisk next to the assembly identification number.

It is concluded that there was no thimble tube processing anomaly associated with the Wolf Creek thimble tubes that would impact the observed high growth.

5.3 Hot Cell Examination and Tests

The hot-cell examination scope for the RCCA insertion anomaly included the following:

1. Visual examination of the skeletons (H38 and H50)
2. Span wise growth measurements for the selected spans
3. Thimble tube diameter and bow measurements
4. Metallography
5. Hydrogen content

The table below shows the relationship between assembly span number and section numbers.

Span	Section
Top 7	1-1
6	1-2
4	2-2
2	4-1
Bottom 1	4-2

Visual Examination

Components of both skeletons were visually examined through the hot cell windows and selected features were examined through a periscope at magnifications up to 4x. The major purpose of these inspections were to assess both the overall mechanical integrity and the corrosion appearance of the visible portion of the components. These inspections then provided a basis for selecting metallographic and mechanical test specimens. Specific components which were visually examined included thimble tubes, grids, bulge joints, and sleeves.

The examination of the skeletons as seen through the hot cell windows, indicated that they were in good condition with no evidence of unusual deformation, wear, or significant crud deposits. There was no evidence of oxide layer spalling or pitting. In the dashpot area, i.e., the lower most spans, the thimble tubes were black, indicating a relatively thin layer of oxide. Spans 2 and 3 exhibited transition from black to gray with a mottled appearance. Spans 4, 5, and 6 were lustrous dark gray to gray-white. Span 7 showed a transition from gray-white to black in the upper region. The instrumentation tube had appearance similar to the thimble tubes and the grid appearance also corresponded to the thimble tubes. These observations were consistent with expectation of corrosion on skeleton components.

Table 8.2.1: Thimble Tube Lots of equivalent Wolf Creek "H" Assembly Design

Ingot	Lot Number	W/C "H" Assembly
2240	W30-6561	12
	W30-6556	
	- -6564	
2204	W30-6588	3
	W30-6589	
2246	W30-6638	
	W30-6639	26
	W30-6640	
	W30-6777	
	W30-6778	31-32-35-41-42-43
	W30-6779	28
	W30-6780	1-2-6-9-15-22-27-30-37-38
	W30-6781	21
2273	W30-6815	
	W30-6816	5-7-8-11-13-16-20-39-40
	W30-6817	
	W30-6818	
	W30-6819	4-10-14-17-18-19-23-24-25
	W30-6820	
2332	W73-7179	34-36
2333	W73-7226	33
	W73-7222	
	- -7231	
2304	W73-7263	
	W73-7264	
	W73-7265	44
	W73-7266	
2304	W73-7267	
	W73-7280	
	W73-7281	
	W73-7282	59
	W73-7283	46-51-66-75-(80)
	W73-7284	53-58-74-82-(80)
2336	W73-7311	
	W73-7312	61-71-76-77-78-81
	W73-7313	
	W73-7314	54-56-57-63-64
	W73-7353	
2344	W73-7354	
	W73-7355	49-55
	W73-7356	47-48-69
	W73-7357	52-62-72-73-79
	W73-7358	
2379	W73-7543	
	W73-7544	45-60-65-67-68-70-84
	W73-7545	83
2381	W73-7556	50
	W73-7557	
	W73-7558	
	W73-7559	
	W73-7560	
	W73-7561	
	W73-7566	
	W73-7724	

Visual examination of grid #7 and corresponding sleeves of skeleton H-38 showed [.]^{a,b,c} Grid #7 was displaced and separated from the sleeves during handling at the site in the new fuel elevator inspection basket. Similar observations were made on the sleeves from skeleton H-50, which were separated from grid #2 during handling and transport.

Span wise Growth Measurements

Span wise growth measurements were performed on three sections with two grids in place and in the dashpot area. Measurements were made using a [,]^{a,b,c} which is traceable to NIST standards. Lengths between [ ]^{a,b,c} were measured on one thimble tube on each face. The measured data are given in Tables 8.3.1 and 8.3.2 for skeleton H-38 and H-50, respectively. The largest measured growth was in [ ]^{a,b,c} and the lowest growth was measured in [.]^{a,b,c} In Figure 8.3.1, the growth measurements are summarized and compared to the overall growth of fuel assemblies H-38 and H-50 measured at the site examination. The incremental growth is consistent with the fluence/temperature power profiles, although the overall growth of the assembly was [ ]^{a,b,c} from the previous database.

The relatively [.]^{a,b,c} Therefore, the measured values for [ ]^{a,b,c} has been omitted from Figure 8.3.1.

Thimble Tube Diameters and Bow Measurements

These measurements were made using a laser micrometer and a translation/rotation system controlled by a PC. The measurements were made at 15° rotation azimuthally and at 1 inch increments along the length on selected tubes. The tubes represent the extremes of the burnup, interference, and the individual probe profiles from the site examination. The measured average diameters are tabulated in Table 8.3.3.

The data showed diameter increases up to approximately [.]^{a,b,c} An increase in ovality of approximately [ ]^{a,b,c} was observed in some of the tubes. The diameter changes correspond to length changes and are related to oxide thickness and hydride content. Figure 8.3.2 compares the dimensional changes to the oxide thickness and hydride content to show the correspondence. As shown in Figure 8.3.3 for H50, the bow direction varies within an assembly but seems to be somewhat directional in that the majority of bows are in a similar direction. The data in this figure has been offset along the X-axis to make the data for the different spans visible.

In Figure 8.3.4, the maximum, minimum and average bow for each span is shown for the thimbles in both assemblies. The bow is largest near the top of the assemblies and decreases as you progress through span 4. There is then a modestly increasing swell through span 3, decreasing again through the bottom span. As shown in Figures 8.3.5 and 8.3.6, the thimble tube diameter does increase with axial elevation in the assembly. [.]^{a,b,c} As shown in Figure 8.3.7 , the ovality of the thimbles is small, is

not directional and does not seem to have any practical impact on this overall thimble tube distortion phenomena.

Table 8.3.1: Skeleton Assembly H38 Span Wise Growth Data

a,b,c

GE

Table 8.3.2: Skeleton Assembly H50 Span Wise Growth Data

a,b,c

Figure 8.3.1: Skeleton Assemblies H50 and H38 Measured Span Growth

a,b,c

a,b,c

Table 8.3.3: Measured Average Diameters

Figure 8.3.2: Assemblies H50 and H38 Profile with Oxide, Hydrogen and Dimensional Changes

a,b,c

Note: % values are based on nominal drawing dimensions, H38 values are in brackets, H50 values are not in brackets

Figure 8.3.3: BOW VECTORS FOR THIMBLES IN EACH SPAN ASSEMBLY H50

a,b,c

Figure 8.3.4
Overall Summary of Span Bow
For Assemblies H38 & H50

a,b,c

FIGURE 8.3.5 MEASURED DIAMETER PROFILE

(THIMBLE TUBE C 12 FROM H38)

a,b,c

FIGURE 8.3.6 PROFILE OF % GROWTH IN OD

(THIMBLE TUBE C12 FROM 38)

a,b,c

a,b,c

Figure 8.3.7: Assembly H50 Thimble Tube Ovality vs Axial Position for Spans 6 & 7

Metallography
Selected transverse and longitudinal sections of the thimble tubes from the two assemblies were metallographically examined to determine the oxide thickness on the OD and ID of the specimen. The samples were then etched with a suitable chemical reagent to observe the hydride morphology.

Thimble tube results showed that the OD and ID oxide thickness were the same, although there may be a slight trend for ID oxide to be thicker than the OD oxide. Typically, the measured values showed approximately [

.]a,b,c

On transverse specimens, [

.]a,b,c In longitudinal sections, [
.]a,b,c These observations indicate that

preferential [

.]a,b,c

Hydrogen Content
Hydrogen content in the thimble tube specimens was determined by LECO Corporation Hydrogen Determinator equipment. The method consists of fusing a small specimen with a flux and driving the released hydrogen using Argon carrier gas. The hydrogen content is determined by change in the conductivity of the carrier gas. Special standards were prepared by hydriding Zircaloy-4 thimble tubes to known levels of hydrogen content to calibrate the equipment. The hydrogen samples were taken from tube sections adjacent to the metallographic specimens to correlate the oxide thickness and hydrogen content. The nominal values at selected axial heights are shown in Table 8.3.4 with corresponding oxide thickness values. The measurement technique has an accuracy of about [ ]a,b,c and therefore, an average of several measurements at each location were used to obtain an estimate of the hydrogen content. To check the hydrogen readings obtained, six tube samples were analyzed at the AECL Chalk River hot cells using the hot vacuum extraction technique. The information in Table 8.3.4 is a summary of the hydrogen measurements from both the Westinghouse and AECL hot cell tests.

Table 8.3.4: Hydrogen Content of Assembly H50 and H38 Samples

[ ] a,b,c

9.0 Materials Growth Models

9.1 Oxide/ Hydrogen Growth

The objective of these tests was to determine the impacts of surface oxide and internal hydride formation on the thimble tube growth. It is known that there is about a 50% volume expansion when the zirconium metal is converted to oxide. As the oxide is formed on the inner and outer surfaces of the thimble tubes this volume expansion produces stresses and resultant creeping of the base material. These dimensional changes have been documented by Donaldson in ASTM STP 1132 and Hillner in WAPD-TM-307 to list a few.

During the oxide formation in a water or steam environment, there is some hydrogen released during the reaction and a portion of the hydrogen is absorbed into the base metal. This hydrogen forms hydrides which have nominally a 16% volume expansion over the metal that it replaces. This volume expansion also produces stresses which result in material growth/creep.

Testing was performed and is continuing to determine the specific impacts on thimble tube growth from the formation of the oxide and hydrides during reactor operation. Specifically some thimble tube samples were exposed to an accelerated corrosion test in [ ]^{a,b,c} lithium and the length and diameter changes were measured as a function of the surface oxide thickness. Figures 9.1.1 and 9.1.2 are plots of the results. The dimensional changes are significant and are due both to the oxide and hydride formation.

Since the accelerated test results in abnormally high hydrogen absorption compared to normal reactor conditions the effects of the [.]^{a,b,c} A series of tubing samples were hydrided (no oxide formation) by exposing the samples to a hydrogen/argon gas environment at [ ]^{a,b,c} and measuring the hydrogen levels and the diameter and length changes. The results from these initial tests are reported in Figure 9.1.3. The data indicates that there is a [ ]^{a,b,c} absorbed for levels up to about [.]^{a,b,c} The data indicates a rate change to about [ ]^{a,b,c} expansion.

The oxide formation produces a stress on the material that is directly proportional to the metal thickness and thus the effects of oxide are very dimensional dependent. The hydride is an internal volume expansion and is not as sensitive to the material dimensions. It is postulated that the effects on dimensional changes due to the oxide and hydride are not independent since the material expansions due to hydride formation can reduce the stresses from the oxide film. Additional evaluations are proceeding to better quantify these effects.

Figure 9.1.1: Corrosion Impacts on Length and Diameter Changes in Zircaloy 4 Thimble Tube Samples
(680 F, 700 PPM Li Water Tests)

a,b,c

Figure 9.1.2: Corrosion Impacts on Length and Diameter Changes in Zircaloy 4 Thimble Tube Samples (600 F, 700 PPM Li Water Tests)

a,b,c

Figure 9.1.3: HYDROGEN GROWTH FACTORS

a,b,c

Figure 9.1.4: Estimate of Oxide and Hydride Impact on Assembly H50 Measured Growth

a,b,c

Note: Values in parenthesis represent growth difference between measured and estimated oxide/hydride impacts

From the hot cell examination of thimble tubes from assembly H50 the oxide thickness and hydrogen levels are known at various locations along the assembly length. Applying an estimate of the average unirradiated hydrogen and oxide growth factors developed from the autoclave and hydride tests an approximation of the oxide/hydride contributions to the measured assembly growth has been made and is summarized in Figure 9.1.4. The measured diameter changes have been adjusted to remove the increase due to the oxide thickness. The estimated growths are compared to the measured growth in the appropriate spans of the assembly. If it is assumed that the normal saturated irradiation growth is on the order of [ ][a,b,c] can account for a significant portion of the higher observed growth. As noted, evaluations are continuing to better quantify the contributions of the [ ][a,b,c] formation.

9.1.2 Accelerated Growth

A number of factors combine to produce the observed thimble tube growth. Simplified, the total growth is the sum of a normal [ ][a,b,c] component. The normal [ ][a,b,c] at relatively low burnups and may have a mild linear increase with higher fluences. The [ ][a,b,c] is a function of [ ][a,b,c] factors. In particular there are numerous industry reports that correlate c-loop dislocation densities with [.][a,b,c] The c-loop dislocations increase at the higher temperature and at the higher fluences.

Temperature and fluence are reported to be significant factors in both the formation of the c-loops and their stabilization by dissolution of iron/chrome precipitates into the matrix. Temperature and exposure time are also significant factors in the oxide and hydride formation rates. It is postulated that the c-loop dislocation increase combined with vacancy/interstitials formed and the stresses from the oxide/hydride formation result in an increase in the growth rate observed at the higher fluences and temperatures.

There is not much published information on the accelerated growth rates for the specific temperature/fluence/material represented by the Wolf Creek assemblies. The information that is available was reviewed and industry experts were consulted regarding the observations of the accelerated growth. From the available information an empirical model for irradiation growth with an accelerated growth factor for the higher temperature and fluence was extrapolated for use in the mechanical model development (see Section 10).

10.0 Mechanical Model - Thimble Tube Distortion

<u>Description</u>

A mechanical model has been developed to calculate thimble tube distortion. Input to the model includes:

a,b,c

- calculate change in thimble load due to elastic growth increment

a,b,c

Typical outputs at each time step include:

- Assembly growth
- Assembly holddown spring load
- Assembly lateral bow per grid
- Clad elastic modulus per span
- Fuel rod axial load per span
- Fuel rod growth per span
- Grid drag per grid
- Thimble oxide thickness per span
- Thimble axial creep per span
- Thimble axial growth due to oxide per span
- Thimble axial load per span
- Thimble axial stress free irradiation growth per span
- Thimble elastic modulus per span
- Thimble lateral bow per span

Model Benchmarking

With any model of this nature and complexity, one must perform sufficient benchmarking to assure that the code can adequately address a range of designs and empirical observations. First, the model was checked against Wolf Creek assembly H50. This assembly was chosen since it had the longest growth, highest drag, and significant hot cell data available for comparison.

Since the [ ][a,b,c] has the highest level of uncertainty, it was chosen as the adjustment parameter to improve agreement with overall length and the length of span 6. Following this adjustment, a number of "H", Wolf Creek "J" assemblies, South Texas and a variety of other assembly designs for which we have growth data were analyzed and benchmarked. The specific plants and assembly types are shown in Table 10.1.

Table 10.1: Plant Data Included in Benchmarking		
NA	North Anna	17x17 V5H
PB	Point Beach	14x14 OFA
STEX	South Texas	17x17 XL-STD
SUM	VC Summer	17x17 OFA+IFM+ZIRLO
SUR	Surry	15x15 OFA
SVV	VC Summer	17x17 OFA + IFM
VOG	Vogtle	17x17 OFA + IFM
WCH	Wolf Creek	17x17 V5H
WCJ	Wolf Creek	17x17 V5H+IFM

The agreement between predicted and measurements is reasonably good considering the scatter in the measurement data. This scatter is evident in Figure 10.2 where the maximum and minimum values (connected by a vertical bar) are shown as well as the average for two sets of data for "H" assemblies. These assemblies were of identical design and symmetric in the core (identical power & temperature histories). The largest discrepancies are evident for the SVV and SUM data where the growths are over predicted. These cases are being examined closer to assure correct operating and design conditions. Figures 10.1 and 10.2 show the comparisons of predicted versus measured in two different forms.

Table 10.2 and 10.3 show the measured versus predicted span lengths and bows. Notice the order/relative magnitude of the span lengths are predicted, as well as the absolute magnitude. The measure growth in [ ][a,b,c] is an estimate that is based on drawing dimensions. The [

.][a,b,c] Therefore, the value has been omitted from Table 10.1. With regard to Table 10.3, it should be noted that the model predicts average span bow (24 tubes) where the measured values are the average of [.][a,b,c] Still, the prediction gives the right order of magnitude.

Table 10.2: Measured and Predicted Span Length
H50

[ ]^{a,b,c}

Table 10.3: Measured and Predicted Span Bow (mils)
H50

[ ]^{a,b,c}

Additional "Qualitative" Model Assessments

In order to test the models credibility against criteria other than fuel assembly growth, three assembly types were analyzed with respect to span bow predictions. H50, which was previously discussed, as well as Wolf Creek assembly J32 and South Texas assembly F26. The following observations of the results (Figures 10.3 - 10.5) are of interest.

1. The [ ]^{a,b,c} of the span 1 bow for H50 is caused by [ ]^{a,b,c} at the end of cycle 2. This reduces the [ ]^{a,b,c} to the compressive load in the thimble tubes and thus [ ]^{a,b,c} the bow.

2. The relative span bow magnitudes agree with drag and probe results,[.]^{a,b,c}

Conclusions

As illustrated in Tables 10.2 and 10.3 and in Figures 10.1 and 10.5, the model predicts the fuel assembly growth and bow in Wolf Creek "H", "J", and South Texas reasonably well.

Figure 10.1: MEASURED vs PREDICTED ASY GROWTH

(REVNAC/ZORBA, 500/1.85 MPR)

a,b,c

Figure 10.2: Predicted and Measured Assembly Growth

a,b,c

Figure 10.3

WC H50 ROD & ASSEMBLY GROWTH
(REF CASE)

a,b,c

WC H50 THIMBLE SPAN BOW
(REF CASE)

a,b,c

Figure 10.4

WC J32 ROD & ASSEMBLY GROWTH
(REFCASE)

a,b,c

WC J32 THIMBLESPAN BOW
(REF CASE)

a,b,c

Figure 10.5

ST F26 ROD & ASSEMBLY GROWTH

a,b,c

ST F26 THIMBLE BOW

a,b,c

11.0 Root Cause Conclusions

The following conclusions were drawn based on the results of the detailed test programs and analysis:

1. The trip history data from the plants demonstrated that there were a significant number of assemblies operating at high burnup levels under control rod locations without showing insertion problems.

2. Review of the available worldwide experience indicated that in almost all cases that RCCA insertion problems have been reported (other than those cases that have been attributed to debris of Control Rod drive mechanism problems), the causes were related to excessive compressive loads on the fuel assembly guide thimble tubes.

3. The detailed manufacturing review indicated that this problem was not related to a manufacturing anomaly. Additionally, thimble tubes in other plants from the same lot and similar burnups as Wolf Creek did not show unusual growth, thereby confirming that this was not a manufacturing related issue.

4. A detailed review of plant operations and fuel management showed that the Wolf Creek assemblies that showed incomplete insertion were somewhat unique in their power history behavior. These assemblies operated for three cycles with relatively high power in the second and third cycles in a high temperature environment.

5. The results of the growth measurements showed that fuel assemblies that showed high growth were only seen in the high temperature plants. However, high temperature seemed to be a necessary but not a sufficient condition for high growth. For high temperature plants, specific power histories seemed to influence growth, especially those that have long residence times and high power in the later stages of operation.

6. The hot cell results from the two incomplete insertion assemblies showed that a significant portion of the growth was related to oxide formation. As well known, oxide formation is a strong function of temperature and residence time. Also, the remainder of the growth was greater than what would be expected for normal saturation growth. This component was attributed to accelerated growth, a phenomenon that is reported in the literature and is shown to be very temperature sensitive.

7. Data from the literature on Zircaloy growth suggested that depending on the temperature and fluence level, accelerated growth could occur. This growth would proceed after an incubation period. The point at which this growth would initiate, as well as the slope of the growth versus fluence curve was very temperature dependent. It is postulated that the high temperature in the later cycles of operation (consistent with the incubation period theory) would exacerbate the accelerated growth mechanism.

8. The detailed mechanical model predicted the growth differences between the Wolf Creek incomplete insertion assemblies, the Wolf Creek complete insertion assemblies and the South Texas assemblies reasonably well. In addition, the model was able to reasonably reproduce the span dependent bow measurements that were obtained from the hot cell on the Wolf Creek incomplete insertion assemblies. This model used a free growth correlation with

the accelerated growth component normalized to the actual growth measurement from one of the Wolf Creek incomplete insertion assemblies.

Based on the above analysis of measurements and models for Westinghouse fuel, the root cause conclusions are as follows:

- The incomplete RCCA insertions observed at Wolf Creek have been caused by excessive compressive loads on the fuel assembly guide thimble tubes leading to excessive thimble tube distortion.

- For Wolf Creek, the increased compressive load was caused by unusual fuel assembly growth over and above what would normally be expected as a result of irradiation exposure.

- The unusual growth component is a combination of growth due to oxide accumulation and accelerated growth, both of which are temperature sensitive.

- The unusual growth is observed only in high temperature plants on those high burnup fuel assemblies that have certain types of power histories.

- The apparent cause of the incomplete Rod Cluster Control Assembly insertion at the South Texas Project is fuel assembly thimble tube distortion resulting from high, in-vessel, compressive loading imparted on the assembly skeleton. The problematic distortion is limited to the assembly dashpot area of the thimble tubes which prevents complete control rod insertion. Westinghouse will continue to work with the South Texas Project to identify the root cause, along with short and long term corrective actions. The final conclusions of this control rod insertion anomaly will be documented in future Nuclear Regulatory Commission Bulletin 96-01 correspondence.

Appendix A

Site Test Data

Table A.1: Fuel Features of Root Cause Test Assemblies a,b,c

a,b,c

Table A.2: Summary of Plant Data

Table A.2: Summary of Plant Data

a,' c

a,b,c

Table A.2: Summary of Plant Data

Table A.2: Summary of Plant Data

a,b,c

a,b,c

Table A.2: Summary of Plant Data

Figure A.1: Dashpot Drag and Fast Fluence Data (Drag Measured after Reactor Trip)

a,b,c

Figure A.2: Upper Guide Thimble Drag and Fast Fluence Data (Drag Measured after Reactor Trip)

a,b,c

Figure A.3: Dashpot Drag and Fast Fluence Data
(Spent Fuel Pool Testing)

a,b,c

Figure A.4: Upper Guide Thimble Drag and Fast Fluence Data (Spent Fuel Pool Testing)

a,b,c

Appendix B
Power History Data for the Statistical Analysis

The data used to draw Figures 7.1 and 7.2 in this report and on which the statistical analysis is based is presented in this Appendix. The following list gives an explanation of each of the columns in the data table and how they were determined. The actual data table starts on the next page.

a,b,c

Appendix B (continued): Power History Data for Statistical Analysis

a,b,c

Appendix B (continued): Power History Data for Statistical Analysis

a,b,c

Appendix B (continued): Power History Data for Statistical Analysis

a,b,c

Appendix C

NRC Questions and Responses

1) **While the proposed root cause for the Wolf Creek incomplete RCCA insertions is a plausible explanation, it is not conclusive. The model for growth due to oxide accumulation is based on a very small number of data points and Westinghouse has stated that it is extremely sensitive to temperature. The model provides a possible explanation, but it has not been verified. Verification of the model would not be possible because data are not sufficient to establish confidence levels or sensitivity studies involving the key parameters.**

We believe that the data and analysis resulting from the root cause investigation of Wolf Creek as reported in PPE-96-249 is consistent and substantiates the root cause as being thimble tube distortion caused by excessive compressive loads on the fuel assembly thimble tubes. Unusual fuel assembly growth contributed to the excessive compressive loads.

Fortunately, the Wolf Creek IRI experience is unique to 12 ft. cores, but this also means that Wolf Creek at this point in time is the only source of definitive information on the growth of thimble tubes due to oxide accumulation. Recognizing this, we are developing an [

.]^{a,b,c} Current plans are for this system to be operational by the end of March, 1997. It is our intent to obtain oxide measurements in various fuel assemblies under a variety of plant operating temperatures and burnup conditions. The analysis of this data will give us added confidence in our model.

2) **The Westinghouse explanation of the root cause for the Wolf Creek event has not been extended to the South Texas event and it is the staff's understanding that it can not be, since the accelerated growth observed at Wolf Creek was not observed at South Texas. The phenomenon appears to be dependent on a number of factors, the interaction of which is not clearly understood. Nothing in the Westinghouse explanation would preclude other fuel designs, such as the 14x14 and 15x15 fuel, from exhibiting similar behavior at different combinations of burnup, power history, core exit temperature, and other factors that might be important.**

The root cause for the insertion anomaly experienced at Wolf Creek is thimble tube distortion. This is also the root cause for the insertion anomaly at South Texas. In both cases the cause of the thimble tube distortion is excessive compressive loads on the fuel assembly. Because of significant mechanical differences in the two fuel assembly designs, the application and results of the compressive loads differ greatly.

At Wolf Creek the compressive loads were caused by several factors including accelerated growth. The result in the Wolf Creek design (single dashpot - 12 foot active length) was distortion in the dashpot as well as the upper spans of the guide thimbles.

At South Texas the conditions for accelerated growth were present, but the growth was not manifested in fuel assembly length measurements. The compressive loads were caused by a combination of [

.]^{a,b,c} The hold down springs on the South Texas design have a higher spring constant which yields more compressive load for each increment of deflection as well as a higher initial hold down force. This puts more axial constraints on the XL fuel assembly preventing some of the growth. The 14 foot active length fuel assembly uses a double dashpot . This has a short section of guide tube diameter between two sections of reduced diameter as shown in Figure 1. [.]^{a,b,c}
The design in which the insertion anomaly occurred uses a guide thimble of larger diameter above the dashpot (larger than 12 foot assemblies with zircaloy mid-grids). This further pushes the weak link to the dashpot transition. The result in this assembly design is large distortions in the dashpot and minimal distortions in the upper guide thimbles.

[

.]^{a,b,c} Therefore it is more probable that the RCCAs for XL fuel could stick due to high drag in the dashpot only.

The XL fuel design is distinctive from the 12 foot fuel design in the mode in which the thimble tubes distort. There is also a major difference in the location and magnitude of the resulting drag. Although the root cause of the "sticking RCCAs" is the same for both designs, the mechanical design differences cause the assemblies to behave differently. They must be analyzed separately, and different criteria for factors such as burnup and measured drag are expected.

For 14x14 and 15x15 fuel designs, no indications of an insertion anomaly have appeared. It is judged this is because these plants run at a relatively low temperature, and therefore [

.]^{a,b,c} Therefore, the degree of thimble tube distortion required for an anomaly does not occur.

In summary, the root cause of the insertion anomalies at Wolf Creek and South Texas is thimble tube distortion caused by compressive loads on the fuel assemblies. At Wolf Creek accelerated growth was a major contributor to the compressive load. The result in the Wolf Creek design was large distortions in the dashpot and also in the upper spans of the guide thimbles.

At South Texas high fuel assembly growth was not manifested in fuel assembly length measurements, although the conditions for high growth were present. The behavior of the assembly was different than Wolf Creek because of major differences in mechanical design. The result was thimble tube distortions and large drag in the dashpot only.

3) While fuel with intermediate flow mixing grids (IFMs) would appear to be stiffer and thus less susceptible to distortion, it has not been shown that this fuel is not susceptible to thimble tube bowing from compressive loads. Furthermore, since the mid spans would be strengthened, the top and bottom spans might be left as the most susceptible portions of the fuel assembly and distortion of the top span could lead to control rod sticking very high in the core. Thus, the staff does not agree that plants with fuel assemblies containing IFMs are not susceptible.

In Figures 3 through 8, the drag data that was presented in the Incomplete RCCA Insertion report are differentiated by:

- assembly type (IFM, Zr-4 thimble tubes, ZIRLO thimble tubes)
- temperature

The data in Figures 5 and 8 shows that IFM assemblies usually have lower upper guide thimble drag than non-IFM assemblies. As shown in those figures, the total upper guide thimble drag is usually [.]^{a,b,c} Because of the lower upper guide thimble drag values, the RCCAs in IFM assemblies have greater momentum going into the dashpot which means a greater likely-hood that the RCCA will fully insert.

In the Westinghouse assembly design, IFMs are not located above grid seven (7) and below grid four (4). Since the upper guide thimble drag in IFM assemblies is usually less than [,]^{a,b,c} the IFMs have helped to minimize thimble tube distortion above the dashpot. Also as shown in Table 1, the top span drag values in IFM assemblies are much lower than the top span drag values of non-IFM assemblies. Insertion drag data is provided in the table. The insertion drag is "identical" to the withdrawal drag for the top span and upper guide thimble. Therefore, it is highly unlikely that RCCAs would stick high in the core in an IFM assembly.

The data in Figures 4 and 7 shows that the dashpot drag values are comparable for IFM and non-IFM assemblies. As noted previously for 12 foot fuel, both high dashpot and upper guide thimble drag is necessary for incomplete insertion. IFM assemblies have low upper guide thimble drag making them more resistant to incomplete insertion.

In conclusion, Westinghouse considers that there is sufficient data available from actual plant testing and analyses performed to permit the operation of Westinghouse fuel assemblies with IFMs to burnups within the current licensed range. The data which supports this conclusion is summarized below.

1. There have been no reports of incomplete RCCA insertion in fuel assemblies which have IFMs and have experienced a burnup up to approximately [.][a,b,c]

2. Drag tests of fuel assemblies with IFMs have indicated that in no case has any IFM fuel assembly exceeded both the Westinghouse F Specification guidelines.

3. Successful RCCA insertion has been reported in IFM fuel assemblies at VC Summer which have experienced operation with temperatures and burnups as well as power histories in the range of those fuel assemblies at Wolf Creek which had incomplete RCCA insertion.

4. The Westinghouse mechanical model predicts lower fuel assembly thimble tube bow for IFM fuel assemblies than the bow predicted for the Wolf Creek fuel assemblies that experienced incomplete RCCA insertions.

4) While most of the high drag data reported as a result of Bulletin 96-01 has been in high temperature plants, there have been a number of cases of high drag in lower temperature plants thus, it is not clear that plants with T Core Hot < 615°F are not susceptible to thimble tube bowing.

In Figures 3 through 5, the drag data is differentiated to investigate the temperature effect. In the Figure 3, assemblies that have greater than 615 F exceed the dashpot drag and upper guide thimble drag guidelines. The majority of the low temperature assemblies that were tested have dashpot drag and upper guide thimble drag values within the drag guidelines. The data points that exceed the upper guide thimble drag guidelines but are within the dashpot drag guidelines are 14x14 and 15x15 data points. Based on the drag data it does appear that plants with T-hot less than 615 F are less susceptible to thimble tube distortion since only plants with $T_{HOT} > 615°F$ exceeded both F-Spec guidelines.

Comparing average drag data, the following results were obtained: The high temperature plants typically had an increase of approximately [

.][a,b,c]

For IFM assemblies there is not much difference between high and low temperature

drag. Although as stated elsewhere, the IFM drags are generally less than the non-IFM drags on the average.

5) **As yet, no explanation has been given for the high drags measured in several types of fuel or the number of cases in which a dummy control rod could not be fully inserted into an assembly. It is our understanding that length measurements showed normal growth for these assemblies and thus, excessive growth could not be the explanation for the distortion causing the high drag forces or inability to fully insert a dummy control rod.**

When fuel assemblies are drag tested in the spent fuel pool, a light weight tool is used for the most accurate results. In some cases the drag in the fuel assembly may exceed the buoyant weight of the RCCA and handling tool. In these cases the RCCA will stop at the elevation were the drag reaches the tool and RCCA weight [ ]^{a,b,c}

When an RCCA does not fully insert, the preferred action is to push the RCCA fully into the fuel assembly, estimating the force required to achieve full insertion. The RCCA can then be re-tested during withdrawal and the numbers compared to refine the estimated drag. This requires additional tooling, procedures and time. In cases where these resources are not available, it is simply recorded that the RCCA did not fully insert.

During drag testing in the spent fuel pool at Wolf Creek RCCA RS31 did not fully insert in fuel assembly H53. In this case the drag on withdrawal was already available since the RCCA was fully inserted when the assembly was removed from the core. The breakaway drag measured on withdrawal in the dashpot was [,]^{a,b,c} and the midpoint of the dashpot was [.]^{a,b,c} Since this is significantly higher than the dead weight (RCCA and tool) it was not surprising full reinsertion was not achieved. It is noted a significant portion of the total drag is from the guide thimbles [.]^{a,b,c} This indicates a high degree of thimble tube distortion, and caused an insertion anomaly during a trip.

During drag testing at Sequoyah the dummy RCCA did not fully insert in fuel assembly E22. The RCCA was pushed in to full insertion and the drag measured on withdrawal was [.]^{a,b,c} Since this exceeds the dead weight, it is expected the RCCA would stop before reaching full insertion under test conditions. This assembly had very low drag in the guide thimbles [ ]^{a,b,c} on both insertion and withdrawal. Based on experience at Vogtle and V.C. Summer regarding assemblies with high drag in the dashpot and low drag in the guide thimbles, it is concluded that an insertion anomaly would not have taken place in this assembly.

When drag testing fuel assemblies 5G68 and 5G84 at Vogtle, the dummy RCCA did not fully insert. Due to constraints on resources the RCCA was not pushed to full insertion. Therefore, the drag in the dashpot is not available, but it is known this drag [.]^{a,b,c} Although the dashpot drag is considered high there is no reason to believe these assemblies are significantly different from other assemblies of similar design and burnup. Because of the low drag in the guide thimbles it is judged an insertion anomaly would not have occurred in these assemblies. Fuel assembly 5G80 at Vogtle showed high drag in the dashpot [ ]^{a,b,c} and achieved full insertion in a trip.

Questions on Susceptibility of Fuel Assemblies with IFMs

1) **What is the basis (in addition to lack of incomplete insertions) for the conclusion that fuel assemblies with IFMs are not susceptible? Please give full details and data to validate this claim.**

A separate document (NSD-NRC-97-4944) has been prepared to address the susceptibility of IFMs to IRI including supporting data.

2) **Please present side by side comparisons of assembly growth for assemblies with and without IFMs. Since temperature and power history are such important factors, the assemblies compared should have the same temperatures and power histories.**

The fuel assembly growth data available from measurements at the plant sites are presented in Figure 9. However, since these are from a variety of plant sites and operating cycles, the assemblies do not have the same power histories and temperatures. Figures 19 and 20 show the results of our mechanical model for assembly H50 (w/o IFMs) and J32 (w/IFMs). Since the mechanical model is normalized to the hot cell results of H50, the addition of IFM grids as part of the fuel assembly structure is straight forward. The comparison of the results from the two fuel assembly types is meaningful. The temperature and power used to analyze J32 are identical to those experienced by H50.

A review of the figures shows[

.]^{a,b,c} However, two additional pieces of information are noteworthy:

1) the magnitude of bow is still below the degree of bow]^{a,b,c} at which we would expect to see any drag. [
]^{a,b,c} and

2) of the 12 IFM assemblies measured during the root cause testing, [
.]^{a,b,c} The average drag in this Span being [
.]^{a,b,c} This is typically within the background noise of the data.

3) **Please explain why there would not be a temperature power history combination for which the top span and the bottom span would bow sufficiently to cause control rod sticking.**

[

.]^{a,b,c} This in fact is very much like the power history of H50. Therefore, our analysis of H50/J32 discussed above should be close to a worse case power history. We are currently performing a parametric study of power histories and temperatures to identify possible areas of concern. The boundary conditions of equivalent length and burnup through 3 cycles dictates allowable combinations of power histories. Formulating a parametric matrix that meets these boundary conditions is complex. We will notify you when such studies are complete.

4) Plotting the Vogtle drag data and the North Anna data together indicates that there is a greater drag for the IFM assemblies. Please explain how this is consistent with the position that fuel assemblies with IFMs are not susceptible.

IFMs do improve the lateral stability of the guide thimbles at the axial location of the IFMs. As IFMs are located in the upper guide thimble area, reduction in drag forces will be experienced at these locations. Figure 10 shows the drag in the upper guide thimble area for both Vogtle and North Anna. [

.]^{a,b,c} Figure 11 shows the dashpot drag for both of these assembly types.

[

.]^{a,b,c}

Therefore, the RCCAs in IFM assemblies have greater momentum upon entering the dashpot. Because of the extra momentum, the RCCAs in IFM assemblies are less susceptible to incomplete RCCA insertion if they have similar dashpot drags.

5) Please give details of the Wolf Creek temperature and power history. How is it different from other power histories and temperatures?

The power histories and temperatures for the assemblies examined in the root cause testing program were delineated in Appendix B of PPE-96-249. [

.]^{a,b,c} Our growth models indicate that high temperatures and fluence lead to accelerated growth.

The core average outlet temperatures in cycle 2 and 3 were 619° and 620°F. Although there are some plants which have temperatures slightly higher (1-2°F), Wolf Creek outlet temperatures are definitely higher than the average plant population.

Questions on the Preliminary Report

1) **Please provide the technical justification for the susceptibility conclusions on Page 31 of the report. (Lack of incomplete RCCA insertion is not sufficient justification.)**

Paragraph 7.0 (page 31) of PPE-96-249 states:

"7.0 Based on plant trip information, site test results and observations of growth data, Westinghouse presented the following susceptibility conclusions to the NRC on June 27, 1996:

- Based on the data and analysis to date, fuel with IFMs are not susceptible to incomplete insertion.
- The manufacturing period does not affect the susceptibility to incomplete insertion.
- Twelve foot Westinghouse fuel is not susceptible below a burnup of 40,000 MWD/MTU.
- Based on the data to date, while it does not appear that 14x14 and 15x15 fuel are less susceptible, it is difficult at this time to make a definitive conclusion."

A comprehensive discussion of IFM susceptibility is found in NSD-NRC-97-4944.

Section 8.2 of PPE-96-249 discusses the manufacturing process and associated facts and information which lead to this conclusion.

Figure 12, 13, and 14 show the drag information used to demonstrate the field experience/data which leads to the conclusion that 12 ft. Westinghouse assemblies less than 40 GWD/MTU are not susceptible to IRI.

Figure 12 shows that only Wolf Creek with drags greater than [ ]^{a,b,c} in the upper guide tube and dashpot respectively experienced IRI.

This same data is plot versus fluence in Figures 13 and 14. Note that a fluence of 7.5×10^{21} NVT corresponds to 40 GWD/MTU. There are no assemblies to the left of 40 GWD/MTU which experienced IRI as previously shown in Figure 12. In fact, the lowest burnup on one of the Wolf Creek assemblies which experienced IRI is FA #H16 with a burnup of 48.566 GWD/MTU (FA# H32 , 48.233 GWD/MTU, IRI cold test). Therefore, we believe 40 GWD/MTU is

conservative for assemblies of the Wolf Creek (H) design.

Responses to general question 2 addresses the susceptibility of 14x14 and 15x15 designs to IRI.

2) **The root cause conclusions for Wolf Creek stated that unusual growth is observed only in high temperature plants with certain power histories. Please specify the characteristics of this power history. How this will be avoided? How are you certain that only this power history can cause the problem?**

The first part of this question was answered in the response to Questions on Susceptibility of Fuel Assemblies with IFMs, Question 5.

We are taking a conservative position by not allowing three cycle, non-IFM assemblies to exceed 40 GWD/MTU in rodded positions in high (> 615°F) temperature plants regardless of power histories.

As previously stated, a parametric study will be performed to better understand the relationship of growth/bow to power histories. We will discuss these results when the analysis is complete.

3) **The South Texas experience shows that high drag in the dashpot region alone is sufficient to cause incomplete RCCA insertion. This contradicts the conclusion that RCCAs will completely insert if one of the F spec criteria is met. Please explain.**

The South Texas (ST) fuel design is different than the standard Westinghouse 12 foot assembly in many ways. One of the major differences is the double dashpot in the ST design as compared to the single dashpot in the majority of the remaining 12 foot designs. Figure 1 shows the differences between the standard 12 foot single dashpot design and the ST double dashpot design. The single dashpot design has one transition. This means the diameter of the thimble changes one time, from large to small, in the dashpot area. The double dashpot has three transitions in this area, which means the diameter of the thimble goes from large to small to large and back to small again. At these transitions the tubing is more flexible and can be more easily deformed laterally. The lateral deformations can cause high drag if they are large enough. The ST design which has three transitions is much more susceptible to high drag than the standard 12 foot single transition designs.

An additional consideration that makes the double dashpot feature more susceptible to high drag is that because there are lateral supports, grids and bottom nozzle, both above and below both of the dashpots, the bow expected in the dashpots can be in any orientation independent of one another. This means that

the bow in the upper dashpot for instance could be at a [ ]^{a,b,c} while the bow in the lower dashpot could be [ ]^{a,b,c} to that. Two bows in two different orientations over such a small axial length can cause excessive drag and accentuate the possibility of an IRI. A single dashpot on the other hand is supported only above and below the dashpot. This design will only take on a single orientation of bow which is much less severe from a dashpot drag standpoint. Figure 2 has been included to pictorially show this phenomena.

4) There were several assemblies at various plants into which the dummy RCCA could not be inserted and thus no drag data was taken. The RCCA was fully inserted and drag data taken for all the Wolf Creek assemblies. Please explain why the thimble tube distortion on the assemblies into which the dummy RCCA could not be inserted is not as serious as that of the Wolf Creek assemblies. Since these assemblies did not exhibit unusual growth, what is the explanation for the excessive thimble tube distortion? Why would this not cause incomplete RCCA insertion?

This question is essentially the same as question 5 in the main body of the letter. Please see response to that question.

5) The most likely root cause for the South Texas incomplete RCCA insertions was stated as "inadequate resistance to buckling in the fuel assembly design." Many other fuel assemblies at various plants exhibited high drag forces and thimble tube distortion in the dashpot area. Is the root cause for the distortion in these assemblies the same as in South Texas? Please explain your conclusion.

On page 66 of the report we state the following:

"The apparent cause of the incomplete Rod Cluster Control Assembly insertion at the South Texas Project is fuel assembly thimble tube distortion resulting from high, in-vessel, compressive loading imparted on the fuel assembly skeleton. The problematic distortion is limited to the assembly dashpot area of the thimble tubes which prevents complete control rod insertion."

Refer to the response that is given for general question #2.

6) Please explain Westinghouse plans to mechanically strengthen the fuel assemblies in order to avoid thimble tube distortion.

Our first priority in making design changes to eliminate thimble tube distortion is our 14 ft design used in South Texas Units 1 and 2. A list of the <u>potential</u> changes under consideration are as follows together with a brief explanation of how these changes will reduce distortion:

a,b,c

The first two changes are being evaluated for incorporation into the next region of Unit 1 scheduled for delivery ~ 8/97. The remaining changes will take longer to incorporate and are being considered for subsequent regions. In addition, a substantial portion of the 12 ft. designs scheduled for manufacture are incorporating

ZIRLO, and others may incorporate some of the above mentioned modifications to provide additional margin at higher burnups.

7) **It has been stated that the accelerated growth model was reviewed with "Non-Westinghouse experts (including GE)". Have you considered extending such an independent "peer review" to the overall mechanical model to validate confidence in it? How is creep handled in the mechanical model?**

We agree that a "peer review" of the overall mechanical model is appropriate, and plans for conducting such a review is being formulated by Westinghouse. The timing of such a review is important since the model has been recently developed and benchmarking is still ongoing as additional data becomes available.

We will keep you informed as to our progress.

Creep in the mechanical model is handled in the following manner. [

.]^{a,b,c} This sequence is repeated at each time step until the end of life.

8) **Please estimate the sensitivity of the influence of changing input parameters over a reasonable range to the model, if a full parametric study is not feasible, at least give an indication with reference to the irradiation growth model and the oxide growth model. What are the estimated confidence limits on input curves to the model such as growth vs. fluence and their sensitivity to the current number of data points and the optimum number expected to be used.**

The mechanical model needs some modifications to efficiently perform a parametric study. As previously stated, a parametric study will ´ ꞉ performed to better understand the relationship of growth/bow to power histories. ', ıe additional oxide data we plan to take will strengthen the confidence in the oxide growth model.

In addition we will also study the sensitivity of the growth models. We will discuss these results when the analysis is complete.

9) **Please provide growth data and strength data for ZIRLO to validate the claim that ZIRLO is not susceptible to thimble tube distortion.**

The basic material properties between ZIRLO and Zirc-4 are significant with regard to thimble tube distortion as follows:

- Growth Rate: Figure 15 shows the measured fuel assembly growth (thimble tube) data for Zirc-4 and ZIRLO up to fluences corresponding [ ]^{a,b,c} GWD/MTU. The improvements in the growth of ZIRLO is clearly evident.

- Creep Rate: Typical fuel rod diametrical creep is shown in Figure 16. Again, ZIRLO clearly [ ]^{a,b,c} than Zirc-4.

- Oxide Data: Figure 17 shows typical fuel rod oxide data for ZIRLO and two Zirc-4 materials. Again there is a significant improvement in the oxide thickness for ZIRLO relative to Zirc-4.

10) **Please explain why there would not be a power history and temperature combination for which accelerated growth would occur for ZIRLO.**

As we discussed earlier, our parametric study to illustrate the relationship between temperature and cycle power history is incomplete, however, we have performed an analysis showing the improvement in growth and bow had Wolf Creek assembly had ZIRLO instead of Zirc-4. Comparing the ZIRLO H50 results from Figure 18 with the Zirc-4 H50 results in Figure 19, we concluded that [

.]^{a,b,c}

Table 1: Measured Top Span, Guide Thimble and Dashpot Drag Data

a,b,c

Figure 1: 14 ft Fuel Assembly vs. 12 Ft Fuel Assembly Lower Guide Tube Geometry

a,b,c

Figure 2: Typical Dashpot Distortion for 14 ft and 12 ft Fuel Assemblies

a,b,c

Figure 3: NRC 96-01 Dashpot & Upper Guide Thimble Drag Data

a,b,c

Figure 4: NRC 96-01 Dashpot Drag Data

a,b,c

Figure 5: NRC 96-01 Upper Guida Thimble Drag Data

a,b,c

Figure 6: Dashpot & Upper Guide Thimble Drag Data - Root Cause Testing

a,b,c

Figure 7: Dashpot Drag Data - Root Cause Testing

a,b,c

Figure 8: Upper Guide Thimble Drag Data - Root Cause Testing

a,b,c

Figure 9: Recent Fuel Assembly Growth Data - Zr-4 Grids

a,b,c

Figure 10: North Anna and Vogtle Upper Guide Thimble Drag Data @ Fluence

a,b,c

Figure 11: North Anna & Vogtle Dashpot Drag Data @ Fast Fluence

a,b,c

Figure 12: Dashpot and Upper Guide Thimble Drag Data
(Drag Measured after Reactor Trip)

a,b,c

Figure 13: Dashpot Drag and Fast Fluence Data
(Drag Measured after Reactor Trip)

a,b,c

Figure 14: Upper Guide Thimble Drag and Fast Fluence Data (Drag Measured after Reactor Trip)

a,b,c

Figure 15: ASSEMBLY GROWTH DATA (ZIRLO VS ZR-4 THIMBLES)

a,b,c

Figure 16: North Anna Creep Measurements

a,b,c

Figure 17: North Anna Corrosion Measurements

a,b,c

Figure 18

WC H50 ROD & ASSEMBLY GROWTH
(ZIRLO)

a,b,c

WC H50 THIMBLE SPAN BOW
(ZIRLO)

a,b,c

Figure 19

WC H50 ROD & ASSEMBLY GROWTH

(REF CASE)

a,b,c

WC H50 THIMBLESPAN BOW

(REF CASE)

a,b,c

Figure 20

WC J32 ROD & ASSEMBLY GROWTH

(H50 POWER HISTORY)

a,b,c

WC J32 THIMBLESPAN BOW

(H50 POWER HISTORY)

a,b,c

Appendix D

Plant Reports

Wolf Creek EOC-8

Fuel Assembly/RCCA Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek near the end of Cycle 8. The reactor tripped resulting in a SCRAM. During this SCRAM, five RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the anomaly, and three additional RCCAs did not fully insert. The objective of this investigation was to determine, to the fullest extent possible, the nature of these anomalies. A decision tree for the investigation was developed and issued under PPE-96-043 prior to the initiation of testing, to be used as a guide in the investigative process.

Table 1.1: Fuel Assemblies With RCCA Insertion Difficulties

Core Position	F/A ID	Burnup (MWD/MTU)	Comments
H02	H16	48566	Did not fully insert in SCRAM Not tested in cold drop
K06	H53	51182	Did not fully insert in SCRAM Not tested in cold drop
F06	H50	50347	Did not fully insert in SCRAM & cold drop
K10	H59	51167	Did not fully insert in SCRAM & cold drop
H08	H38	50062	Did not fully insert in SCRAM & cold drop
B08	H32	48233	Did not fully insert in cold drop
H14	H11	48590	Did not fully insert in cold drop
P08	H03	48399	Did not fully insert in cold drop
F10	H45	50797	Fully inserted - no recoil in cold drop
H04	H69	44687	Fully inserted - one recoil in cold drop
H12	H54	44902	Fully inserted - one recoil in cold drop

2.0 Full Length RCCA Drag Tests

The following RCCA drag tests were conducted in an effort to better understand the anomaly.

- Drag test with upper internals in place
- Drag test of RCCA in mating fuel assembly in spent fuel pool
- Drag test of RCCA in a reference fuel assembly

The objectives of these tests were to determine:

(1) The location of the interference causing the anomaly (F/A, RCCA, or Upper Internals); and

(2) Determine the magnitude on interference.

2.1 Drag Test with Upper Internals in Place

A total of 27 RCCA positions were selected for drag testing with the upper internals in place. They included assemblies where RCCAs did not fully insert, and a sample of assemblies with various burnups. Fuel assemblies H03, H16, H53 and H59 also had RCCAs that did not fully insert, however, these assemblies were not selected because of the risk that they may not be reinsertable.

2.1.1 General Test Procedure

The reactor head was previously removed. The RCCA drive shafts remain attached to the RCCAs. A load cell and strip chart recorder are used in conjunction with the crane to withdraw the RCCA from the fuel assembly while recording total weight as a function of axial position of the RCCA in the fuel assembly.

2.1.2 Test Results

The results of the in core drag tests are tabulated in Table 2.1 and graphed in Figures 2.1 and 2.2 in Appendix A. Each of the thrice burned fuel assemblies (Region "H") showed a high drag in both the dashpot and the major diameter of the guide thimbles. With only one exception (assembly H69), all "H" assemblies would have exceeded the guidelines in F-spec [.][a,b,c] The twice burned assemblies (Region "J") showed an intermediate drag, and the once burned (Region "K") showed low drag.

On the "H" assemblies, although the highest drag was observed in the dashpot, a relatively high drag was observed over the entire length of the major diameter. The "J" and "K" assemblies exhibited negligible drag in the major diameter, and light to moderate drag in the dashpot.

Table 2.1: Wolf Creek EOC-8 In-Core RCCA Drag Test Results with Upper Internals in Place

a,b,c

2.2 Drag Tests in the Spent Fuel Pool

Seventeen fuel assemblies were selected for this test based on the results of the in core tests. The assemblies were as follows.

a,b,c

Table 2.2: Wolf Creek EOC-8 Fuel Assemblies Tested in Spent Fuel Pool

2.2.1 General Procedure

The selected RCCAs were latched with a handling tool and withdrawn approximately 108 inches, then reinserted back into the fuel assembly. These tests were performed in the same fuel assemblies in which the RCCAs were used in Cycle 8.

2.2.2 Test Results

The highest drag observed was on the "H" F/As, which also have the highest burnups. The drag measured on withdrawal at the dashpot midpoint for these assemblies ranged from [.] a,b,c For the F/As that had incomplete RCCA insertion during the trip, the lowest drag at this point was [ ] a,b,c The two F/As that fully inserted in both the SCRAM & cold drops showed the lowest drag (for mid point of dashpot). The drag was [.]a,b,c for F/A H45 and [ ] a,b,c for F/A H54. The assemblies that inserted on the scram, but not during the cold drops also showed a relatively low drag of [ ] a,b,c for F/As H32, H03 and H11 respectively.

The drag observed at the mid point of the major diameter ranges from [.] a,b,c A similar pattern to the dashpot was observed with the highest drag in the assemblies that had RCCAs that did not fully insert on the trip ranging from[.] a,b,c for F/A H53. Intermediate drag was observed in the assemblies that inserted on the SCRAM, but not the cold drops. These drags were [ ] a,b,c for F/A H11 and [ ]a,b,c for F/A H32. The low drags were observed on the two assemblies that inserted on both the scram and cold drops. These drags were [.] a,b,c

The drag observed on the "J" assemblies ranged from [ ] a,b,c at the mid point of the dashpot, and from [ ] a,b,c at the midpoint of the major diameter. The higher burnup assemblies showed the higher drag. The drag observed in the "K" F/As was [ ] a,b,c at the dashpot midpoint and [ ] a,b,c at the mid point of the major diameter.

The drag observed on insertion for the "H" F/As ranged from [.] a,b,c Three assemblies (H38, H50 and H53) had RCCAs that did not fully insert by the dead weight [ ] a,b,c The drag at the midpoint of the major diameter for the "H" assemblies ranged from [ ] a,b,c The same pattern observed on withdraw was repeated. Assemblies that had RCCAs that did not insert during the scram showed the highest drag, assemblies that had RCCAs that did not insert on cold drop showed intermediate drag (compared to "H" assemblies) and assemblies that inserted fully showed the lowest drag.

The "J" assemblies showed intermediate drag with the higher burned assemblies tending to show higher drag in the dashpot. The drag for these assemblies ranges from [ ] a,b,c at the midpoint of the dashpot and from [ ] a,b,c at the midpoint of the major diameter. The "K" assemblies showed the lowest drag on insertion. The values were [ ] a,b,c at the dashpot midpoint and [ ] a,b,c at the major diameter midpoint.

In general, the highest drag was observed at the bottom of the dashpot (breakaway) then would decrease to a constant (relatively high value) through the rest of the dashpot. There is usually a sharp decrease as the tips of the rod exit the dashpot. The drag typically decreases constantly but slowly through the major diameter until it is stopped at about [.] a,b,c The drag for the "H" assemblies was still relatively high at the end of withdrawal.

Chatter was observed on 8 "H" F/As (H03, H16, H11, H38, H50, H45, H59,and H53). The typical chatter would start shortly after the tips or the rods exited the dashpot, and continue for[ ] a,b,c of withdrawal. Chatter was not observed on insertion. On RCCA R27 (hafnium) in F/A H16, the chatter had a much different frequency and amplitude.

Table 2.3 provides a summary of spent fuel pool drag forces at selected elevations.

a,b,c

Table 2.3: Wolf Creek EOC-8 Spent Fuel Pool RCCA Drag Data

2.3 Drag Tests of RCCAs in Reference Fuel Assembly

Each of the RCCAs listed in Section 2.2 above were drag tested in a new fuel assembly (L54) using the same test procedure. In all cases, including hafnium RCCA R27, the drag observed was less than 20 lb.. This drag is judged to be insignificant.

2.4 Conclusions

The results of the above drag tests indicate that a binding interference exists between the thimble tubes and the RCCAs, causing the high drag. Based on the test of the RCCAs in a reference fuel assembly, the RCCAs show no indications of damage or deformation. The problem appears to reside within the fuel assembly.

3.0 Drag Test with Mock RCCA (Short Rodlets)

A drag test was performed on seven fuel assemblies with a mock RCCA with 13 inch rodlets. The objective of this test was to determine the condition of the thimble tubes at the top of the fuel assembly and the top nozzle alignment.

3.1 Test Procedure

The procedure for this test was similar to the full length RCCA drag test. The mock RCCA was attached to the handling tool and lowered into the test fuel assembly, then withdrawn. The total load was measured and recorded during insertion and withdraw.

3.2 Test Results

Table 3.1: Drag Test Results for Mock RCCA with Short Rodlets

a,b,c

3.4 Conclusions

The twice and thrice burned assemblies displayed a higher drag than the once burned (control) assembly. In all cases the drag measured with the mock (short) RCCA was significantly lower than the drag measured with the full length RCCA. Results from the single tube probe tests in Section 4 of this report indicate there are thimble tube distortions located slightly lower in the fuel assemblies. The Short RCCA test indicates these distortions extend to the top of the thimble tubes, but to a lesser degree. This conclusion is also supported by the results of the 36 inch long thimble tube probe. Based on the results of this test combined with the single tube probes and the video inspections there is no evidence of top nozzle misalignment.

4.0 Single Tube Probe

Fuel assemblies that show relatively high drag in the RCCA test have been selected for this test. Therefore, it is known there is an interference between the RCCA rodlets and thimble tubes. It was the objective of this test to determine the condition of the thimbles with respect to the following:

- Are the dashpots and/or major diameters distorted?
- Are the distortions "bows" or "kinks"?
- Are the distortions localized at a particular elevation?
- Are all the thimble tubes within an assembly distorted?

Fuel assemblies with low and intermediate drag were also selected for this test. The objective for these assemblies was to establish a baseline and observe the progression of single tube results as compared to RCCA drag test results.

4.1 General Procedure

Probes were fabricated in a progression of lengths and diameters to test both the dashpot and major diameters. The probes were assembled per drawing [ ] a,b,c starting with group 01. The probes were then lowered into each thimble tube and allowed to insert by their own weight. If the probe was inserted the entire length of the thimble tube (for dashpot probes) a "GO" was recorded. If the probe stopped before bottom, the elevation was recorded and the tube was designated to be "NO GO". For the guide thimble probes, the top of the dashpot was "bottom".

Some "NO GO" tubes were selected for drag testing with one of the guide thimble probes and a full length [ ] a,b,c probe. For these tests, the probe was allowed to drop by its own weight until it stopped, then was pushed to bottom. The probe was then withdrawn at slow speed, and the total load (drag and weight) was recorded as a function of elevation on a strip chart recorder.

4.3 Test Results

4.3.1 Go/ No-Go Summary - # of Tubes Passed/ # of Tubes Tested

Table 4.3.1: Go/No Go Testing of F/A Guide Thimble Tubes a,b,c

The assemblies that had RCCA insertion difficulties did not perform well in the H06 probe test. The high burnup assemblies did not perform well in the H02 and H03 probe tests.

The minimum major ID of the thimble tube is [.]^{a,b,c} Since the H06 probe has a [ ]^{a,b,c} diameter, a phenomena is occurring in the thimble tubes that is using more than [ ]^{a,b,c} of diametrical clearance over a length no longer than [.]^{a,b,c} The probe H06 no-go point varied along the assembly length.

The H03 probe went to a [ ]^{a,b,c} elevation in the dashpot than the H02 probe for assemblies J03, H16, H38, H50 and H81. This tends to indicate that the diametrical clearance was more important than the length.

A constant area for "GO" results was not observed in the assemblies. The "go" results were [ ]^{a,b,c} in an assembly area consisting of [ ]^{a,b,c} tubes, or located at random locations in the fuel assembly. At least one of the thimble tubes that surround the [ ]^{a,b,c} was a no-go indication in the tests with no-go results.

4.3.2 Thimble Tube Drag Test Summary

Table 4.3.2 below shows a comparison of the single tube rodlet drag test results to the RCCA drag test results. In the K06 results, the tests are not comparable since the H02 probe diameter is [ ]^{a,b,c} larger than RCCA rodlet diameter. In the other assemblies, the drag test results are the sum of the individual thimble tube drag results. Therefore, if the rodlet result is multiplied by the appropriate number to equal 24 tubes, you would expect the rodlet number to be higher than the RCCA number. This is usually true for the thimble tube and dashpot exit results, but it is not usually true for the initial and mid dashpot results.

Table 4.3.2: Summary of Guide Thimble Drag Test Results a,b,c

[ ]

The thimble tube drag tests results usually peaked at the thimble tube entrance and at the bottom of the dashpot. In the dashpot, the peaking could be attributed to small changes in the thimble tube bow, but at the thimble tube entrance another mechanism is causing the drag peaking results.

Assembly K06: The thimble tube go/no-go data and drag test data are summarized in Figures 4.1.1 and 4.1.2. The thimble tube go/no-go results in Figure 4.1.1 show that go results were achieved for dashpot probe H01 and thimble tube probes H04 and H06. The [ ] a,b,c thimble tubes [ ] a,b,c that did not pass the H02 test successfully passed the H03 test because the H03 diameter is [ ] a,b,c less restrictive than the H02 diameter. Thimble tubes 9 and 16 are center diagonal thimble tubes.

The tubes that did not pass the probe H02 go/ no-go test were drag tested with the H02 probe as shown in Figure 4.1.2. The maximum drag was [ ] a,b,c in the guide thimbles. The drag peaked at the end of the dashpot and at approximately [ ] a,b,c above the bottom of the dashpot for most of the tubes.

Assembly J03: In Figures 4.2.1, 4.2.2 and 4.2.3, the thimble tube go/ no-go data and drag test data are summarized. With the dashpot probes, 6 thimble tubes passed the H01 test. These

tubes [ ] a,b,c did not pass the H02 probe test because of the more restrictive length [.] a,b,c All 24 thimble tubes did not pass the H03 dashpot probe test with the [ ] a,b,c diameter but more restrictive length [.] a,b,c In the thimble tube probe tests, [ ] a,b,c thimble tubes did not pass the H04 probe test and [ ] a,b,c thimble tubes did not pass the H06 probe test. Thimble tubes [ ] a,b,c did not pass the H01, H03, H04 and H06 tests.

In Figures 4.2.2 and 4.2.3, drag test data is given for the full length [ ] a,b,c OD rodlet and probe H04 [,] a,b,c respectively. Thimble tubes [ ] a,b,c were tested on insertion and withdrawal. With the [ ] a,b,c rodlet, drag results tend to peak near the end of the dashpot and at the entrance to the tube. The tubes showed the same behavior with the drag peaking around 6 pounds in the dashpot and being approximately 2 to 3 pounds for the majority of the thimble tube. The drag tests with the H04 probe showed similar trends.

Assembly H16: In Figures 4.3.1, 4.3.2 and 4.3.3, the thimble tube go/ no-go data and drag test data are summarized. With the dashpot probes, [ ] a,b,c passed the H01 test and these were in the Face 1/ Face 2 corner of the assembly. These tubes [ ] a,b,c did not pass the H02 probe test because of the more restrictive [length (12").] a,b,c The thimble tubes [ ] a,b,c that passed the H03 dashpot probe test with the [ ] a,b,c diameter but more restrictive [ ] a,b,c were also mainly in the Face 1/ Face 2 corner of the assembly.

In the thimble tube probe tests, 17 thimble tubes did not pass the H04 probe test and [ ]a,b,c of those tubes passed the H05 probe test. The H06 probe barely entered the assembly for all of the tubes. The thimble tubes that passed the H04 test were mainly peripheral thimble tubes.

In Figures 4.3.2 and 4.3.3, drag test data is given for the full length [ ] a,b,c rodlet and probe H05 [,] a,b,c respectively. Thimble tubes [ ]a,b,c were tested on withdrawal. With the [ ] a,b,c rodlet, drag results tend to peak near the end of the dashpot. The tubes showed the same behavior with the drag peaking around [ ] a,b,c in the dashpot and being approximately [ ] a,b,c for the majority of the thimble tube.

The H05 probe drag tests in Figure 4.3.3 have peaking in the measured results between the grids. In thimble [ ] a,b,c, the drag peaks at [ ] a,b,c between grids [ ].a,b,c All of the tubes showed similar behavior.

Assembly H38: In Figures 4.4.1, 4.4.2 and 4.4.3, the thimble tube go/ no-go data and drag test data are summarized. With the dashpot probes, 7 thimble tubes passed the H01 test and three of those tubes were in the Face 3/ Face 4 corner of the assembly. These tubes [ ] a,b,c did not pass the H02 probe test because of the more restrictive [ ] a,b,c. Thimble tubes [ ] a,b,c passed the H03 dashpot probe test with the

[ ] a,b,c less restrictive diameter. [ ] a,b,c of these tubes are [ ] a,b,c in the Face 2/ Face 3 area of the assembly.

In the thimble tube probe tests, [ ] a,b,c the thimble tubes did not pass the H04 probe test. Thimble [ ] a,b,c the H05 probe test and the H06 probe [ ]a,b,c entered the assembly for [ ] a,b,c that were tested. Two of the three thimble tubes that did not pass the H04 test were peripheral Face 1 thimble tubes.

In Figures 4.4.2 and 4.4.3, drag test data is given for the full length [ ] a,b,c rodlet and probe H05 [ ] a,b,c, respectively. Thimble tubes 1, 3, and 7 were tested on insertion and withdrawal. With the [ ] a,b,c rodlet, drag results tend to peak near the end of the dashpot. The tubes showed the same behavior with the drag peaking around [ ] a,b,c in the dashpot and being approximately [ ] a,b,c for the majority of the thimble tube.

The H05 probe drag tests in Figure 4.4.3 have [ ] a,b,c throughout the measured length. All of the tubes showed similar behavior with the drag varying between [ ] a,b,c.

Assembly H50: In Figures 4.5.1, 4.5.2 and 4.5.3, the thimble tube go/ no-go data and drag test data are summarized. With the dashpot probes, the two thimble tubes [ ] a,b,c that passed the H01 test did not pass the H02 probe test because of the more restrictive length [.]a,b,c Thimble [ ] a,b,c was the only tube to pass the H03 dashpot probe test with the [ ] a,b,c less restrictive diameter.

In the thimble tube probe tests, thimble [ ] a,b,c did not pass the H04 probe test. Thimble tubes [ ] a,b,c were able to pass the subsequent H05 probe test. The H06 probe [ ] a,b,c the assembly for [ ] a,b,c thimble tubes. [ ] a,b,c thimble tubes that did not pass the H04 test were in the Face 1/ Face 2 area of the assembly.

In Figures 4.5.2 and 4.5.3, drag test data is given for the full length [ ] a,b,c rodlet and probe H05 [ ] a,b,c, respectively. Thimble tubes [ ] a,b,c were tested on withdrawal. With the [ ] a,b,c rodlet, drag results tend to peak near the end of the dashpot. Tubes [ ] a,b,c showed similar behavior. After the initial breakaway there an increase in drag to about [ ] a,b,c pounds in the middle of the dashpot. The drag was about [ ] a,b,c pounds at the dashpot entrance and continued to [ ] a,b,c from the top of the assembly. The trends for Tubes [ ] a,b,c are shown on Figure 4.5.2.

The H05 probe drag tests in Figure 4.5.3 have [ ] a,b,c throughout the measured length. All of the tubes showed similar behavior with the drag varying between [ ] a,b,c pounds.

Assembly H81: In Figures 4.6.1, 4.6.2, 4.6.3, 4.6.4 and 4.6.5, the thimble tube go/ no-go data and drag test data are summarized. With the dashpot probes, [ ]^{a,b,c} tubes passed the H01 test, but [ ]^{a,b,c} the H02 probe test with the more [ ]^{a,b,c}. The [ ]^{a,b,c} tube that passed the H03 dashpot probe test with the [ ]^{a,b,c} less restrictive diameter were [ ]^{a,b,c} and [ ]^{a,b,c} of the tubes were in the Face 1/ Face 2 area of the assembly.

In the thimble tube probe tests, thimble tubes [ ]^{a,b,c} did not pass the H04 probe test but passed the subsequent H05 probe test with the [ ]^{a,b,c}. [ ]^{a,b,c} tubes passed the H06 test, but the thimble tubes that did not pass the H06 test had no-go indications in the [ ]^{a,b,c} of the assembly.

In Figures 4.6.2, 4.6.3, 4.6.4 and 4.6.5, drag test data is given for the full length [ ]^{a,b,c} rodlet, probe H04 [ ]^{a,b,c} and probe H05 [ ]^{a,b,c}. Thimble tubes [ ]^{a,b,c} insertion and withdrawal results are provided on Figure 4.6.2 and thimble tubes [ ]^{a,b,c} insertion and withdrawal results are provided on Figure 4.6.3. The drag results were usually flat for most length, but in some of the tubes the drag peaked at the end of the dashpot or at the entrance to the thimble tube.

The H81 assembly was drag tested with probe H04 and H06. The probe H04 results for tubes [ ]^{a,b,c} are provided in Figure 4.6.4. The drag [ ]^{a,b,c} between [ ]^{a,b,c} pounds in the upper half of the assembly. The H06 probe results for thimble tubes [ ]^{a,b,c} are provided in Figure 4.6.5. Sharp drag [ ]^{a,b,c} occurred [ ]^{a,b,c} with the H06 probe. The H81 assembly was the only assembly with RCCA insertion difficulties that had H06 probe go/no-go success. The probe [ ]^{a,b,c} on insertion for tubes [ ]^{a,b,c}.

4.4 Conclusions

The single tube probe tests clearly demonstrate that distortion exists in varying degrees in the fuel assembly guide thimble tubes. These distortions were observed in both the dashpots and major diameters of the guide tubes. The tubes are bowed (not kinked) and the distortion is localized over relatively small axial lengths within the assemblies. The highest degree of guide tube distortion was observed in the upper half of the fuel assembly, particularly between grids 6 and 8. Some assemblies showed a secondary distortion just above grid 2.

The degree of distortion varies from tube to tube within a fuel assembly. In some fuel assemblies both "good" and "bad" tubes were observed. The number of distorted tubes, as well as the degree of distortion, increased with RCCA drag and fuel assembly burnup.

5.0 Fuel Assembly Bow

Seventeen fuel assemblies were measured for bow in the spent fuel pit. The bow was measured by suspending a plumb bob against the fuel assembly's top nozzle and measuring the distance between the string and the edge of the assembly. This method does not provide a "true" indication of shape because the assembly prevents the plumb bob from moving in the negative direction.

5.1 Measured Bow Shape

The measured bow is shown graphically in Figures 5.1 through 5.8. The data has been adjusted by assuming that the bottom nozzle measurement is zero displacement. Banana bow and C-shaped bow were the identified shapes. The bow was centered when the top nozzle and bottom nozzle bow measurements were equivalent. The assembly may have interfered with the plumb bob at grid 1 for assemblies H32, H38 and H53.

Table 5.1: Summary of Measured Bow Shape

a,b,c

5.2 Measured Bow Change

Because most of the RCCAs were stopping in the dashpot the change in bow was examined in that area. The data is tabulated below for the different fuel assemblies and is shown graphically in Figure 5.9. The top nozzle-bottom nozzle misalignment is the difference between the top nozzle and bottom nozzle bow measurement .

Table 5.2: Summary of Measured Bow Change

a,b,c

The dashpot bow change method was not able to completely differentiate between the three categories, but shows the following trends at [:] a,b,c

[ ] a,b,c

The top nozzle-bottom nozzle misalignment is high [ ] a,b,c on at least one face for most of the H-assemblies. However, RCCA problems were not observed for the K46, H45 and H54 assemblies which had misalignments [.] a,b,c This indicates that the top nozzle-bottom nozzle misalignment is not as important as the dashpot area bow change in assemblies experiencing RCCA insertion anomalies.

6.0 Fuel Assembly Growth

Fuel assembly length measurements were performed on a total of 26 assemblies. The measurements were made using a standard of known length and a measuring device which has a dial indicator. The data were corrected for the spent fuel pool water temperature.

The 26 assemblies consisted of three "G", fourteen "H", seven "J", and two "K" assemblies. The "H", "J", and "K" assemblies are of the [ ] a,b,c design, while the "G" assemblies are of the [ ] a,b,c design. Thimble tube material of the "H", "J" and "K" is [;] a,b,c all "G" assemblies utilized [.] a,b,c Both "H" and "G" assemblies were thrice burnt; the "J" assemblies were twice burnt; and the "K" assemblies were once burnt. Table 6.1 lists the measured growth for each of the 26 assemblies.

Table 6.1: Wolf Creek EOC-8 Assembly Growth Data

a,b,c

It should be noted that assembly H81 showed relatively low growth since the assembly was irradiated for only two cycles and had been stored in the Spent Fuel Pool.

Figure 6.1 plots the measured assembly growth data as a function of fluence. The figure also compares the Wolf Creek data with assembly growth data from other plants. The growth data

from the "H" assemblies appears to be higher than the existing data, possibly due to the initiation of breakaway growth at the higher burnups.

7.0 Fuel Rod Growth

For selected F/As, the axial gap between each peripheral rod and the F/A top nozzle was manually measured from the low magnification TV tapes obtained during the EOC-8 fuel examination. When combined with the F/A growth information previously obtained, a value for fuel rod growth can subsequently be derived.

Conversion factors from the measured gaps to the actual gaps were obtained by measuring the TV image of several grid spring heights on the outer straps in the top and bottom grids on each assembly face and by comparing the measured spring height to the corresponding manufacturing drawing nominal dimension. This assumes a [.]^{a,b,c}

A total of 11 assemblies were measured for the rod-to-nozzle gaps. They are G18, G35, G46, H07, H43, H50, H62, J29, J46, J61, and K46. The cladding material used in the "G" assemblies was standard Zircaloy-4. The cladding material used for the "H", "J", and "K" assemblies was Improved Zircaloy-4. Almost all peripheral rods in the "H" and "J" assemblies were seated on the bottom nozzle. It was also observed that the top gaps in most of the assemblies were fairly even, except that some interior rods in assemblies J29, H62, and H43 appeared higher than the exterior rods. These rods may be experiencing breakaway growth, or simply may not be seated on the bottom nozzle.

Fuel rod growth was derived from pre- and post- gap data and the measured fuel assembly growth using the following equation:

$$\% \text{ Rod Growth} = [(A + B - C)/D] \times 100\%$$

where,
A = pre-irradiation nominal rod to nozzle total gap
B = irradiation increase in rod to nozzle gap due to fuel assembly growth
C = post-irradiation rod to nozzle total gap
D = pre-irradiation nominal rod length

The calculated fuel rod growth ranged from:

"G" F/As	[ ]^{a,b,c}
"H" F/As	[ ]^{a,b,c}
"J" F/As	[ ]^{a,b,c}
"K" F/A	[ ]^{a,b,c}

Figure 7.1 plots the Wolf Creek rod growth data as a function of fluence and compares the results with rod growth data from other plants. Appendix "B" contains the tabulated rod growth data for each F/A. The data shows that the Wolf Creek rod growth data are within the Westinghouse data base, although they display slightly lower than average growth at higher burnup levels.

8.0 Top Nozzle Gap Measurements

An attempt was made to measure the distance between the bottom of the top nozzle and the top of the top grid at the two opposite sides on the same assembly face to determine if there is any detectable cocking of t! top nozzle. The distance was measured at the two opposite sides of Face 3 of F/A J03. Considering the large uncertainty involved in the measurement, no significant difference in the two distances was detected, and no additional measurements were performed on the other assemblies.

9.0 Guide Thimble Borescope Examinations

Borescope examinations were conducted on all guide thimbles in the following Wolf Creek fuel assemblies: H16, H38, H81, J03, and K06. The assemblies were chosen based upon the results of their RCCA drag force measurements and their burnup.

Every guide thimble in the selected assemblies was examined to determine:

- The presence of obvious physical anomalies and the general condition of the tube;
- The presence of debris or debris-related scarring on the thimbles; and
- The quantity and severity of wear marks believed to be present in the guide thimbles based upon their drag force results.

Videotapes of the inspections were forwarded to Columbia for analysis. The orientation of the wear marks was recorded at each grid location in a fuel assembly (excluding IFM locations) to detect any trends in their axial location or orientation. This mapping of the wear mark orientations at each grid elevation revealed no trends, but visual observations of wear patterns over the entire thimble length consistently showed a [ ] a,b,c in higher burnup assemblies (H38, H16, and J03). The [ ] a,b,c also appeared to increase with increasing burnup. There were no thimbles that were completely free of marks, although some assemblies had thimbles with more narrow and intermittent marks, primarily in the bottom half of the assembly.

The wear marks seem to suggest that individual RCCA rodlets were forced to [ ] a,b,c their way through the guide thimble tubes, thereby causing increased RCCA drag loads. This indicates that the thimbles may be distorting into various [ ] a,b,c, similar to that produced when [ ] a,b,c. Further investigation will be required to determine the root cause for such a phenomena. Individual borescope observations for each fuel assembly are given below.

H38 All 24 thimble tubes showed wear marks near the top nozzle, and the marks continued along almost the entire length of each tube. The marks appeared to follow a [ ] a,b,c down the tube, frequently making one complete [ ] a,b,c over the length of a single [ ] a,b,c grid span. The marks were wider and more continuous in the upper half of the tube (between grids 5 through 8). In the lower portion of the tube, the rub marks became more intermittent and narrow. They often disappeared immediately above and below the grid locations. Similar marks were also observed in the dashpot region. All marks appeared to be superficial.

J03 All 24 thimble tubes displayed wear marks near the top nozzle, but they appeared less pronounced than those seen in H38. The marks continued along almost the entire length of each thimble tube. The marks appeared straighter than those seen in H38, although a gradual [ ] a,b,c was evident.

H16 Only one tube had a wear mark near the top nozzle. [ ] a,b,c tubes had no marks at Grid #8, and all tubes showed wear marks beyond that point. The marks were less pronounced than those on F/A H38, and showed a gradual [ ] a,b,c. The marks became narrow and intermittent over the bottom half of the tubes. The marks often disappeared immediately above and below the grid locations. Several tubes showed a distinctive wear mark just above the flow holes. [ ] a,b,c tubes had no marks in the region of Grid #1.

H81 [ ] a,b,c tubes had no wear marks near the top nozzle, while all but [ ]a,b,c showed marks at Grid #8. All had marks thereafter. The marks were significantly less pronounced than the previous H and J assemblies. The marks showed a very gradual [ ] a,b,c nature. The bottom half of the tubes showed narrow and intermittent marks that often disappeared immediately above and below the grid locations.

K06 Near the top nozzle, [ ] a,b,c tubes showed wear marks. At Grid #8, 23 of 24 tubes were marked. After passing Grid #8, continuous wear marks were observed [,] a,b,c but the marks were significantly less pronounced than those on F/As H38 and J03. The marks were relatively straight and were also very intermittent in the lower half of the tube.

Table 9.1: Summary of Guide Thimble Borescope Examinations

a,b,c

10.0 Overall Summary

The direct cause of the incomplete RCCA insertions at Wolf Creek is thimble tube distortion. A binding interference exists between the thimble tubes and the RCCAs, causing the high drag. Tests of the RCCAs in a reference fuel assembly show no indications of damage or deformation. The problem appears to reside within the fuel assembly. The drag loads and thimble tube distortions also increase with increasing burnup/residency time, which indicates a correlation between the two phenomena.

Appendix 'A'

Supporting Charts & Graphs

Figure 2.1: Wolf Creek EOC-8

Withdrawl Force vs. Fluence, Measured in Reactor Core

a,b,c

Figure 2.2: Wolf Creek EOC-8
Insertion Force vs. Fluence, Measured in Reactor Core

a,b,c

[ ]

a,b,c

Figure 4.1.1: Wolf Creek EOC-8 Assembly K06 Thimble Tube Go/ No-Go Probe Data

a,b,c

Figure 4.1.2: Wolf Creek EOC-8 Assembly K06 Thimble Tube Drag Data - Probe H02

a,b,c

Figure 4.2.1: Wolf Creek EOC-8 Assembly J03 Thimble Tube Go/ No-Go Probe Data

a,b,c

Figure 4.2.2: Wolf Creek EOC-8 Assembly J03 Thimble Tube Drag Data - Full Length Rodlet

a,b,c

Figure 4.2.3: Wolf Creek EOC-8 Assembly J03 Thimble Tube Drag Data - Probe H04

a,b,c

Figure 4.3.1: Wolf Creek EOC-8 Assembly H16 Thimble Tube Go/ No-Go Probe Data

a,b,c

Figure 4.3.2: Wolf Creek EOC-8 Assembly H16 Thimble Tube Drag Data - Full Length Rodlet

a,b,c

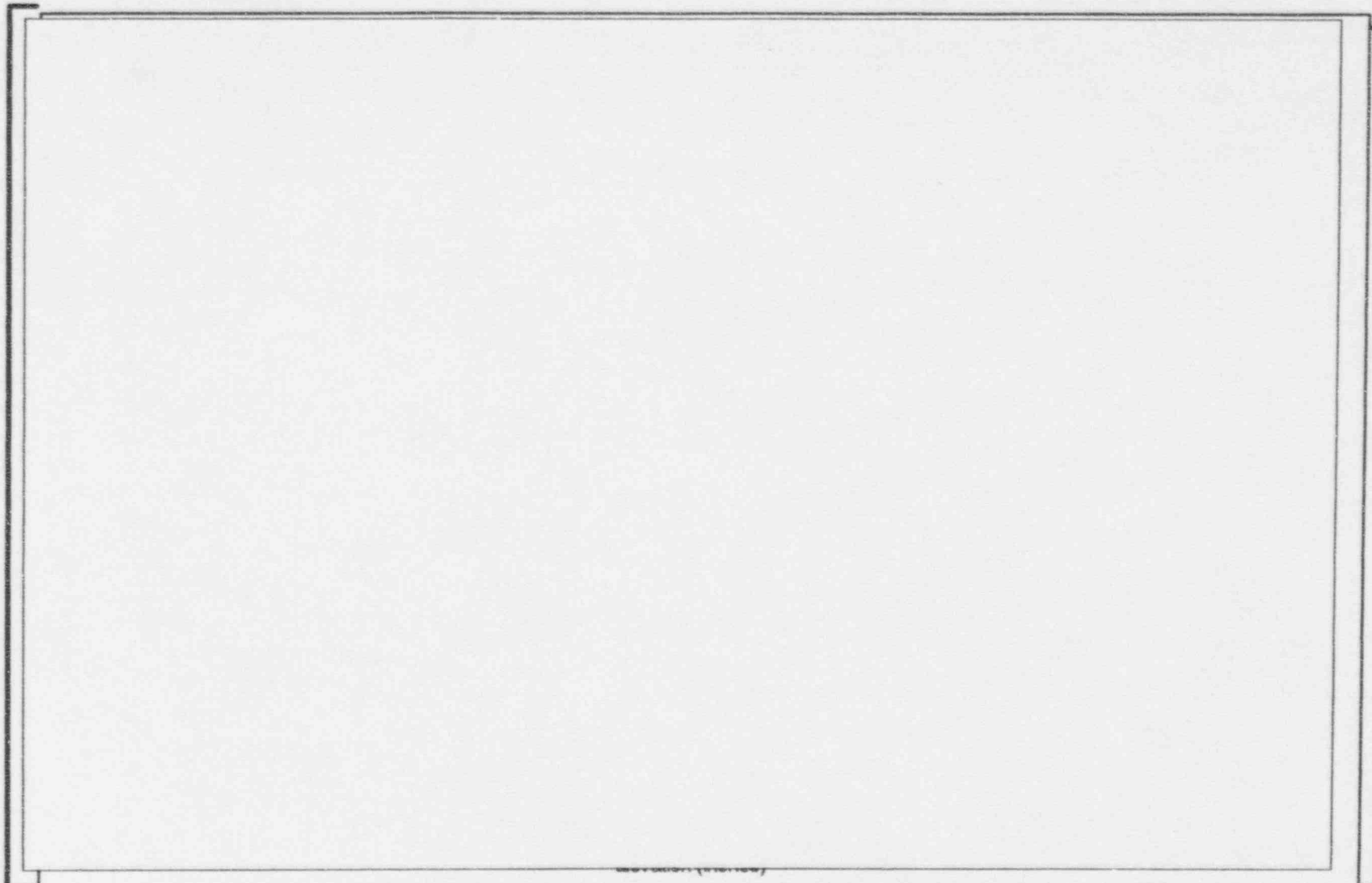


Figure 4.3.3: Wolf Creek EOC-8 Assembly H16 Thimble Tube Drag Data - Probe H05

a,b,c

Figure 4.4.1: Wolf Creek EOC-8 Assembly H38 Thimble Tube Go/ No-Go Probe Data

a,b,c

Figure 4.4.2: Wolf Creek EOC-8 Assembly H38 Thimble Tube Drag Data - Full Length Rodlet

a,b,c

Figure 4.4.3: Wolf Creek EOC-8 Assembly H38 Thimble Tube Drag Data - Probe H05

a,b,c

Figure 4.5.1: Wolf Cresk EOC-8 Assembly H50 Thimble Tube Go/ No-Go Probe Data

a,b,c

Figure 4.5.2: Wolf Creek EOC-8 Assembly H50 Thimble Tube Drag Data - Full Length Rodlet

a,b,c

Figure 4.5.3: Wolf Creek EOC-8 Assembly H50 Thimble Tube Drag Data - Probe H05

a,b,c

Figure 4.6.1: Wolf Creek EOC-8 Assembly H81 Thimble Tube Go/ No-Go Probe Data

a,b,c

Figure 4.6.2: Wolf Creek EOC-8 Assembly H81 Thimble Tube Drag Data - Full Length Rodlet

a,b,c

Figure 4.6.3: Wolf Creek EOC-8 Assembly H81 Thimble Tube Drag Data - Full Length Rodlet

a,b,c

Figure 4.6.4: Wolf Creek EOC-8 Assembly H81 Thimble Tube Drag Data - Probe H04

a,b,c

Figure 4.6.5: Wolf Creek EOC-8 Assembly H81 Thimble Tube Drag Data - Probe H06

a,b,c

Figure 5.1: Wolf Creek EOC-8 Bow Data for H50, H59 and H38 Assemblies

a,b,c

Figure 5.2: Wolf Creek EOC-8 Bow Data for H16 and H53 Assemblies

a,b,c

Figure 5.3: Wolf Creek EOC-8 Bow Data for Assemblies H45 and H54

a,b,c

Figure 5.4: Wolf Creek EOC-8 Assembly Bow Data for H11 and H03 Assemblies

a,b,c

Figure 5.5: Wolf Creek EOC-8 Bow Data for H81 and H32 Assemblies

a,b,c

Figure 5.6: Wolf Creek EOC-8 Bow Data for K46 and K06 Assemblies

a,b,c

Figure 5.7: Wolf Creek EOC-8 Bow Data for J37 and J50 Assemblies

a,b,c

Figure 5.8: Wolf Creek EOC-8 Bow Data for J03 and J52 Assemblies

a,b,c

Figure 5.9: Wolf Creek EOC-8 Dashpot Arae and Assembly Bow Data

Figure 6.1: Wolf Creek EOC-8 Fuel Assembly Growth Data

a,b,c

FIGURE 7.1 WOLF CREEK EOC-8 ROD GROWTH DATA

a,b,c

Appendix 'B'

Fuel Rod Growth Data Tables

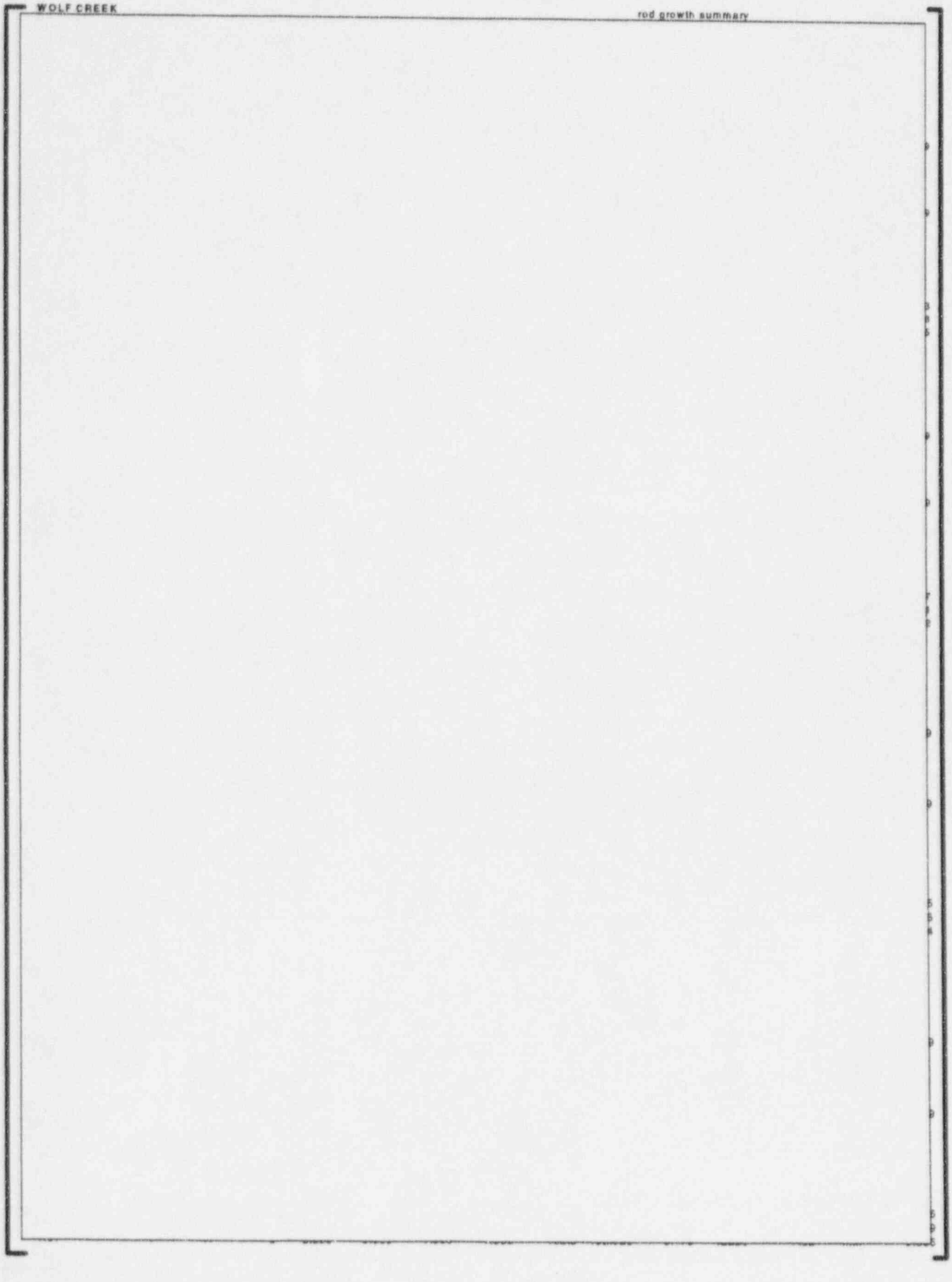
WOLF CREEK

rod growth summary

a,b,c

a,b,c

a,b,c



a,b,c

a,b,c

WOLF CREEK

rod growth summary

a,b,c

WOLF CREEK

rod growth summary

a,b,c

WOLF CREEK

rod growth summary

a,b,c

a,b,c

WOLF CREEK

rod growth summary

a,b,c

rod growth summary

a,b,c

North Anna Unit 1/Unit 2

Fuel Assembly Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek near the end of Cycle 8. The reactor tripped resulting in a SCRAM. During this SCRAM, five RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the anomaly, and three additional RCCAs did not fully insert. A subsequent inspection program (PPE-96-088) concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. A binding interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly show no indications of damage or deformation. The problem appears to reside within the fuel assemblies. Drag loads and thimble tube distortions at Wolf Creek also increase with increasing burnup/residency time, which appears to indicate a correlation between the two phenomena due to some as yet unknown root cause.

The objective of the North Anna inspection program was to determine if high burnup fuel at North Anna has experienced similar thimble tube distortions that could result in incomplete RCCA insertion. The data will be used to help establish whether the thimble tube distortion phenomena previously observed at Wolf Creek is generic to high burnup fuel.

The following tests were scheduled to be conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (also referred to as Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements; and
(4) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to establish that the growth of the fuel assemblies and fuel rods is within the anticipated range for the listed F/A burnup.

Videotaping of the rod-to-nozzle gaps for each of the North Anna fuel assemblies was not completed due to time limitations. Fuel rod growth data is therefore unavailable for North Anna at this time.

2.0 Full Length RCCA Drag Tests in Spent Fuel Pool

Fuel assemblies fabricated for seven different contracts were drag tested in the spent fuel pool. The specific fuel features for each assembly are shown in Table 2.1. All of the assemblies share the following common features:

[ ] a,b,c

Fuel assemblies manufactured during contracts VGHF, VGIF, VRIF, VRJF and VRKF were manufactured with [ ] a,b,c and have features identical to the Wolf Creek assemblies that experienced the RCCA incomplete insertion problem. Fuel assemblies manufactured during contract VRKF also have additional features to allow the assemblies to obtain [.] a,b,c

Table 2.1: Fuel Features of North Anna 17x17 Fuel Assemblies

[ ] a,b,c

The drag test results are tabulated in Table 2.2 and are graphed in Figures 2.1, 2.2 and 2.3. As shown in Table 2.2, some fuel assemblies were recently discharged from the reactor core and others have been in the spent fuel pool for 1 or 2 cycles. [.] [a,b,c] Due to constraints on resources the RCCA was not pushed to full insertion. Therefore, the drag in the dashpot is not available, but it is known this drag exceeds [.] [a,b,c]

In Figure 2.1 the North Anna dashpot and guide thimble data is shown. Fuel assembly 3L4 was the only assembly to exceed the F-spec dashpot and guide thimble drag guidelines of [.] [a,b,c] in the dashpot and [ ] [a,b,c] above the dashpot. Figures 2.2 and 2.3 display the dashpot drag and guide thimble drag data plotted versus their corresponding fast fluence values. At Wolf Creek, the incomplete insertions occurred in fuel with fast fluence values greater than [ ] [a,b,c] when the dashpot and guide thimble drag guidelines were exceeded. Fuel assembly 3L4 (VGIF) is displaying high dashpot drag similar to the fuel assemblies that experienced incomplete RCCA insertion at Wolf Creek. However, it should be noted that even the highest upper guide tube drag of [.] [a,b,c] in North Anna assembly 3L4 is about [ ] [a,b,c] of the minimum upper guide tube drag load of [.] [a,b,c] for assemblies that had RCCAs that did not fully insert at Wolf Creek. North Anna fuel assemblies 0A1, 0A2, 0A8 and 2A8 could not be drag tested because the dashpot drag forces were too high.

Table 2.2: North Anna Drag Test Data

a,b,c

Figure 2.1: North Anna Dashpot and Guide Thimble Drag Data

a,b,c

Figure 2.2: North Anna Dashpot Drag and Fast Fluence Data

a,b,c

Figure 2.3: North Anna Guide Thimble Drag and Fast Fluence Data

a,b,c

3.0 Single Tube Probe

Fuel assemblies that show relatively high drag or dashpot interference in the RCCA drag tests were selected for single-tube probing. The objective of this test was to determine the condition of the thimbles with respect to the following:

- Are the dashpots and/or major diameters distorted?
- Are the distortions "bows" or "kinks"?
- Are the distortions localized at a particular elevation?
- Are all the thimble tubes within an assembly distorted?

Fuel assemblies with intermediate drag and burnups are normally selected for this test. These assemblies help establish a baseline and track the progression of single tube distortions compared to RCCA drag test results. However, time restrictions during the inspection did not allow for single tube probing on this category of assembly at North Anna.

Probes were fabricated in various lengths and diameters to test both the dashpot straightness and major diameter distortion. The probe was assembled per [ ] a,b,c starting with group 01. The probe was then lowered into each thimble tube and allowed to insert by its own weight. If the probe was inserted the entire length of the thimble tube (for dashpot probes) a "GO" was recorded. If the probe stopped before bottom, the elevation was recorded. For the guide thimble probes, the top of the dashpot was "fully inserted".

Table 3.1details the go/no-go thimble tube probe and thimble tube drag test results.

a,b,c

Table 3.1: Go/No-Go Summary - Tubes Passed/ Tubes Tested **= Not tested

[ ]

Two assemblies which would not allow for complete insertion of the RCCAs, 0A1 and 2A8, were high burnup assemblies which would not accept probe Items 1 or 3. Since the other two assemblies probed also had high dashpot loads [ ] a,b,c it appears that all of the assemblies tested have experienced a large amount of dashpot distortion which affects both dashpot apparent diameter (ovality) and bow over the entire dashpot length. This observation is supported by the data from the [ ] a,b,c diameter which would not pass [ ] a,b,c tubes in any assembly tested. high burnup assemblies did not perform well in the H02 and H03 probe tests. The test data indicates that the upper guide thimble on the assemblies which do not fully accept the RCCAs are also significantly distorted. This observation is particularly apparent for assembly 0A1, where [ ] a,b,c tubes would pass the [ ] a,b,c probe.

4.0 Fuel Assembly Growth

Fuel assembly length measurements were performed on 16 assemblies (11 from Unit 1, and 5 from Unit 2). Measurements were made using a standard of known length and a measuring device with a dial indicator. The data was corrected for the spent fuel pool water temperature. The measured growth of the 16 assemblies is listed below in Table 4.1.

13 of the 16 assemblies are of the 17x17 [ ] [a,b,c] and the remaining 3 are of the 17x17 [.] [a,b,c] The thimble tube material for assemblies 2A8, K17, K32, Y08, and X09 is standard Zircaloy-4; the remaining assemblies have thimbles made from Improved Zircaloy-4.

The measured assembly growth ranged from [ ] [a,b,c]. Figure 4.1 plots the measured F/A growth data as a function of fluence, and compares the North Anna data with F/A growth data from other plants. It indicates that the North Anna growth data is normal and lies within our database. The data showed no evidence of breakaway growth.

a,b,c

Table 4.1: North Anna Fuel Assembly Growth Data

[ ]

Figure 4.1: Fuel Assembly Growth
SAP, VRA, CGE, WEP, GAE

a,b,c

[ ]

5.0 Overall Summary

Fuel assemblies tested at North Anna displayed higher dashpot drag forces on a number of assemblies that are consistent with the thimble tube dashpot distortions previously seen at Wolf Creek. Even though four assemblies would not allow an RCCA to fully insert during the spent fuel pool testing, the data indicates upper guide tube drag loads are within reasonable levels. The maximum upper guide tube drag load measured at North Anna was [ ] a,b,c.

The assemblies at North Anna are showing a trend of increased guide thimble distortion with increased burnup. The assemblies tested indicate that the dashpot distortion is creating the majority of the drag measured. Even though the upper guide tube is also experiencing deformation and contributing to increased drag, the extent of the distortion is less than that experienced by the "H" region fuel at Wolf Creek which did not allow RCCA insertion.

Only one assembly [ ] a,b,c showed drag in excess of the [ ] a,b,c guideline in the specifications. This assembly was still [ ] a,b,c below the threshold of [.] a,b,c for an assembly which did not allow insertion at Wolf Creek. The North Anna fuel is generally not experiencing thimble tube distortion of the same degree experienced by the "H" region fuel at Wolf Creek.

V. C. Summer

Fuel Assembly Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek near the end of Cycle 8. The reactor tripped resulting in a SCRAM. During this SCRAM, five RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the anomaly, and three additional RCCAs did not fully insert. A subsequent inspection program (PPE-96-088) concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. A binding interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly show no indications of damage or deformation. The problem appears to reside within the fuel assemblies. Drag loads and thimble tube distortions at Wolf Creek also increase with increasing burnup/residency time, which appears to indicate a correlation between the two phenomena due to some as yet unknown root cause.

The objective of the V. C. Summer inspection program was to determine if high burnup fuel at V. C. Summer has experienced similar thimble tube distortions that could result in incomplete RCCA insertion. The data will be used to help establish whether the thimble tube distortion phenomena previously observed at Wolf Creek is generic to high burnup fuel.

The following tests were scheduled to be conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (also referred to as Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements; and
(4) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to establish that the growth of the fuel assemblies and fuel rods is within the anticipated range for the listed F/A burnup.

Guide thimble plug gage exams (Item #2 above) and videotaping of the rod-to-nozzle gaps (Item #4 above) for each of the V. C. Summer fuel assemblies was not completed due to time limitations. Plug gage and fuel rod growth data are therefore unavailable for V. C. Summer at this time.

2.0 Full Length RCCA Drag Tests in Spent Fuel Pool

Fuel assemblies fabricated for four different contracts were drag tested in the spent fuel pool. The special features of the fuel assemblies are shown below in Table 2.1. As shown in the table the common feature in the assemblies are as follows:

[ ] a,b,c

The CGGF and CGHF assemblies have many of the features included in the Vantage + design. The CGFF assemblies have many of the features included in the Vantage 5H design while the CGIF assemblies have many of the features in the Performance + design.

a,b,c

Table 2.1: Fuel Features of VC Summer 17x17 Optimized Fuel Assemblies

The drag test results are tabulated in Table 2.2 and are graphed in Figures 2.1, 2.2 and 2.3. As shown in Table 2.2 most fuel assemblies were recently discharged from the reactor core and others have been in the spent fuel pool for 1 cycle.

In Figure 2.1 the V.C. Summer dashpot and guide thimble data is shown. Fuel assemblies K47, H50 and H46 did exceed the F-spec dashpot drag guideline [ ] a,b,c but none of the assemblies exceeded the F-spec upper guide thimble drag guideline [.] a,b,c The upper guide thimble drag loads were [ ] a,b,c for all assemblies tested. At Wolf Creek, the assemblies exhibiting incomplete RCCA insertions exceeded both the dashpot and guide thimble drag guidelines.

Figures 2.2 and 2.3 show the dashpot drag and guide thimble drag data plotted versus their corresponding fast fluence values. At Wolf Creek the incomplete insertions occurred in fuel with fast fluences greater than [,] a,b,c when the dashpot and guide thimble drag guidelines were exceeded. The V.C. Summer fuel assemblies that were tested had fast fluence values less than or equal to [.] a,b,c The V.C. Summer assemblies did not display characteristics similar to the Wolf Creek assemblies that experienced incomplete RCCA insertion for comparable fluences.

The V.C. Summer fuel assemblies that have been stored in the spent fuel pool for one cycle are not showing higher drag values than the fuel assemblies that were recently discharged from the core.

a,b,c

Table 2.2: VC Summer Drag Test Data

Figure 2.1: VC Summer Dashpot and Guide Thimble Data

a,b,c

Figure 2.2: VC Summer Dashpot Drag and Fast Fluence Data

a,b,c

Figure 2.3: VC Summer Guide Thimble Drag and Fast Fluence Data

a,b,c

3.0 Single Tube Probe

Single tube probe testing was not conducted at V.C. Summer due to time limitations during the refueling outage.

4.0 Fuel Assembly Growth

Fuel assembly length measurements were performed on a total of 8 assemblies (4 F/As from Region H and 4 F/As from Region J). The measurements were made using a standard of known length and a measuring device with a dial indicator. The data was corrected for the spent fuel pool water temperature. Assembly J34 that was stored in the SFP was re-measured to verify the accuracy of the assembly length measuring tool. Table 4.1 lists the measured assembly length and growth values for each of the 8 assemblies.

"H" assemblies are of the 17x17 [ ] ^{a,b,c} and "J" assemblies are of 17x17 [ ]^{a,b,c} design. The thimble tube material in assemblies H46 & H51 is [ ] ^{a,b,c}; assemblies H47 & H50 have [ ] ^{a,b,c} thimbles assemblies J09, J10, J13, and J22 have [ ]^{a,b,c} thimbles .

The measured growth ranged from [ ] ^{a,b,c} for the "H" assemblies and from [ ] ^{a,b,c} for "J" assemblies. Figure 5.1 plots the measured assembly growth data as a function of fuel assembly fast fluence. The figure also compares the V.C. Summer data with assembly growth data from other plants. It shows that the "H" assembly growth figures are normal and lie within the Westinghouse database. The data shows no evidence of breakaway growth. The "J" assembly growth figures are well below our database. It confirms that [ ]^{a,b,c} thimble growth is significantly less than [ ] ^{a,b,c} thimble growth.

Table 4.1: V. C. Summer Fuel Assembly Growth Data a,b,c

[ ]

Figure 4.1: Fuel Assembly Growth Plot
SAP, VRA, CGE, WEP, GAE

a,b,c

[ ]

5.0 Overall Summary

Three fuel assemblies tested at V.C. Summer displayed dashpot drag forces in excess of the [ ] a,b,c guideline in Field Specification . However, all RCCAs at V.C. Summer were able to fully insert. The data indicates upper guide tube drag loads are very low. None of the assemblies showed upper guide tube drag forces in excess of the [ ] a,b,c guideline in the F-spec. The maximum upper guide tube drag load measured at V.C. Summer was [ ] a,b,c

The assemblies at V.C. Summer also show a general trend of guide thimble drag loads increasing with increasing burnup. The assemblies tested indicate that dashpot interference/distortion is responsible for the majority of the drag measured. The extent of the interference/distortion is much less than that experienced by the "H" region fuel at Wolf Creek, which did not allow RCCA insertion.

Point Beach Unit 1/Unit 2

Fuel Assembly Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek near the end of Cycle 8. The reactor tripped resulting in a SCRAM. During this SCRAM, five RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the anomaly, and three additional RCCAs did not fully insert. A subsequent inspection program (PPE-96-088) concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. A binding interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly show no indications of damage or deformation. The problem appears to reside within the fuel assemblies. Drag loads and thimble tube distortions at Wolf Creek also increase with increasing burnup/residency time, which appears to indicate a correlation between the two phenomena due to some as yet unknown root cause.

The objective of the Point Beach inspection program was to determine if high burnup fuel at Point Beach has experienced similar thimble tube distortions that could result in incomplete RCCA insertion. The data will be used to help establish whether the thimble tube distortion phenomena previously observed at Wolf Creek is generic to high burnup fuel.

The following tests were scheduled to be conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements; and
(4) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to establish that the growth of the fuel assemblies and fuel rods is within the anticipated range for the listed F/A burnup.

2.0 Full Length RCCA Drag Tests in Spent Fuel Pool

Fuel assemblies fabricated for four different contracts were drag tested in the spent fuel pool. The specific fuel features for each assembly are shown in Table 2.1. All of the assemblies share the following common features:

[ ] [a,b,c]

The [ ] [a,b,c] fuel features without the [ ] [a,b,c] were used in fuel assemblies manufactured for contracts WEHQ, WEIQ and WIFQ. Fuel assemblies manufactured for contract WEFQ did not have [.] [a,b,c]

Table 2.1: Fuel Features of Point Beach 14x14 Optimized Fuel Assemblies

[ ][a,b,c]

The drag test results are tabulated in Table 2.2 As shown in the table, some fuel assemblies were recently discharged from the reactor core and others have been in the spent fuel pool for up to 2 cycles.

The Point Beach dashpot and guide thimble data is shown in Figure 2.1. Fuel assemblies Y11, V75, V77, V78, Z11 and Z12 exceeded the F-spec upper guide thimble drag guideline of [.][a,b,c], but none of the assemblies exceeded the F-spec dashpot drag guideline of [.][a,b,c] At Wolf Creek, the assemblies experiencing incomplete RCCA insertion exceeded both the dashpot and upper guide thimble drag guidelines.

Figures 2.2 and 2.3 show the dashpot and guide thimble drag data graphed versus their corresponding F/A fast fluence values. At Wolf Creek, incomplete RCCA insertions occurred in fuel with F/A fluences greater than [,] [a,b,c] when the dashpot and guide thimble drag guidelines were exceeded. None of the Point Beach assemblies displayed these characteristics at comparable fluences.

The Point Beach fuel assemblies that have been stored in the spent fuel pool for 1 or 2 cycles do not show significantly different drag values than the recently discharged fuel assemblies having similar burnups.

Table 2.2: Point Beach Drag Test Data

a,b,c

Figure 2.1 Point Beach Dashpot and Guide Thimble Drag Data

a,b,c

Figure 2.2: Point Beach Dashpot Drag and Fast Fluence Data

a,b,c

Figure 2.3: Point Beach Guide Thimble Drag and Fast Fluence Data

a,b,c

3.0 Single Tube Probe

Single tube probing was conducted on two fuel assemblies at Point Beach. The assemblies were selected based on their high burnup and high drag measurements as summarized below :

[ ] a,b,c

The objective of this test was to determine the extent of distortion in the guide tubes of these two assemblies. A series of probe lengths and diameters per drawing P8534C23 Rev. 01 was used. The order for the probes is shown on Figures 3.1 & 3.2 for the dashpot and thimbles respectively. Each probe was lowered into the thimble tube and allowed to drop by its own weight. A "GO" was recorded if the probe hit bottom. If the probe did not hit bottom, a "NO GO" was recorded and the axial position were the probe stopped was reported.

F/A Z11 Results

The first dashpot probe [ ] [a,b,c] was NO GO in [.] [a,b,c] These [ ][a,b,c] were then probed with a [ ] [a,b,c] long probe which was GO in [.][a,b,c] The [ ][a,b,c] that were GO with the [ ] [a,b,c] long probe were NO GO when probed with the [ ] [a,b,c] long probe. [ ][a,b,c] of the tubes were GO with the [ ] [a,b,c] long probe. These results are summarized on Figure 3.3.

The first thimble probe [ ] [a,b,c] was NO GO in [.][a,b,c] The probe stopped at [ ] [a,b,c] of the assembly in about half of the tubes. The other half stopped between [.] [a,b,c] One tube stopped at [ ] [a,b,c]. All tubes were then probed with a [ ] [a,b,c] long probe which was GO in [ ] [a,b,c]. The tubes that were NO GO stopped [ ] [a,b,c] from the top. The [ ] [a,b,c] tubes that were GO were probed with a [ ] [a,b,c] long probe, and were NO GO. The probe stopped at [ ] [a,b,c] inches from the top in [ ][a,b,c] in which the probe stopped at [ ] [a,b,c]. These results are summarized on Figure 3.4.

F/A Y11 Results

All tubes were GO when the dashpot was probed with [.] [a,b,c] All tubes were NO GO with the [ ] [a,b,c] long probe. These results are summarized on Figure 3.5.

All thimble tubes were NO GO when probed with the [.] [a,b,c] Four of the tubes stopped at [ ] [a,b,c] inches from the top of the thimble. [ ][a,b,c] stopped the probe at [ ] [a,b,c] from the top. [

.] a,b,c

Figure 3.1

DASHPOT PROBES "GO/NO GO"
14x14 FUEL ASSEMBLIES

a,b,c

Figure 3.2

GUIDE THIMBLE PROBES "GO/NO GO"
14x14 Fuel Assemblies

a,b,c

Figure 3.3

POINT BEACH DASHPOT PROBES
F/A Z11

a,b

Figure 3.4

POINT BEACH GUIDE THIMBLE PROBES
F/A Z11

a,b,c

Figure 3.5

POINT BEACH DASHPOT PROBES
F/A Y11

a,b,c

Figure 3.6

POINT BEACH GUIDE THIMBLE PROBES
F/A Y11

a,b,c

4.0 Fuel Assembly Growth

Assembly length measurements were performed on a total of 10 assemblies (6 from Unit 1 and 4 from Unit 2). The measurements were made using a standard of known length and a measuring device with a dial indicator. The data was corrected for the spent fuel pool water temperature. Table 4.1 lists the measured growth for each of the 10 assemblies.

All 10 assemblies are of the [ ] a,b,c. Thimble tube material of assemblies V75, V76, V77, V78, Y11, and Z11 is [ ] a,b,c; that of V17,V20,V22, and V26 is [ ] a,b,c.

The measured growth ranged from [.] a,b,c Figure 4.1 plots the measured assembly growth data as a function of fluence. The figure also compares the Point Beach data with assembly growth data from other plants. It shows that the growth data of the Point Beach assemblies are normal and within the Westinghouse database. The data shows no evidence of breakaway growth.

Table 4.1: Point Beach Fuel Assembly Growth Data a,b,c

[ ]

Figure 4.1: Fuel Assembly Growth
SAP, VBA, CGE, WEP, GAE

[ ] a,b,c

5.0 Fuel Rod Growth

The axial gaps between each peripheral rod and the assembly nozzles were measured from the low magnification TV tapes of 10 assemblies to determine fuel rod growth. The F/A Ids of the measured assemblies are V75, V76, V77, and V78 from Unit 2 and V17, V20, V22, V26, Y11, and Z11 from Unit 1.

Measurements were performed using a divider and steel scale. Magnification conversion factors relating the measured gaps to the actual gaps were obtained by measuring the height of several outer strap grid spring slots on the top and bottom grids for each assembly face and comparing the measured slot height to the as-built dimension. This technique assumes that the [ ] a,b,c. The rod gap data is summarized in Appendix A.

Only a few rods in Point Beach assemblies were seated on the bottom nozzle. All rods in the "V" assemblies were close to the bottom nozzle. It was noted that the bottom gaps of assemblies Y11 and Z11 were much larger than the top gaps. These rods were originally positioned closer to the top nozzle during manufacture. Some rods in these two assemblies showed signs of rod slippage.

Fuel rod growth was derived from pre and post irradiation gap data and the measured fuel assembly growth using the following equation:

% Rod Growth = 100 x (A + B - C)/D   where,

A = pre-irradiation nominal total gap
B = irradiation change in nozzle-to-nozzle length due to assembly growth
C = post-irradiation total gap
D = pre-irradiation nominal fuel rod lengtn

The calculated rod growth is also summarized Appendix A. The maximum, average, and minimum rod growth values for each assembly are listed in Table 5.1. The data ranged from [ ] a,b,c for the V assemblies, from [ ] a,b,c for the Y assembly, and from [ ] a,b,c for the Z assembly. Figure 5.1 plots the assembly average rod growth data of the 10 assemblies as a function of fluence and compares it with the Wolf Creek assembly average rod growth data and a best estimate regression line. The regression line was calculated using all rod growth data obtained in the past from the V.C. Summer rods and North Anna demo rods. The Point Beach rod growth values are slightly lower than the best estimate line at the higher burnup levels.

Table 5.1: Summary of Point Beach Assembly Average Rod Growth

a,b,c

Figure 5.1: Assembly Average Rod Growth Data

a,b,c

6.0 Overall Summary

Fuel assemblies tested at Point Beach displayed high drag forces in the lower part of the guide thimble major diameter in some assemblies. The contribution of the dashpot to the total drag (when the bottom of the RCCA is in the dashpot) was [ ] a,b,c that observed in the 17x17 fuel designs.

The assemblies at Point Beach show a trend of thimble tube distortion in the major diameter with increased burnup. The distortion seems to be localized in the [ ] a,b,c of the major diameter. The distortion in the dashpot of the Point Beach is small when compared to 17x17 fuel designs at similar burnups.

The growth of the fuel assemblies and fuel rods measured at Point Beach is within the current database. There was no indication of "breakaway" fuel assembly growth.

The Point Beach assemblies differ from the anomalous assemblies at Wolf Creek in that the most significant distortion is located near the bottom of the major diameter, and the contribution from

the dashpot is much lower. It is judged that none of the tested assemblies at Point Beach are susceptible to the RCCA insertion anomaly phenomena.

Appendix 'A'

Fuel Rod Growth Data Tables

PLANT POINT BEACH 1

a,b,c

PLANT POINT BEACH 1

[ ] a,b,c

PLANT POINT BEACH 1

a,b,c

a,b,c

a,b,c

PLANT POINT BEACH 2

a,b,c

PLANT POINT BEACH 2

Assembly LV77 endplug slot length: 0.833 t/n chamfer: 0.06 rod growth summary:

a,b,c

a,b,c

PLANT POINT BEACH 1

a,b,c

PLANT POINT BEACH 1

a,b,c

Vogtle Unit 1/Unit 2

Fuel Assembly Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek near the end of Cycle 8. The reactor tripped resulting in a SCRAM. During this SCRAM, five RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the anomaly, and three additional RCCAs did not fully insert. A subsequent inspection program concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. A binding interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly show no indications of damage or deformation. The problem appears to reside within the fuel assemblies. Drag loads and thimble tube distortions at Wolf Creek also increase with increasing burnup/residency time, which appears to indicate a correlation between the two phenomena due to some as yet unknown root cause.

The objective of the Vogtle inspection program was to determine if high burnup fuel at Vogtle has experienced similar thimble tube distortions that could result in incomplete RCCA insertion. The data will be used to help establish whether the thimble tube distortion phenomena previously observed at Wolf Creek is generic to high burnup fuel.

The following tests were scheduled to be conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements; and
(4) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to establish that the growth of the fuel assemblies and fuel rods is within the anticipated range for the listed F/A burnup.

Fuel rod oxide measurements were also taken for a number of Vogtle assemblies as part of an ongoing program with Southern Nuclear. The results of the oxide exam will be provided in a separate report.

2.0 Full Length RCCA Drag Tests in Spent Fuel Pool

Fuel assemblies fabricated for five different contracts were drag tested in the spent fuel pool. Fuel assemblies manufactured for contracts GADF, GAEF, GAFF and GBCF were 17x17 optimized fuel assemblies (OFA) with the following features:

[ ] a,b,c

The assembly manufactured for contract GABF was a [.] a,b,c

Drag test results are tabulated in Table 2.1. Some assemblies were recently discharged from the reactor core, while others have been in the spent fuel pool for up to 2 cycles. Fuel assemblies 5G68 and 5G84 were not tested because the dummy RCCA would not insert completely into those assemblies. The assembly burnup values were supplied by Susan Hoxie-Key of the Southern Nuclear Operating Company.

In Figures 2.1, 2.2 and 2.3 test data from two different programs are shown. Drag testing was performed in the spent fuel pool in response to NRC Bulletin 96-01 and to assist in the root cause determination of the RCCA insertion problem.

The Vogtle dashpot and guide thimble data is shown in Figure 2.1. None of the assemblies exceeded the F-spec upper guide thimble drag guideline of [.] ^{a,b,c} Eight assemblies exceeded the F-spec dashpot drag guideline of [.] ^{a,b,c} At Wolf Creek, assemblies experiencing incomplete RCCA insertion exceeded ***both*** the dashpot and upper guide thimble drag guidelines.

Figures 2.2 and 2.3 show the dashpot and guide thimble drag data graphed versus their corresponding F/A Fast Fluence values. At Wolf Creek, incomplete RCCA insertions occurred in fuel with fluences greater than [ ] ^{a,b,c} nvt, when the dashpot and guide thimble drag guidelines were exceeded. None of the Vogtle assemblies displayed these characteristics at comparable fluences.

The Vogtle fuel assemblies that have been stored in the spent fuel pool for 1 or 2 cycles do not show significantly different drag values than recently discharged fuel assemblies having similar burnups.

Table 2.1: Vogtle Drag Test Data

a,b,c

Table 2.1 (continued): Vogtle Drag Test Data

a,b,c

Figure 2.1: Vogtle Dashpot and Upper Guide Thimble Withdrawal Drag Data
(NRC 96-01 and Root Cause Testing)

a,b,c

Figure 2.2: Vogtle Dashpot Withdrawal Drag and Fast Fluence Data (NRC 96-01 and Root Cause Testing)

a,b,c

Figure 2.3: Vogtle Upper Guide Thimble Withdrawal Drag and Fast Fluence Data (NRC 96-01 and Root Cause Testing)

a,b,c

3.0 Single Tube Probe

The objective of this test was to determine the extent of distortion in the guide tubes of these assemblies. The probe lengths and diameters used are shown below. A total of five assemblies were probed. Each probe was lowered into the thimble tube and allowed to drop by its own weight. A "GO" was recorded if the probe hit bottom. If the probe did not hit bottom, a "NO GO" was recorded and the axial position were the probe stopped was reported.

Table 3.1: Probe Dimensional Summary

a,b,c

The first number in the table below represents the number of tubes which passed the probe and the second number represents the total number of tubes tested by each probe type.

Table 3.2: Probe Test Results

a,b,c

The probe data shows that the fuel assembly upper guide thimbles are only mildly distorted, and that high fuel assembly drags can be attributed primarily to gradual dashpot area bowing to varying degrees. The extent of dashpot drag is consistent with the number of dashpot no-goes. The higher the number of no-goes the higher the dashpot drag experienced. Assemblies 5G84 and 5G68 would not allow for complete RCCA insertion during the test program and were therefore not drag tested.

4.0 Fuel Assembly Growth

Fuel assembly length measurements were performed on a total of 14 assemblies - 1 assembly from Region "D" , 8 assemblies from Region "F", and 3 assemblies from Region "G" of Vogtle Unit 1. Two assemblies from Region "R" of Vogtle Unit 2 were also measured. The measurements were made using a standard of known length and a measuring device with a dial micrometer. The data was corrected for the spent fuel pool water temperature. Table 4.1 lists the measured assembly length and growth values of all 14 assemblies.

Assembly 5D28 has the 17x17 [.] a,b,c The 'F', 'G' and 'R' assemblies have the 17x17 OFA design [.] a,b,c Thimble tube material of assembly 5D28 is standard [;] a,b,c all thimbles in the "F", "G" and "R" assemblies contain [.] a,b,c Fuel assemblies 5F59 and 5F69 have [ ] a,b,c fuel rods and [ ] a,b,c thimbles.

The measured growth was [ ] a,b,c for assembly 5D28. Assembly growth ranged from [ ] a,b,c for F assemblies, from[ ] a,b,c for G assemblies, and from [ ] a,b,c for R assemblies. In Figure 4.1, the measured assembly growth data as a function of fluence is shown. The figure also compares the Vogtle data with assembly growth data from other plants. It shows that the Vogtle growth data are normal and within the Westinghouse experience database. The data showed no evidence of unusual growth.

Table 4.1: Vogtle Fuel Assembly Growth Data

a,b,c

Figure 4.1: Recent Assembly Growth Data

a,b,c

5.0 Fuel Rod Growth

The axial gaps between each peripheral rod and the assembly nozzles were measured from the low magnification TV tapes of 14 Vogtle Unit 1 and 2 assemblies to determine fuel rod growth. Assemblies 5D28, 5F43, 5F47, 5F57, 5F59, 5F65, 5F69, 5F27, 5F41, 5G71, 5G73, and 5G84 from Unit 1 and 5R19 and 5R43 from Unit 2 were measured..

Measurements were performed using a divider and steel scale. Magnification conversion factors relating the measured gaps to the actual gaps were obtained by measuring the TV image of the height of several outer strap grid spring slots on the top and bottom grids for each assembly face, then comparing the measured slot height to the as-built dimension. This technique assumes that the irradiation growth of [.]^{a,b,c} Individual rod growth data is summarized in Appendix "A".

Some rods in assemblies 5F59, 5G71, 5G84, 5R19, 5R43 were seated on the bottom nozzle. Most of the rods in all of the assemblies were close to the bottom nozzle.

Fuel rod growth was derived from pre and post irradiation gap data and the measured fuel assembly growth using the following equation:

% Rod Growth = 100 x (A + B - C)/D

where,

A = pre-irradiation nominal total gap
B = irradiation change in nozzle-to-nozzle length due to assembly growth
C = post-irradiation total gap
D = pre-irradiation nominal fuel rod length

The maximum, average, and minimum rod growth values for each assembly are listed in Table 5.1. The data ranged from [ ]^{a,b,c} for the "D" assembly, from[ ]^{a,b,c} for the "F" assemblies, from [ ]^{a,b,c} for the "R" assemblies, and from [ ]^{a,b,c} for the "G" assemblies.

Figure 5.1 plots the assembly average rod growth data of the 14 assemblies as a function of fluence and compares it with: (1) the Wolf Creek and Point Beach assembly average rod growth data; and (2) a best estimate regression line. The regression line was calculated using all rod growth data obtained in the past from the V.C. Summer rods and North Anna demo rods. The Vogtle rod growth values are slightly lower than the best estimate line at the higher burnup levels.

a,b,c

Figure 5.1: Assembly Average Rod Growth Data

Table 5.1: Summary of Vogtle Assembly Average Rod Growth a,b,c

[ ]

6.0 Overall Summary

The assembly drag and probe data shows that the fuel assembly upper guide thimbles are only mildly distorted, and that high fuel assembly drags can be attributed primarily to gradual dashpot area bowing to varying degrees. The extent of dashpot drag load is consistent with the higher number of dashpot no-goes and appears directly related to the higher dashpot drags recorded.

None of the assemblies exceeded the F-spec upper guide thimble drag guideline of [.] a,b,c while eight assemblies exceeded the F-spec dashpot drag guideline of [ ] a,b,c Fuel assemblies 5G68 and 5G84 could [.] a,b,c in those assemblies. Incomplete RCCA insertions occurred at in Wolf Creek fuel with fluences greater than [,] a,b,c when ***both*** the dashpot and guide thimble drag guidelines were exceeded. None of the Vogtle assemblies displayed these characteristics.

Assemblies that were stored in the spent fuel pool for 1 or 2 cycles show no significant differences in drag values than recently discharged fuel assemblies having similar burnups.

The growth of the fuel assemblies and fuel rods measured at Vogtle is within the current database. There was no indication of "breakaway" fuel assembly growth. The Vogtle rod growth values were slightly lower than the best estimate regression line at the higher burnup levels.

In conclusion, none of the tested assemblies at Vogtle appear susceptible to the RCCA insertion anomaly phenomena experienced at Wolf Creek.

Appendix A

Fuel Rod Growth Data

for

Vogtle Units 1 & 2

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 1

a,b,c

VOGTLE 2

a,b,c

VOGTLE 2

a,b,c

Surry Unit 1/Unit 2

Fuel Assembly Inspection Program

1.0 Background and Objectives

RCCA insertion anomalies were recently experienced at Wolf Creek and South Texas. During Scrams, several RCCAs did not fully insert. Wolf Creek and South Texas conducted drop tests after their anomalies, and four additional RCCAs did not fully insert. A subsequent inspection program concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek and South Texas was thimble tube distortion. A binding interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Drag loads and thimble tube distortion in Region "H" fuel at Wolf Creek increase with increasing burnup/residency time, which indicates a correlation between the two factors due to some as yet unknown root cause.

The objective of the Surry inspection program was to determine if high burnup fuel at Surry has experienced similar thimble tube distortions that could result in incomplete RCCA insertion. The data will be used to help establish whether the thimble tube distortion phenomena previously observed at Wolf Creek and South Texas is generic to high burnup fuel.

The following tests were scheduled to be conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(3) Fuel Assembly (F/A) Length Measurements; and
(4) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to establish that the growth of the fuel assemblies and fuel rods is within the anticipated range for the listed F/A burnup.

2.0 Full Length RCCA Drag Tests in Spent Fuel Pool

Fuel assemblies fabricated for six different contracts were drag tested in the spent fuel pool. The specific fuel features for each assembly are shown in Table 2.1. Most of the assemblies share the following common features:

[ ] a,b,c

Table 2.1: Fuel Features of Surry 15x15 Optimized Fuel Assemblies

[ ] a,b,c

The drag test results are tabulated in Table 2.2 As shown in the table, some fuel assemblies were recently discharged from the reactor core and others have been in the spent fuel pool for up to 3 cycles. No distinction could be established for assemblies based on discharge time.

Two assemblies from region VPIF (0F3 and 0F6), [ ] a,b,c, were drag tested as part of the inspection plan. These assemblies had burnups greater than 49,000 MWD/MTU and showed negligible upper guide tube and dashpot drag. These 15x15 standard assemblies appear resistant to the dashpot and guide tube distortions seen in other designs and are clearly a separate population.

The burnup values in Table 2.2 were obtained from Virginia Power Company's June 13, 1996 response to NRC Bulletin 96-01 (Reference 2). Averaged RCCA drag values (withdrawal & insertion) were reported in that letter. Small differences exist between the values reported in that letter and the values reported in this memo. These differences appear to be a function of drag trace interpretation, and they have no impact on the conclusions reached.

Data from two different test agendas is shown in Figures 2.1, 2.2, and 2.3. Reactor trip testing was performed in response to NRC Bulletin 96-01. The spent fuel pool testing was performed to aid in determining the root cause behind the RCCA insertion problem.

At Wolf Creek, assemblies which experienced incomplete RCCA insertions exceeded both the dashpot and upper guide thimble F-spec drag guidelines. These assemblies also showed a sustained upper guide tube drag in excess of [.] a,b,c. At South Texas, all assemblies pass the upper guide tube guideline but exceed the dashpot drag guideline. The distinctions are important in understanding the differences between the Surry assemblies which also exceeded the F-spec guidelines, but still scram properly during the shutdown testing.

Dashpot and guide thimble drag data for Surry are shown in Figure 2.1. In Figures 2.2 and 2.3, dashpot and guide thimble drag loads are graphed against their corresponding F/A fast fluence values. At Wolf Creek, incomplete RCCA insertions occurred in fuel with F/A fluences greater than [,] a,b,c when the F-spec dashpot and guide thimble drag guidelines were exceeded. Fuel assemblies 3H8, 5H1, 4G1 and 0V2 exceeded the F-spec upper guide thimble drag guidelines of [.] a,b,c and the F-spec dashpot drag guidelines of [..] a,b,c Assemblies 3H8, 5H1 and 0V2 were in control rod locations during their last cycle of operation and Scrammed properly. A review of the drag traces shows that the assemblies generally exhibit a gradual increase in the upper guide tube drag with increasing insertion, consistent with a gradual bowing of the tube. The drag increases slightly when entering the dashpot and continues to gradually increase up to the maximum value recorded. This behavior is more benign than that experienced by Wolf Creek assemblies with comparable burnups. The comparable Wolf Creek assemblies exhibited large, discrete increased drag steps and chattering in the upper guide tube sections and dashpots in assemblies which did not allow complete RCCA insertion. At South Texas, the distortion is isolated in the double dashpot area. These observations are important in underscoring the importance of not only examining the magnitude, but also the duration and location of distortions within the fuel assembly guide tubes.

Table 2.2: Surry Drag Test Data

a,b,c

a,b,c

Table 2.2 (continued): Surry Drag Test Data

[ ]

Figure 2.1: Surry Dashpot and Upper Guide Thimble Drag Data (Reactor Trip and Spent Fuel Pool Testing)

a,b,c

Figure 2.2: Surry Dashpot Drag and Fast Fluence Data
(Reactor Trip and Spent Fule Pool Testing)

a,b,c

Figure 2.3: Surry Upper Guide Thimble Drag and Fast Fluence Data (Reactor Trip and Spent Fuel Pool Testing)

a,b,c

3.0 Single Tube Probe

Single tube probing was conducted on four fuel assemblies at Surry. The assemblies were selected based on burnup and drag measurements listed in Table 3.1 below. The probe information was used to establish the extent of susceptibility of 15x15 designs to the insertion anomaly experienced previously at Wolf Creek.

The objective of the test was to determine the extent and location of distortion in the guide tubes of the assemblies. Each probe was lowered into the thimble tube and allowed to drop by its own weight. A "GO" was recorded if the probe hit bottom. If the probe did not hit bottom, a "NO GO" was recorded and the axial position were the probe stopped was reported.

Table 3.1: Assemblies Tested With Single Tube Probes

a,b,c

The probe results are summarized below in Table 3.2. The first number refers to the number of Go's and the second number refers to the number of tubes tested.
Probe dimensions (inches) are from drawing [.] a,b,c

Table 3.2: Single Tube Probe Test Results

a,b,c

Assembly 5H1 showed the greatest amount of upper guide tube and dashpot distortion, consistent with its relatively high drag force. Even though this assembly had a drag force [ ] [a,b,c] in the dashpot, the actual contribution to drag from entering the dashpot was only an increase of approximately [.] [a,b,c] A large portion of the total drag is attributed to gradual bowing in the upper guide tubes. It is also significant that the burnup of this assembly is as high as any assembly at Wolf Creek which experienced the insertion anomaly. This assembly shows similar dashpot probing behavior as **assembly 1G0**. Both assemblies would not readily pass the [ ] [a,b,c] probe in the dashpot but would accept the [.] [a,b,c] In contrast, **assembly 1G0** would accept the [ ] [a,b,c] upper guide tube probe while **assembly 5H1** would not. These differences help illustrate why the upper guide tube drag forces in **assembly 1G0** are less than **assembly 5H1** while both assemblies have comparable increases in drag when entering their dashpots.

Assembly 3J1 showed the least amount of upper thimble tube and dashpot distortion of the four assemblies tested. The assembly dashpots and upper guide tubes show mild distortion in both areas, consistent with the low drag force readings.

Assembly 0V7 has approximately the same burnup as **assembly 3J1**, but the drag recorded is much higher in **assembly 0V7** than **assembly 3J1**. The probe results show that the dashpots in **assembly 0V7** are somewhat better than those in **assembly 1G0,** while the upper guide tubes are nearly identical. This observation suggests that one or two dashpots in tubes in **assembly 0V7** are contributing more drag than the rest of the population within the assembly.

The probe data shows that the fuel assembly upper guide thimbles and dashpots are only mildly distorted. The observed fuel assembly drags can be attributed to a combination of gradual guide tube and dashpot area bowing to varying degrees. The peak dashpot and thimble tube drag is consistent with the higher number of dashpot and guide tube no-go's. There is no clear evidence of preferential distortion between the dashpots and the upper guide tubes. There is evidence however, that the drag force and guide thimble distortions are increasing with increasing burnup.

4.0 Fuel Assembly Growth

Fuel assembly length measurements were performed on a total of 10 assemblies: 2 from Region "F"; 2 from Region "G"; 2 from Region "H"; and 2 assemblies from Region "J" of Surry Unit 1; and 2 assemblies from Region "V" of Surry Unit 2. Measurements were made using a standard of known length and a measuring device with a dial micrometer. The data was corrected for the spent fuel pool water temperature. Table 4.1 lists the measured assembly length and growth values of all 10 assemblies.

The "F" assemblies are of the 15x15 [ ]^{a,b,c}; "G", "H", "J", and "V" assemblies are of the 15x15 [ ]^{a,b,c}. Assemblies 0F3, 0F6, 1G0, and 4G1 use [ ]^{a,b,c} material, while all of the "H", "J", and "V" F/A thimbles use [ ]^{a,b,c}.

The measured growth ranged from [ ]^{a,b,c} for the "F" assemblies, from [ ]^{a,b,c} for the "G" assemblies, from [ ]^{a,b,c} for the "H" assemblies, from [ ]^{a,b,c} for the "J" assemblies, and from [ ]^{a,b,c} for the "V" assemblies. Figure 4.1 plots the measured assembly growth data as a function of fluence. The figure also compares the Surry data with assembly growth data from other plants. It shows that the Surry growth data are normal and within the Westinghouse experience database. The data showed no evidence of unusual growth.

Table 4.1: Surry Fuel Assembly Growth Data

a,b,c

[ ]

Figure 4.1: Recent Fuel Assembly Growth

a,b,c

5.0 Fuel Rod Growth

The axial gaps between each peripheral rod and the assembly nozzles were measured from the low magnification TV tapes of 5 Surry Unit 1 assemblies to determine fuel rod growth. They are assemblies 0F3, 1G0, 4G1, 5H1, and 3J1.

Measurements were performed using a divider and steel scale. Magnification conversion factors relating the measured gaps to the actual gaps were obtained by measuring the rod diameters near the top and bottom ends. This is based on the assumption that the rod diameter near the rod end does not change the dimension significantly during irradiation. The measured rod gap and calculated actual gap data are summarized in Appendix A.

Some rods were seated on the bottom nozzle. Most of the rods in all of the assemblies were close to the bottom nozzle.

Fuel rod growth was derived from pre and post irradiation gap data and the measured fuel assembly growth using the following equation:

$$\% \text{ Rod Growth} = 100 \times (A + B - C)/D$$

where,

A = pre-irradiation nominal total gap
B = irradiation change in nozzle-to-nozzle length due to assembly growth
C = post-irradiation total gap
D = pre-irradiation nominal fuel rod length

The maximum, average, and minimum rod growth values for each assembly are listed in Table 5.1. The data ranged from [.][a,b,c] Figure 5.1 plots the assembly average rod growth data of the 5 assemblies as a function of fluence and compares it with the Wolf Creek, Vogtle and Point Beach assembly average rod growth data. The Surry rod growth data is consistent with the Westinghouse fuel rod growth database.

Table 5.1: Summary of Surry Assembly Average Rod Growth [a,b,c]

[ ]

Figure 5.1: Assembly Average Rod Growth Data

a,b,c

6.0 Summary

Drag testing at Surry shows that the [ ] [a,b,c] is extremely resistant to thimble tube distortions, and should not be considered susceptible to the RCCA insertion anomalies associated with such distortion as experienced at Wolf Creek and South Texas.

Drag testing also shows that the [ ] [a,b,c] in high-burnup designs are susceptible to varying degrees of thimble tube distortion. The drag generally increases with burnup and can be expected to remain below the F-spec screening guidelines to burnups of at [.] [a,b,c] The drag test data and reactor scram data show that violation of the F-spec guidelines does not correspond to a condition resulting in incomplete RCCA insertion. The data does support the need to understand the thimble tube distortion characteristics to establish the likelihood of incomplete RCCA insertion. Although no absolute threshold could be identified during the Surry exam, evidence exists that dashpot and upper thimble tube drags of [ ] [a,b,c] pounds respectively will successfully scram in this design.

The probe data shows that the fuel assembly upper guide thimbles and dashpots are mildly distorted. The observed fuel assembly drags can be attributed to a combination of gradual guide tube and dashpot area bowing to varying degrees. The peak dashpot and thimble tube drag observed in each assembly is consistent with the number of dashpot and guide tube no-goes. There is no clear evidence of preferential distortion between the dashpots and the upper guide tubes. There is evidence however, that the drag force and guide thimble distortions are increasing with increasing burnup.

The growth of the fuel assemblies and fuel rods measured at Surry is consistent with previous Westinghouse experience. There was no indication of "breakaway" fuel assembly growth.

In conclusion, although 15x15 high burnup designs exhibit some tendency for thimble tube distortion and increased drag with burnup, the extent of tolerable distortion appears to be dependent upon not only the magnitude of the observed insertion drag, but on other characteristics such as location, amplitude, and length of associated thimble tube distortion. Based on information obtained at Surry, the [ ] [a,b,c] is not susceptible to the insertion anomalies experienced at South Texas and Wolf Creek within limitations of exposure comparable to those measured at Surry [.] [a,b,c]

Appendix A

Fuel Rod Growth Data

for

Surry Units 1 & 2

SURRY 1

a,b,c

SURRY 1

[ ] a,b,c

SURRY 1

a,b,c

SURRY 1

a,b,c

SURRY 1

a,b,c

Wolf Creek

Fuel Assembly Inspection Program
Phase 2

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek and South Texas Unit 1. During Scrams, several RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the event and additional RCCAs did not fully insert. A subsequent inspection program concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. An interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly showed no indications of damage or deformation to these RCCAs. The problem resides within the fuel assemblies. Drag loads and thimble tube distortions in the Region "H" fuel at Wolf Creek increase with increasing burnup/residency time.

The objective of the Phase 2 Wolf Creek inspection program was to build on the results of the original inspection program (PPE-96-088). The following tests were scheduled to be conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements;
(4) Fuel Assembly Bow Measurements;
(5) Fuel Rod-to-Nozzle Gap Measurements;
(6) Detailed Visual Inspections;
(7) Fuel Rod Oxide Measurements;
(8) Fuel Rod Profilometry Measurements;
(9) Top Nozzle Spring Load/Deflection Measurements;
(10) Lateral Grid Width Measurements;
(11) Grid Cell Size and Force Measurements; and
(12) Disassembly of H50 and H38 fuel assembly elements for hot cell examinations.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to determine if the growth of these fuel assemblies and fuel rods is within the anticipated range. The fuel rod oxide and profilometry results (items 7 and 8) were presented in PPE-96-204. The results of the top nozzle spring load/deflection measurements, lateral grid width measurements, grid cell size and force measurements and hot cell investigations will be presented in later reports.

2.0 Full Length RCCA Drag Tests in the Spent Fuel Pool

The results that were provided in the original report (PPE-96-088) showed that the RCCA insertion problem which occurred at Wolf Creek was related to drag which increased with fast fluence. The problem occurred when the measured drag exceeded the F-spec guidelines in the

[

.] a,b,c

The results of the additional fuel assembly testing and skeleton assembly drag testing are provided below. Additional 'G' region and 'H' region assemblies were examined to gather additional information and to record differences between the regions.

Fuel Assemblies

Six additional fuel assemblies were selected for drag testing. Two 'G' region and four 'H' region assemblies were tested. The 'G' region assembly burnup values were 35 and 54 GWD/MTU. The 'H' region assembly burnup values were 34.3, 37.4, 39.7 and 43.7 GWD/MTU.

Both 'G' region assemblies showed low drag in the upper guide thimbles. Assembly G33 (35 GWD/MTU) showed low drag in the dashpot and assembly G68 (54 GWD/MTU) showed high drag in the dashpot. Because of the low upper guide thimble drag values it was judged that neither 'G' region assemblies were at risk for the insertion anomaly problem during operation.

The 'H' region assemblies also showed relatively low drag in the in the upper guide thimbles and intermediate to high drag in the dashpot. The drag in the four assemblies could not be differentiated by burnup. Based on the low upper guide thimble drag, it was judged that none of these 'H' region assemblies were at risk of an insertion anomaly during operation. It is noteworthy that even though the upper guide thimble drags were low, they were still on average higher than the 'G' region assemblies tested.

The drag results are tabulated below and are shown in Figure 2.1. In the figure, the drag results are shown with data from other power plants. [

.] a,b,c

a,b,c

H50 Skeleton Assembly

After the fuel rods were removed from fuel assembly H50, a drag check measurement was performed with the dummy RCCA. The purpose was to determine what difference, if any, could be measured with the fuel rods removed. The measurements were taken in the new fuel elevator with the skeleton clamped down.

The drag measured in the empty skeleton was somewhat lower than the drag in the fuel assembly, but was still in the high range. The small decrease in drag indicates that the deformations in the fuel assembly skeleton are primarily plastic (i.e., permanent) rather than elastic or associated with fuel rod loading. The results are tabulated below.

a,b,c

Figure 2.1: Dashpot and Upper Guide Thimble Drag Data

a,b,c

3.0 Guide Thimble Plug Gage Exams

The single tube probing was performed on the dashpot of fuel assembly G68. This assembly was selected because of the high drag in the dashpot [.] a,b,c The drag above the dashpot was negligible; therefore, single tube probing was not done in the upper guide thimble.

Probes of various lengths and diameters [ ] a,b,c were used. The probe end required to assemble group 07 on the drawing was not available for this test. The order of the probes is shown in Figure 3.1. Each probe was lowered into the thimble tube to the dashpot and allowed to drop by its own weight. A "GO" indication was recorded if the probe hit the bottom of the dashpot. If the probe did not hit the bottom of the dashpot, a "NO GO" indication was recorded and the axial position where the probe stopped was recorded.

The first dashpot probe [ ] a,b,c was "NO GO" [.] a,b,c The probe [ ] a,b,c of the dashpot. Since the probe end that was needed to assemble the group 07 probe was not available, no additional probing was done on these [ ] a,b,c thimbles.

The second dashpot probe [ ] a,b,c was used in the [ ] a,b,c guide thimbles that had "GO" indicates for the first probe. [ ] a,b,c guide thimbles were "NO GO" with this probe. The third dashpot probe [ ] a,b,c was used in these eight (8) guide thimbles. [ ] a,b,c of the guide thimbles had "NO GO" indications at approximately [ ] a,b,c inches from the bottom of the dashpot. These results are summarized in Figure 3.2. The data shows that significant bowing in the dashpot is primarily responsible for the high observed drag forces.

4.0 Fuel Assembly Growth Data

The fuel assembly length measurements were performed on 8 assemblies (2 assemblies from Region G,2 assemblies from Region J and 4 assemblies from Region H). The measurements were made using a standard of known length and a measuring device that has a dial indicator. The data were corrected for water temperature. In Appendix A, the measured assembly length and growth values for all 8 assemblies is provided.

The 'G' assemblies have the 17x17[ ] a,b,c while the 'J' and 'H' assemblies have the 17x17 [ ] a,b,c. The 'G' assemblies use [ ] a,b,c as the thimble tube material, but [ ] a,b,c is used for the 'J' and 'H' assemblies.

The measured growth range was [ ] a,b,c for the G assemblies (G33 was twice burnt and G68 was three times burnt), [ ] a,b,c for J assemblies and [ ] a,b,c for H assemblies. It should be noted that, of the 4 'H' assemblies, only H61 was irradiated for three cycles. Assemblies H35, H67 and H83 were irradiated for two cycles.

In Figure 4.1, the measured assembly growth data as a function of fluence is shown for Wolf Creek and other plants. The data trend that was observed in Phase 1 is seen in the Phase 2 data. The assembly growth of the 'H' assemblies is higher than other plant data (including Wolf Creek J assemblies). This also occurs in the lower fluence range.

Figure 3.1: DASHPOT PROBES "GO/NO GO"
17x17 FUEL ASSEMBLIES

a,b,c

hgonogo.vsd

Figure 3.2: WOLF CREEK DASHPOT PROBES F/A G68

a,b,c

Assembly H50 was measured a total of four times. The first two measurements were performed during Phase 1 Campaign. The measured growth was [,] a,b,c respectively. The assembly was again measured during Phase 2 Campaign. The measured value was [.] a,b,c The assembly was again measured during Phase 2 Campaign after all fuel rods were removed from the assembly. The measured growth was [.] a,b,c The data showed that the assembly length did not change after the fuel rods were removed.

Figure 4.1: Recent Assembly Growth Data

a,b,c

5.0 Fuel Rod Growth Data

The axial gaps between each peripheral rod and the assembly nozzles were measured from the low magnification TV tapes of 10 Wolf Creek assemblies to determine fuel rod growth. The assemblies were G33, G68, H35, H53, H54, H61, H67, H83, J32, AND J37.

The measurements were performed using a divider and steel scale. The actual gaps were determined from conversion factors. Conversion factors were obtained by measuring the TV image of several grid spring heights on the outer straps in the top and bottom grids. The factors were obtained by comparing the measured spring height to the as-built dimension. This is based on the assumption that [ ] a,b,c . The

measured rod gap and calculated actual gap data are summarized in Appendix B. The rods did not touch the bottom nozzle.

Fuel rod growth was derived from pre- and post- gap data and the measured fuel assembly growth using the following equation:

$$\% \text{ Rod Growth} = 100 \times (A + B - C)/D$$

where,
A = pre-irradiation nominal total gap
B = irradiation change in nozzle-to-nozzle length due to assembly growth
C = post-irradiation total gap
D = pre-irradiation nominal rod length

The calculated rod growth is summarized Appendix B. The maximum, average, and minimum rod growth values for each assembly are listed below. The data range was [ ] [a,b,c] for the G assemblies (G33 was twice burnt and G68 was three times burnt), [ ] [a,b,c] for the J assemblies, and [ ] [a,b,c] for the H assemblies (H35, H67, and H83 were twice burnt). In Figure 5.1, the assembly average rod growth data of the 10 assemblies as a function of fluence is shown for Wolf Creek and other plants. The data shows that the Wolf Creek rod growth values are within the expected limits at comparable burnup levels.

[ ] a,b,c

Figure 5.1: Recent Rod Growth Data

a,b,c

6.0 Fuel Assembly Bow Data

In the first phase, the corrected assembly bow shape and bow magnitude was provided for seventeen (17) fuel assemblies. The bow for assemblies H50 and H38 was re-measured by two additional methods (direct view & profile view). This was done to correct for the inaccuracies in the "plumb bob" method that were discussed in report PPE-96-088. The plumb bob, profile view and direct view methods are not 100% comparable.

In the plumb bob method, one end of the measurement reference (string) is fixed near the top nozzle of the assembly. The corrected bow is obtained from the measured distance between the string and the grid's edge.

The string is fixed at the top and bottom nozzles for the profile view and direct view methods. In both methods, the corrected bow is also obtained from the measured distance between the string and the grid's edge. The profile view and the plumb bob methods are similar since the bow is measured parallel to the assembly face. In the direct view method the bow is measured normal to the assembly face.

In Figures C.1 to C.4 of Appendix C, Figure 6.1 and in the table below, the H50 and H38 bow data are provided to show the effect of the fuel rods on the results. It is worth mentioning that when the measurement error is considered the curves are very similar. Therefore, care must be used when interpreting the data. As shown in the following table, the bow in assembly H50 changed little when the fuel rods were removed because the bow increased on one assembly face while it decreased on the adjacent assembly face.

a,b,c

Figure
C.1
C.2
C.3
C.4 6.1

a,b,c

Figure 6.1: Fuel Assembly H50, Face 3 Bow Data - Direct View

7.0 Visual Inspections

Visual inspections were performed to obtain additional information on assemblies H50 and H38. The peripheral thimble tube welds were examined in assembly H50 after 3 fuel rod rows were removed from the assembly. The welds were also examined in assemblies H50 and H38 after all fuel rods were removed from the assemblies. These inspections were performed because grid 7 in assembly H38 had moved to the grid 8 location during the phase 1 testing (Figure 7.1). Details of the skeleton corrosion and mechanical properties will be provided in a separate hot cell report.

During the visual inspections, some of the thimble tubes appeared distorted. At times the distortion did occur immediately below the dashpot area of the thimble tubes. In Figure 7.2, examples of tube distortion are shown.

a,b,c

[ ]

Figure 7.1: Grid 7 relocated to Grid 8 during Phase 1 Testing

a,b,c

Figure 7.2: Examples of Thimble Tube Distortion for Assembly H50

8.0 Summary

Fuel assemblies tested during phase 2 at Wolf Creek displayed high drag forces in the lower part of the guide thimble dashpots. The contribution of the dashpot to the total drag (when the bottom of the RCCA is in the dashpot) was comparable to that observed in other plant tests. None of the assemblies tested exhibited high upper guide thimble drag that was associated with the previous incomplete RCCA insertions. This difference is significant in understanding the unique drag characteristics of the 'H' region fuel assemblies which stuck and the other 'H' region assemblies which had complete RCCA insertions. This observation also indicates that the progression of the thimble tube distortion is from the bottom up (i.e., distortion begins in the dashpot and progresses up into the upper guide thimble with time).

The growth of the 'H-region' fuel assemblies and fuel rods measured at Wolf Creek is not within the anticipated range. These assemblies have indications of "breakaway" fuel assembly growth. Breakaway fuel assembly growth has not occurred in the other fuel regions measured; even within fuel at other plants from identical thimble tube lots.

The phase 2 testing further supports the conclusion that some operational factors specific to the 'H' region fuel assemblies led to the accelerated assembly growth. Very high assembly growth leads to more thimble tube distortion which yields higher drag forces and a greater potential for incomplete RCCA insertions.

Appendix A Fuel Assembly Growth Data For Wolf Creek - EOC-8

a,b,c

Appendix B

Fuel Rod Growth Data

For

Wolf Creek - EOC-8

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

WOLF CREEK

a,b,c

Appendix C

Fuel Assembly Bow Data

For

Wolf Creek - EOC-8

Figure C.1: Fuel Assembly H50, Face 4 Bow Data - Profile

a,b,c

N

Figure C.2: Fuel Assembly H38, Face 2 Bow Data - Profile

a,b,c

Figure C.3: Fuel Assembly H50, Face 4 Bow Data - Direct

a,b,c

Figure C.4: Fuel Assembly H50, Face 3 Bow Data - Direct

a,b,c

South Texas 1

Fuel Assembly Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek and South Texas Unit 1. During Scrams, several RCCAs did not fully insert. Both plants conducted additional drop tests after the anomaly, and additional RCCAs did not fully insert. A subsequent inspection program concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. A binding interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly showed no indications of RCCA damage or deformation. The problem resides within the fuel assemblies. Drag loads and thimble tube distortions in the Region "H" fuel at Wolf Creek increase with increasing burnup/residency time. This indicates a correlation between the two phenomena due to some as yet unknown root cause.

The objective of the South Texas Unit 1 program was to support the root cause determination of incomplete RCCA insertions (IRI). The data will also be used to establish whether the thimble tube distortion phenomena previously observed at Wolf Creek is present in 17x17 XL (14 foot) fuel.

The following tests were scheduled to be conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements;
(4) Fuel Assembly Bow Measurements
(5) Fuel Rod-to-Nozzle Gap Measurements; and
(6) Borescope inspection.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to determine if the growth of the fuel assemblies and fuel rods was within the anticipated range.

2.0 Full Length RCCA Drag Tests (Spent Fuel Pool)

Fuel assemblies fabricated for four different contracts were drag tested in the spent fuel pool. The specific fuel features for each assembly are shown in Table 2.1. Most of the assemblies share the following common features:

[ ] a,b,c

The drag test results are tabulated in Table 2.2. The South Texas Unit 1 dashpot and guide thimble data is shown in Figure 2.1. Figures 2.2 and 2.3 display the dashpot and guide thimble drag data graphed versus their corresponding F/A fast fluence values. At Wolf Creek, incomplete RCCA insertions occurred in fuel with F/A fluences greater than [,] a,b,c when the dashpot drag and guide thimble drag guidelines [ ] a,b,c were exceeded.

In contrast to the Wolf Creek fuel, none of the South Texas Unit 1 fuel assemblies exceeded the F-spec upper guide thimble drag guideline of [.] a,b,c All the significant drag is attributable to the dashpot interference.

A review of the drag traces [ ] a,b,c shows that the assemblies generally exhibit a small, steady upper guide tube drag with increasing insertion. This is consistent with traces from the dummy fuel assembly. The drag then shows a large increase [ ] a,b,c as it enters the upper dashpot. The load generally levels off in the transition piece between the upper and lower dashpots. The load increases again in another large step [ ] a,b,c upon entering the lower dashpot. The process concludes with one final rapid increase to its peak as the RCCA approaches full insertion. An example trace is included as Appendix A. These observations are important in underscoring the importance of examining the duration and location of distortions (in addition to the drag magnitude) within the fuel assembly guide tubes

Table 2.1: Fuel Features of South Texas Unit 1 17x17 Fuel Assemblies

[ ] a,b,c

Table 2.2: South Texas Unit 1 Drag Test Data

a,b,c

[ ]

Figure 2.1: South Texas 1 Dashpot and Upper Guide Thimble Drag Data

a,b,c

Figure 2.2: South Texas 1 Dashpot Drag and Fast Fluence Data

[ ] a,b,c

Figure 2.3: South Texas 1 Upper Guide Thimble Drag and Fast Fluence Data

[ ] a,b,c

3.0 Single Tube Probe

Single tube probing was conducted on eleven fuel assemblies at South Texas Unit 1. Assembly burnup and drag test results were used to select the assemblies (Table 3.1). The objective of the test was to determine the extent and location of distortion in the guide tubes. Each probe was lowered into the thimble tube and allowed to drop by its own weight. A "GO" was recorded if the probe hit bottom. If the probe did not hit bottom, a "NO GO" was recorded and the axial position where the probe stopped was reported. Several very high drag assemblies were probed only in the upper portion of the guide tube. This was done to expedite the inspection and confirm that the upper guide tubes, even in very high drag assemblies, were not significantly distorted.

The probe results are summarized in Table 3.1. The first number refers to the number of go's and the second number refers to the number of tubes tested. Probe dimensions (in inches) are from drawing [.] a,b,c

Assembly F26 showed the greatest amount of upper guide tube and dashpot distortion. This is consistent with it not allowing complete RCCA insertion and with the very high dashpot drag forces recorded. Assemblies F01, F25, F26, F53 and F64 were not drag tested since the RCCA stuck too high to safely release and allow drag testing of the thimbles. Assembly F26 has severe, localized dashpot distortions as evidenced by the inability to accept even the [ ] a,b,c probe in [ ] a,b,c of the dashpots. Of the [ ] a,b,c other dashpots which would pass the probe, none would pass the [ ] a,b,c probe.

Assemblies R31 and R27 have nearly identical burnups and power histories. These assemblies are particularly interesting since assembly R31 exhibited the least amount of dashpot and thimble tube distortion, while assembly R27 exhibited some of the worst dashpot and thimble tube distortion. For example, assembly R31 dashpots passed [ ] a,b,c tubes with the [ ] a,b,c probe, but assembly R27 dashpots would not pass any. In the upper guide tube, assembly R31 passed the [ ] a,b,c probe in all the guide tubes, while assembly R27 would only pass the probe in [ ] a,b,c guide tubes.

It is noteworthy that nearly all the upper guide tubes successfully passed the [ ] a,b,c probe in the upper guide tube, even in assemblies which stuck or with incomplete RCCA insertions. This observation supports the conclusion that the degree of distortion is much less severe in upper guide tubes than the dashpot areas and is bounded (in terms of insertion anomalies) by that experienced in the dashpots.

In conclusion, the single tube probing indicates that the insertion anomalies can be attributed to dashpot distortion within the fuel assembly thimble tubes. The degree of distortion appears to be dependent upon burnup. The probe data also indicates that the distortion is progressing upwards into the upper guide tubes and that dashpot distortions are clearly limiting in terms of susceptibility for RCCA insertion problems. None of the upper guide tubes probed indicate severe restrictions or localized distortion as seen at Wolf Creek. The drag test data and probe results indicate that the insertion problems (if it occurs) will occur at an elevation near the entry point into the lower dashpot.

Table 3.1: Single Tube Probe Test Results

a,b,c

4.0 Guide Thimble Borescope Exams

Assembly F26 was chosen for borescope examination based on its incomplete RCCA insertion history. The inspection was aimed at establishing the extent of wear or other evidence of interference visible on the inner diameter of the thimble tubes. The Wolf Creek guide thimble tubes exhibited spiral rub marks. These marks were visible on the upper guide tube areas and dashpot areas.

The fuel assembly was placed on a spacer such that the entire guide tube and dashpot could be examined. All 24 thimble tubes were inspected. Unfortunately the quality of the inspection suffered a serious degradation in resolution which was readily noticeable after inspecting only the first two thimble tubes. The borescope was removed after the first [ ] a,b,c and was cleaned and checked. The cleaning was useful but did not significantly improve the video quality for more than a few minutes. Even with these limitations, the video still provided some useful information.

The borescope examination showed [ ] a,b,c of the guide tube. This is consistent with anticipated light fretting wear normally associated with RCCA stepping. There was **no evidence** of significant wear [ ] a,b,c in the upper guide tube like that seen at Wolf Creek. The dashpot on thimble tube 1 did show the wear marks changing orientation from one side of the tube to the other. This occurred as the borescope was inserted from the upper dashpot area into the lower portion. This observation is consistent with the drag test data that showed distinctive plateaus and steps as the RCCA is inserted or withdrawn in the dashpot area. No observable wear could be detected in the upper guide tubes, but there was evidence of small "burnish" areas located at bulge joint elevations.

In summary, the borescope inspection at South Texas Unit 1 showed evidence of dashpot interference. The location of the rub marks moved from one side of the dashpot to the other when going from upper to lower areas of the dashpot. There was no observable wear or spiraling in the upper guide tube elevations as previously observed at Wolf Creek.

5.0 Fuel Assembly Growth Data

Fuel assembly length measurements were performed on a total of 24 assemblies (3 assemblies from Region C, 2 assemblies from Region E, 17 assemblies from Region F and 2 assemblies from Region R). The measurements were made using a standard of known length and a measuring device that has a dial indicator. The data was corrected for water temperature. The measured assembly length and growth values for the 24 assemblies are tabulated in Appendix B.

The measured growth range was [ ] a,b,c for the C assemblies, [ ] a,b,c for F assemblies, [ ] a,b,c for R assemblies and [ ] a,b,c for E assemblies. In Figure 5.1, the measured assembly growth data as a function of fluence is shown for South Texas and other plants. The South Texas growth data is normal and within the expected range. The data does not show any evidence of breakaway growth.

Figure 5.1: Recent Assembly Growth Data

a,b,c

6.0 Fuel Rod Growth Data

The axial gaps between the peripheral rods and the assembly nozzles were measured from the low magnification TV tapes of 9 South Texas Unit 1 assemblies to determine fuel rod growth. The assemblies were C28, E10, E31, F26, F32, F37, F41, R27 and R31.

The measurements were performed using a divider and steel scale. The actual gaps were determined from conversion factors. Conversion factors were obtained by measuring the TV image of several grid spring heights on the outer straps in the top and bottom grids. The factors were obtained by comparing the measured spring height to the as-built dimension. This is based on the assumption that [.][a,b,c] The measured rod gap and calculated actual gap data are summarized in Appendix C. The rods did not touch the bottom or top nozzles.

Fuel rod growth was derived from pre- and post- gap data and the measured fuel assembly growth using the following equation:

% Rod Growth = 100 x (A + B - C)/D

where,
A = pre-irradiation nominal total gap
B = irradiation change in nozzle-to-nozzle length due to assembly growth
C = post-irradiation total gap
D = pre-irradiation nominal rod length

In Appendix C, the calculated rod growth is summarized. The maximum, average, and minimum rod growth values for each assembly are listed in the table below. The data range was [ ]a,b,c for the C assembly, [ ]a,b,c for the E assemblies, [ ]a,b,c for the F assemblies, and [ ]a,b,c for the R assemblies. In Figure 6.1, the averaged rod growth data as a function of fluence is shown for South Texas 1 and other plants. The data shows that the South Texas rod growth values are within the expected limits at comparable burnup levels.

[ ]a,b,c

Figure 6.[illegible] Recent Rod Growth Data

a,b,c

7.0 Fuel Assembly Bow Data

The bow for assemblies F26, F32, F37 and F41 was measured by two methods (direct view & profile view). The measurements were made to determine the extent of the assembly distortions and to determine if the distortions are present in assemblies that do not have RCCA insertion problems. Care must be used when interpreting the data because the data inaccuracy is approximately 0.1 inches.

The string is fixed at the top and bottom nozzle for the profile view and direct view methods. In these methods, the corrected bow is also obtained from the measured distance between the string and the grid's edge. The grid springs were used at each grid to obtain conversion factors in a manner similar to the method discussed in section 6.0. In the profile view method the bow is measured while viewing a different assembly face. In the direct view method the bow is measured while viewing the assembly face. The direct view method does provide a 'truer" indication of the assembly shape since the measurements are less dependent on the top and bottom nozzles.

In Figures D.1 to D.4 of Appendix D, Figure 7.1 and in the table below, the fuel assembly "direct view" bow data is provided. The data in Figure 7.1 was determined from the vector addition of the bow data from adjacent faces (i.e., the square root of the sum of the squares of the bow data in Appendix D). The Cartesian coordinate system was used to adjust the 'sign' of the data. Positive signs were applied only when the calculated bow for both faces was positive. The small table within Figure 7.1 shows the assembly quadrant based on the assembly bow data (i.e., if

both faces had negative bow values the assembly quadrant is 3). The data in the figure were not adjusted for quadrant changes.

At South Texas, the assemblies tested which have RCCA insertion problems had higher bow changes in the dashpot. This is consistent with the drag test results. The small table in Figure 7.1 could be used to illustrate the way that the assembly shifts between the grid spans. In assemblies F26 and F41, the shift occurs in the dashpot area of the guide thimble. [

.]a,b,c

a,b,c

Figure 7.1: South Texas 1 Assembly Bow Data - (Vector Added)

a,b,c

8.0 Summary

The growth of the fuel assemblies and fuel rods measured at South Texas Unit 1 is consistent with previous Westinghouse experience. There was no indication of "breakaway" fuel assembly growth.

Drag testing results at South Texas Unit 1 show that 17X17 XL thimble tubes in high-burnup designs are susceptible to varying degrees of thimble tube distortion. The drag generally increases with burnup. The results show that the dashpot is responsible for generating the majority of the interference and is sufficient to cause incomplete RCCA insertions. The observation that two assemblies have markedly different drags for the same burnup indicates that other factors besides burnup are also contributing to the observed thimble tube distortion.

The drag tests also show that the double dashpot acts differently than dashpots in other designs. Single dashpot designs do not exhibit the two-step load increase observed in the South Texas double-dashpot designs.

Although no absolute threshold could be identified during the South Texas Unit 1 exam, evidence exists that dashpot distortion remains relatively low through the first and second cycles. Beyond this level, the drag can be seen increasing to various degrees [ ]^{a,b,c} with increasing burnup.. However, some higher burned assemblies (R31, F37, F32) exhibited low dashpot drag. Of the assemblies that did not insert fully upon reactor trip, E10 had the lowest burnup (approx. 32,200 MWD/MTU). The measured upper thimble tube drags in all cases were very low, with the maximum measured as approximately [ ]^{a,b,c} pounds. There was no evidence of "chatter" (areas where the drag load fluctuates rapidly) as experienced during the Wolf Creek drag testing.

The probe data shows that the fuel assembly upper guide thimbles are mildly distorted. The observed fuel assembly drags and incomplete RCCA insertions can be attributed to dashpot distortion. The peak dashpot and thimble tube drag observed in each assembly is consistent with the number of dashpot and guide tube no-goes. There is clear evidence of preferential distortion occurring in the dashpots and limited distortion in the upper guide tubes as the distortion progresses. The evidence shows the dashpots are limiting RCCA insertions long before the upper guide tube can become sufficiently distorted to contribute to the interference. There is evidence that the drag force and guide thimble distortions are increasing with increasing burnup with a threshold near 32,000 MWD/MTU.

In conclusion, 17X17, 14 foot (XL) designs exhibit a tendency for preferential dashpot distortion and increased drag which increases with burnup. The magnitude of the observed insertion drag is quite high. Drag is generated in two discrete steps as the RCCA passes through the upper dashpot and increases quickly upon entry into the second dashpot. Based on information obtained at South Texas Unit 1, the 17X17 XL design is particularly susceptible to RCCA insertion anomalies within limitations of exposure comparable to those measured (i.e., beyond 32,000 MWD/MTU). There is evidence that other contributing factors besides burnup are also impacting the dashpot distortion experienced at South Texas Unit 1. The data collected in this program will be used to support the root cause determination report.

Appendix A: South Texas 1 Sample Fuel Assembly Drag Trace

a,b,c

Appendix B: South Texas 1 Assembly Growth Data

a,b,c

Appendix C

Fuel Rod Growth Data

for

South Texas 1

SOUTH TEXAS 1

a,b,c

SOUTH TEXAS 1

a,b,c

SOUTH TEXAS 1

a,b,c

a,b,c

a,b,c

SOUTH TEXAS 1

a,b,c

SOUTH TEXAS 1

a,b,c

SOUTH TEXAS 1

a,b,c

SOUTH TEXAS 1

a,b,c

Appendix D

Fuel Assembly Bow Data

for

South Texas 1

Figure D.1: South Texas 1 Fuel Assembly F26 Bow Data - Direct View

a,b,c

Figure D.2: South Texas 1 Fuel Assembly F32 Bow Data - Direct View

a,b,c

Figure D.3: South Texas 1 Fuel Assembly F37 Bow Data - Direct View

a,b,c

Figure D.4: South Texas 1 Fuel Assembly F41 Bow Data - Direct View

a,b,c

Sequoyah

Fuel Assembly Inspection Program

1.0 Background and Objectives

A RCCA insertion anomaly was experienced at Wolf Creek and South Texas Unit 1. During Scrams, several RCCAs did not fully insert. Both plants conducted drop tests after the anomaly, and additional RCCAs did not fully insert. A subsequent inspection program concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. A binding interference was shown to exist between the thimble tubes and the RCCAs, which caused the high drag. Drag loads and thimble tube distortions in the Region "H" fuel at Wolf Creek increased with increasing burnup/residency time.

The objective of the inspection program at Sequoyah 2 was to characterize the assemblies, for comparison with data from other plants to determine the type of distortion present.

The following tests were conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements; and
(4) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were used to determine if the growth of the fuel assemblies and fuel rods was within the anticipated range. Items 3 and 4 will be reported in a separate report when the on-site data is available. Re-measurement is necessary because the adjusted assembly growth values measured during the first campaign are abnormally low.

2.0 Full Length RCCA Drag Tests

Fuel assemblies fabricated for eight (8) different contracts were drag tested in the spent fuel pool. The specific fuel features for each contract are shown below. Fourteen of the twenty-one fuel assemblies that were tested were fabricated with Vantage 5H fuel features.

a,b,c

The drag test results are tabulated in Table 2.1. The Sequoyah dashpot and guide thimble data are shown in Figure 2.1 with data from other plants. The lines in the figure represent the dashpot and upper guide thimble drag F-spec guidelines of [,] [a,b,c] respectively. As shown in the figure, [ ] [a,b,c] assemblies exceeded the 100 lb. dashpot drag guideline, but none of the twenty-one assemblies exceeded the [ ] [a,b,c] upper guide thimble drag guideline.

In Figures A.1 and A.2 of Appendix A, the dashpot and guide thimble drag data are graphed versus their corresponding F/A fast fluence values. At Wolf Creek, incomplete RCCA insertions occurred in fuel assemblies with fluences greater than [ ] [a,b,c] when the dashpot and guide thimble drag guidelines were exceeded.

The fast fluence value for assemblies S74 and F61 is greater than [.] [a,b,c] However, the insertion problem probably did not occur in these assemblies because their guide thimble drag values are low [ ] [a,b,c] Assembly E22 was tested three (3) times and at each time the RCCA stuck [.] [a,b,c] This assembly probably would not have experienced an insertion anomaly because of the low upper guide thimble drag value [.] [a,b,c] As shown in Figure A.1, other plants have recorded complete RCCA insertions in the data range of assembly E22.

Table 2.1: Sequoyah Drag Test Data

[ ] a,b,c

Figure 2.1: Dashpot and Upper Guide Thimble Drag Data

a,b,c

3.0 Single Tube Probe

Single tube probing was conducted on three fuel assemblies at Sequoyah Unit 2. The assemblies were selected based on burnup and drag measurements, and are included in the table below. The objective of the test was to determine the extent and location of distortion in the guide tubes of the assemblies. This information will be used to establish the extent of susceptibility of 17X17 designs to the insertion anomaly experienced at Wolf Creek.

[ ] a,b,c

Assembly E22 (Inconel mid-grids) showed the greatest amount of dashpot distortion and the least amount of upper guide tube distortion, consistent with its observed drag forces. This assembly had a drag force of only [ ] a,b,c in the upper guide tube area with a large increase in load as the RCCA was inserted into dashpot. This "standard assembly" was not probed in the upper guide tube, but is expected to have only mild upper guide tube distortion as evidenced by it very low drag readings of [.] a,b,c It is likely that this assembly would have scrammed properly, since the upper guide tube would not have decelerated the RCCA prior to entering the dashpot.

Assembly E-22 is behaving like other standard fuel design assemblies with the majority of distortion occurring in the dashpot, however, its dashpot distortion is considerably higher than that measured in standard design fuel at any other plant. The number of standard design fuel assemblies tested is small; therefore, the unusually high drag observed in the dashpot of this assembly cannot be characterized as anomalous.

Assemblies H-47 and H-55 show the majority of the thimble tube distortion is concentrated in the dashpot areas. Both assemblies show that the dashpot is contributing the highest percentage of RCCA drag. This behavior was also noted in assembly E-22 as mentioned above. The upper thimble tubes show mild distortion as evidenced by the ability of assembly H-47 to accept the [ ] a,b,c probe. This tendency for concentrated distortion in the dashpot areas is consistent with behavior noted at North Anna, V.C. Summer and Vogtle.

4.0 Summary

The probe data shows that the fuel assembly upper guide thimbles are only mildly distorted. The observed fuel assembly drags can be attributed primarily to dashpot area bowing of varying degrees. The peak dashpot and thimble tube drags are consistent with the higher number of dashpot and guide tube no-goes. There is clear evidence of preferential distortion evident in dashpots versus upper guide tubes. There is also evidence that the drag force and dashpot distortions are increasing with increasing burnup. The assembly and rod growth data will be presented in a separate report.

Appendix A

Sequoyah Fuel Assembly Drag Data

Figure A.1: Dashpot Drag and Fast Fluence Data

a,b,c

Figure A.2: Upper Guide Thimble Drag and Fast Fluence Data

a,b,c

Millstone 3

Fuel Assembly Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek and South Texas Unit 1. During Scrams, several RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the event and additional RCCAs did not fully insert. A subsequent inspection program concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. An interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly showed no indications of damage or deformation to these RCCAs. The problem resides within the fuel assemblies. Drag loads and thimble tube distortions in the Region "H" fuel at Wolf Creek increase with increasing burnup/residency time.

The objective of this inspection program was to characterize Millstone 3 thimble tube distortions. The data was compared with that from other plants to determine the extent of thimble tube distortion in the Millstone 3 fuel assemblies.

The following tests were conducted during the inspection program:

(1) RCCA Drag Tests;
(2) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(3) Fuel Assembly Length Measurements; and
(4) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to determine if the growth of the fuel assemblies and fuel rods is within the predicted range.

2.0 Full Length RCCA Drag Tests (Spent Fuel Pool)

Fuel assemblies fabricated for two different contracts were drag tested in the spent fuel pool. The specific fuel features for each contract are shown below. Nine of the ten fuel assemblies that were tested were fabricated with [ ] a,b,c fuel features.

[ ] a,b,c

The drag test results are tabulated in Table 2.1. The Millstone Unit 3 dashpot and upper guide thimble data is shown in Figure 2.1 along with data from other plants. As shown in the figure, the Millstone 3 data is within the F.5.1 guideline for thimble tube drag. The lines in the figure represent the F-spec dashpot and upper guide thimble drag guidelines of [ ] a,b,c respectively.

Figure 2.1: Dashpot and Upper Guide Thimble Drag Data

a,b,c

In Figures A.1 and A.2, the dashpot and guide thimble drag data are graphed versus their corresponding F/A fast fluence. At Wolf Creek, incomplete RCCA insertions occurred in fuel with F/A fluences greater than [,] a,b,c when the dashpot and guide thimble drag F.5.1 guidelines were exceeded. In contrast to the Wolf Creek fuel, none of the Millstone Unit 3 fuel assemblies exceeded the F-spec upper guide thimble drag guideline of [.] a,b,c

Table 2.1: Millstone Unit 3 Drag Test Data

[ ] a,b,c

3.0 Single Tube Probe

Single tube probing was conducted on fuel assembly F02 at Millstone 3. Based on the RCCA drag testing it was judged the tested assemblies at Millstone 3 do not have a significant amount of thimble tube distortion. None of the tested assemblies exceeded the Westinghouse F.5.1 guidelines for RCCA drag.

A series of probes lengths and diameters per drawing [ ] a,b,c were used. The order of the probes is shown on Figures 3.1 and 3.2 for the dashpot and guide thimbles, respectively. Each probe was lowered into the thimble tube and allowed to drop by its own weight. A "GO" was recorded if the probe hit bottom. If the probe did not hit bottom, a "NO GO" was recorded and the axial elevation where the probe stopped was recorded.

Results of the single tube probing are shown in Figures 3.3 and 3.4. The baseline probe [ ] a,b,c would not go in the dashpot of any of the thimble tubes. When the diameter was reduced to [,] a,b,c the probe was a "GO" in all tubes. The probe length was then changed to the [ ] a,b,c long one. This probe was a

"GO" in 13 of 24 tubes. In one tube the probe stopped at [,] a,b,c and in nine tubes the probe stopped between [ ] a,c from full insertion.

Figure 3.1: Dashpot "GO/NO GO" Probes
17x17 Fuel Assemblies

a,b,c

Figure 3.2: Upper Guide Thimble "GO/NO GO" Probes
17x17 Fuel Assemblies
W/ Zircaloy Mid-Grids

a,b,c

lcgonogo1.jr
h

Figure 3.3: Millstone 3 Fuel Assembly F02
Dashpot Probes

a,b,c

Figure 3.4: Millstone 3 Fuel Assembly F02 Upper Guide Thimble Probes

a,b,c

The baseline probe for the upper guide thimbles [ ] [a,b,c] was a "GO" in all tubes. The next probe had an increased length of [.] [a,b,c] and a smaller diameter of [.] [a,b,c] This probe was a "GO" in [.] [a,b,c] In one tube the probe entered the tube and stopped at [.] [a,b,c] from full insertion. The length was then increased to [.] [a,b,c] This probe was a "GO" in [.] [a,b,c] On the same tube that stopped the previous probe at [ ] [a,b,c] also stopped this probe.

4.0 Fuel Assembly Growth Data

Fuel assembly length measurements were performed on 10 assemblies (1 assembly from Region E and 9 assemblies from Region F). The measurements were made using a standard of known length and a measuring device that has a dial indicator. The data was corrected for water temperature. The measured assembly length and growth values of the 10 assemblies are tabulated in Appendix B.

The measured growth was [ ] [a,b,c] for assembly E40 and ranged from [ ] [a,b,c] for the F assemblies. In Figure 4.1, the measured assembly growth data as a function of fluence is shown for Millstone 3 and other plants. The Millstone 3 growth data is normal and within the expected range. The data does not show any evidence of breakaway growth.

5.0 Fuel Rod Growth Data

The axial gaps between the peripheral rods and the assembly nozzles were measured from the low magnification TV tapes of 10 Millstone Unit 3 assemblies to determine fuel rod growth. The assemblies were E40, F85, F18, F02, F87, F86, F01, F11, F81 and F25.

The measurements were performed using a divider and steel scale. The actual gaps were determined from conversion factors. Conversion factors were obtained by measuring the TV image of several grid spring heights on the outer straps in the top and bottom grids. The factors were obtained by comparing the measured spring height to the as-built dimension. This is based on the assumption that Inconel grids do not change dimensions during irradiation. The measured rod gap and calculated actual gap data are summarized in Appendix C. Most of the fuel rods did not contact the bottom nozzle.

Fuel rod growth was derived from pre- and post- gap data and the measured fuel assembly growth using the following equation:

$$\% \text{ Rod Growth} = 100 \times (A + B - C)/D$$

where,
A = pre-irradiation nominal total gap
B = irradiation change in nozzle-to-nozzle length due to assembly growth
C = post-irradiation total gap
D = pre-irradiation nominal rod length

Figure 4.1: Recent Assembly Growth Data

[ ] a,b,c

In Appendix C, the calculated rod growth data is summarized. The maximum, average, and minimum rod growth values for each assembly are listed in the table below. The data range was

[ ] a,b,c for assembly E40 and [ ] a,b,c for the F assemblies. In Figure 5.1, the averaged rod growth data as a function of fluence is shown for Millstone 3 and other plants. The data shows that the Millstone rod growth values are within the expected limits at comparable burnup levels.

[ ] a,b,

Figure 5.1: Recent Rod Growth Data

a,b,c

6.0 Summary

The growth of the fuel assemblies and fuel rods measured at Millstone Unit 3 is consistent with previous Westinghouse experience. There was no indication of "breakaway" fuel assembly growth.

The data from the single tube probes is consistent with the RCCA drag data. The thimble tubes are moderately distorted in the dashpot. The distortion is in the form of gradually bowed tubes. There is no evidence of any cross section changes, such as ovality or kinks. The guide thimbles have only minimal distortions. There is evidence of an obstruction near the top of one tube that stopped the two long probes. This obstruction is possibly due to debris or damage to the guide thimble.

Appendix A

Millstone 3 Fuel Assembly Drag Data

Figure A.1: Dashpot Drag and Fast Fluence Data

a,b,c

Figure A.2: Upper Guide Thimble Drag and Fast Fluence Data

a,b,c

Appendix B

Millstone 3 Assembly Growth Data

a,b,c

Appendix C

Fuel Rod Growth Data

for

Millstone 3

a,b,c

MILLSTONE 3

a,b,c

MILLSTONE 3

a,b,c

a,b,c

MILLSTONE 3

a,b,c

MILLSTONE 3

a,b,c

MILLSTONE 3

a,b,c

MILLSTONE 3

a,b,c

MILLSTONE 3

a,b,c

MILLSTONE 3

a,b,c

Diablo Canyon 2

Fuel Assembly Inspection Program

1.0 Background and Objectives

An RCCA insertion anomaly was experienced at Wolf Creek and South Texas Unit 1. During trips, several RCCAs did not fully insert. Wolf Creek conducted cold drop tests after the event and additional RCCAs did not fully insert. A subsequent inspection program concluded that the direct cause of the incomplete RCCA insertions at Wolf Creek was thimble tube distortion. An interference was shown to exist between the thimble tubes and the RCCAs, causing the high drag. Tests of the Wolf Creek RCCAs in a reference fuel assembly showed no indications of damage or deformation to these RCCAs. The problem resides within the fuel assemblies. Drag loads and thimble tube distortions in the Region "H" fuel at Wolf Creek increase with increasing burnup/residency time.

The objective of this inspection program was to characterize Diablo Canyon 2 thimble tube distortions. The data was compared with that from other plants to determine the extent of thimble tube distortion in the Diablo Canyon 2 fuel assemblies.

The following tests were conducted during the inspection program:

(1) Guide Thimble Plug Gage Exams (Single Tube Probe Tests);
(2) Fuel Assembly Length Measurements; and
(3) Fuel Rod-to-Nozzle Gap Measurements.

Fuel assembly length measurements and fuel rod-to-nozzle gap measurements were needed to determine if the growth of the fuel assemblies and fuel rods was within the anticipated range.

2.0 Single Tube Probe

Single tube probing was conducted on two fuel assemblies at Diablo Canyon Unit 1. The assemblies (T78H and T80H) were selected based on their containing the same thimble tube material lot as the assemblies at Wolf Creek which experienced the RCCA insertion anomaly. This information will be used to establish the extent of susceptibility of 17X17 designs to the insertion anomaly experienced at Wolf Creek. The data for the two assemblies is provided below.

Assembly T78H has slightly higher burnup than T80H, but its thimble tubes are less bowed. Neither assembly demonstrates sufficient bow to exceed either of the F-spec guideline numbers for drag. Unlike Wolf Creek where the upper guide tubes experienced substantial upper guide tube distortion, both assemblies at Diablo Canyon show only moderate to low levels of upper guide tube bow. In fact, assembly T78H is demonstrating extremely good dashpot and upper guide tube dimensional stability. Both assemblies can be characterized as containing only mild distortion of a very gradual nature biased to the dashpot areas. Neither assembly would be expected to inhibit RCCA insertion in any way.

a,b,c

[ ]

3.0 Fuel Assembly Growth Data

Fuel assembly length measurements were performed on 16 assemblies (11 assemblies from Region T, 2 assemblies from Region U and 3 assemblies from Region S). The measurements were made using a standard of known length and a measuring device that has a dial indicator. The data was corrected for water temperature. The measured assembly length and growth values of the 16 assemblies are tabulated in Appendix A. All of the 17x17 OFA assemblies have the [.] a,b,c

The measured growth was [ ] a,b,c for the T assemblies, [ ] a,b,c for the U assemblies and [ ] a,b,c for the S assemblies. In Figure 3.1, the measured assembly growth data as a function of fluence is shown for Diablo Canyon 2 and other plants. The Diablo Canyon 2 growth data is normal and within the expected range. The data does not show any evidence of breakaway growth.

Figure 3.1: Recent Fuel Assembly Growth Data

[ ] a,b,c

4.0 Fuel Rod Growth Data

The axial gaps between the peripheral rods and the assembly nozzles were measured from the low magnification TV tapes of 16 Diablo Canyon 2 assemblies to determine fuel rod growth. The assemblies were S01, S65H, S68H, T13, T14, T15, T21, T23, T27, T35, T39, T41, T78H, T80H, U77H AND U84H.

The measurements were performed using a divider and steel scale. The actual gaps were determined from conversion factors. Conversion factors were obtained by measuring the TV image of several grid spring heights on the outer straps in the top and bottom grids. The factors were obtained by comparing the measured spring height to the as-built dimension. This is based on the assumption that Inconel grids do not change dimensions during irradiation. The measured rod gap and calculated actual gap data are summarized in Appendix B. None of the rods came close to touching the top and bottom nozzles.

Fuel rod growth was derived from pre- and post- gap data and the measured fuel assembly growth using the following equation:

$$\% \text{ Rod Growth} = 100 \times (A + B - C)/D$$

where,
A = pre-irradiation nominal total gap
B = irradiation change in nozzle-to-nozzle length due to assembly growth
C = post-irradiation total gap
D = pre-irradiation nominal rod length

In Appendix B, the calculated rod growth data is summarized. The maximum, average, and minimum rod growth values for each assembly are listed in the table below. The data range was [ ]^{a,b,c} for the S assemblies, [ ]^{a,b,c} for the T assemblies and [ ]^{a,b,c} for the U assemblies. In Figure 4.1, the averaged rod growth data as a function of fluence is shown for Diablo Canyon 2 and other plants. The data shows that the Diablo Canyon 2 rod growth values are within the expected limits at comparable burnup levels.

Assembly	Fluence	Rod Growth (%)		
No	(E21 nvt)	Max.	Avg.	Min.

Assembly No	Fluence (E21 nvt)	Rod Growth (%)		
		Max.	Avg.	Min.

Figure 4.1: Recent Rod Grwoth Data

a,b,c

5.0 Summary

The growth of the fuel assemblies and fuel rods measured at Diablo Canyon 2 is consistent with previous Westinghouse experience. There was no indication of "breakaway" fuel assembly growth.

The thimble tubes tested from Diablo Canyon Unit 2 which contained material from the same lot used to manufacture the assemblies that experienced the RCCA insertion anomaly at Wolf Creek, showed only mild distortion at Diablo Canyon at comparable burnups. The Diablo Canyon tests indicate that other factors besides burnup and material properties are influencing the assembly thimble tube distortion phenomenon.

Appendix A

Diablo Canyon 2 Assembly Growth Data

a,b,c

Appendix B

Fuel Rod Growth Data

for

Diablo Canyon 2

a,b,c

DIABLO CANYON 2

a,b,c

Diablo Canyon 2

a,b,c

DIABLO CANYON 2

a,b,c

DIABLO CANYON 2

a,b,c

a,b,c

DIABLO CANYON 2

a,b,c

DIABLO CANYON 2

a,b,c

DIABLO CANYON 2

a,b,c

DIABLO CANYON 2

a,b,c

a,b,c

DIABLO CANYON 2

a,b,c

DIABLO CANYON 2

a,b,c

DIABLO CANYON 2

a,b,c

DIABLO CANYON 2

a,b,c

a,b,c

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