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SPC Guide Tube Compatibility with Westinghouse Reactor RCCAs

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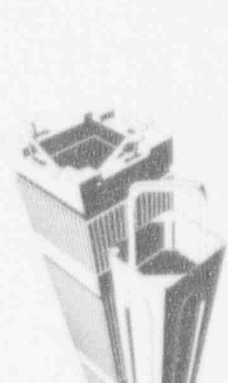

Siemens Power Corporation

Nuclear Division

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SPC Guide Tube Compatibility with
Westinghouse Reactor RCCAs

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SPC Guide Tube Compatibility with Westinghouse Reactor RCCAs

1. Summary

This report provides the technical justification and supporting data which demonstrates that PWR fuel assemblies designed and fabricated by Siemens Power Corporation (SPC) are dimensionally compatible with the control elements throughout their design life. Specifically, the designs maintain the ability to insert RCCAs throughout the life of the fuel. The SPC fuel design assures that:

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With these criteria, the SPC designed fuel assemblies are strong enough that they are not susceptible to significant guide tube distortion this conclusion is valid for designs with and without intermediate flow mixers (IFMs).

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Considering the review of the SPC design process, manufacturing methodology, the supporting reactor RCCA drop and drag test information, and excellent RCCA insertion history in SPC fuel, SPC fuel designs remain compatible with RCCAs throughout their design lifetime. No rodded burnup restrictions or additional RCCA drop or drag test data are required for SPC PWR fuel.

2. Introduction

There have been a number of cases in the United States and elsewhere of incomplete RCCA insertion in PWR fuel assemblies designed and fabricated by other fuel vendors. All of the investigations have concluded that the control rod insertion delays resulted from guide tube deformation due to excessive compressive loading on the assemblies. Investigations conducted for the Westinghouse events conclude this abnormal behavior is the consequence of fuel assembly growth that exceeded the expectations of the fuel vendor. [1] Several causes for the higher-than-anticipated growth are postulated as being corrosion, power history, and temperature effects. In addition to abnormal growth, excessive compressive loading can also result from inadequate guide tube strength or excessive holddown forces.

Since the ability to shutdown the plant is a paramount safety concern, utilities need to assure that their ability to insert control elements is not affected by fuel assembly distortion. The SPC fuel design assures that the fuel assemblies have adequate holddown forces and structural strength throughout their design lifetime while allowing for RCCA insertion.

Specific features in the SPC design and fabrication process ensures that compressive forces are not excessive throughout their irradiation time. In particular SPC designs the fuel such that there is sufficient margin between the compressive loads experienced during irradiation at any exposure and the axial loads required to cause distortion of the assembly. [

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Understanding of assembly behavior during irradiation is essential to assure full compatibility of assembly and control elements. SPC has based the irradiation performance on models developed from in-reactor data that encompass the range of operating conditions seen in PWRs.

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.] SPC uses a conservative growth model to ensure clearance between the fuel assembly and core plates is maintained and that holddown forces are not excessive.

This report presents the results of evaluations performed by SPC as follows:

- Section 3 contains typical fuel assembly design descriptions.
- Section 4 contains the design criteria and a description of the SPC methodology.
- Section 5 contains the results of the testing and design analyses on SPC assembly types.
- Section 6 contains the control rod insertion time and drag force measurement data.

3. Design Description

SPC supplies fuel designs for various reactor types:

3.1 *SPC Fuel for Westinghouse Design Reactors*

SPC currently provides 14X14, 15X15, and 17X17 fuel designs for Westinghouse reactor configurations. The SPC fuel assembly design for Westinghouse reactor configurations consists of a square array occupied by fuel rods, guide tubes, and one instrument tube. Fuel rods are supported by grid spacers that are attached to the guide tubes and instrument tube. The guide tubes and grid spacers form a cage that is attached at each end to stainless steel tie plates. This cage assembly forms the structural frame of the fuel assembly. Typical characteristics of the fuel assemblies are given in Table 1.

3.2 *SPC 14X14 Fuel for Combustion Engineering (CE) Design Reactors*

The SPC fuel assembly design for 14X14 CE reactor configurations consists of a square array occupied by 176 fuel rods and 5 guide tubes. The fuel rods are supported by 9 grid spacers that are attached to the guide tubes. The guide tubes and grid spacers form a cage that is attached at each end to stainless steel tie plates. This cage assembly forms the structural frame of the fuel assembly. Typical characteristics of the fuel assembly are given in Table 2.

3.3 *SPC 15X15 Fuel for CE Design Reactors*

The SPC fuel assembly design for 15X15 CE reactor configurations consists of a square array occupied by 216 fuel rods, 8 guide bars, and 1 instrument tube. The fuel rods are supported by 10 grid spacers that are attached to the guide bars and instrument tube. The guide bars and grid spacers form a cage that is attached at each end to stainless steel tie plates. This cage assembly forms the structural frame of the fuel assembly. Typical characteristics of the fuel assembly are given in Table 3.

4. Fuel Assembly Strength, Buckling, and Growth Design Criteria

4.1 *Guide Tubes*

SPC design requirements include that, for the lifetime of the fuel, the guide tubes shall provide for insertion of control rods, provide adequate strength to carry the weight of the fuel assembly and support the holddown forces applied by the reactor structure. The guide tubes must also be sufficiently corrosion resistant to provide the required functions throughout the fuel assembly design life.

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4.2 *Fuel Assembly*

The length of the fuel assembly is designed to provide clearance for irradiation-induced growth without exceeding the core plate-to-core plate spacing. [.]

5. Design Evaluation

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The growth prediction model used by SPC is based on a broad base of data for a number of different fuel designs and operating conditions. The design growth curves are developed from measured data and observed conditions. Thus these design curves conservatively bound the operation of the SPC fuel assemblies.

5.1 *Guide Tube Design*

Industry experience has identified a number of factors that affect straightness of the guide tubes during operation, including hydriding, manufacturing processes, and excessive axial loads. SPC has identified and eliminated sources of hydriding from the manufacturing process. In addition, specific controls are placed on the production and use of guide tubes to improve the as-manufactured tube performance. Excessive axial loads, leading to guide tube distortion, can result from:

- Insufficient strength of the guide tube for the operational axial loads.
- Differential growth of guide tubes within the fuel assembly.
- Insufficient growth margin for the fuel design resulting in excessive holddown forces or solid contact with the core structure.

SPC guide tubes are designed and evaluated to be compatible with the RCCAs throughout the life of the fuel. The fuel design includes considerations such as RCCA and guide tube dimensions, fuel assembly strength requirements, and EOL irradiation growth effects.

5.1.1 Dimensions

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5.1.2 Strength and Buckling

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5.1.3 Corrosion and Hydriding of Guide Tubes

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5.2 *Fuel Assembly Growth*

SPC controls and evaluates a number of factors relating to fuel assembly irradiation growth.

5.2.1 Guide Tube Manufacture

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5.2.2 Core Structure Compatibility

SPC ensures compatibility with the core structure through verification of the design to the plant specific data. Upper tie plate assembly dimensions allow for EOL growth margin. Upper tie plate components and dimensions, [

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5.2.3 Irradiation Growth Determination

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SPC uses a conservative fuel assembly growth methodology to ensure adequate margin and as input to the holddown and fuel rod growth analyses. [.]

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[.]

The method of design curve development has been reviewed by the NRC as indicated in References 4 and 5.

[.]

[ ] bounds SPC fuel high burnup guide tube growth measurement data to-date.

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Minimum predicted growth clearances for SPC fuel designs for Westinghouse reactor configurations are shown below:
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6. Reactor Plant RCCA Insertion Experience

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As required by the NRC Bulletin 96-01, "Control Rod insertion Problems," March 8, 1996, the utilities having SPC designed fuel have conducted RCCA drop time tests and drag force tests. The drop tests are typically determined from in-core drop testing where the RCCA is released, and the time to insertion to the dashpot and the time to full insertion are measured. Drop tests are normally performed at core operating conditions and cover a range of assembly exposures. The drag tests are typically determined by withdrawal of a fully inserted RCCA from a fuel assembly and the drag force measured. Drag tests are typically performed in the cold condition on selected fuel assemblies.

Figures 13, 14, 15, 16 and 17 show the drop times in SPC fuel as a function of fuel assembly exposure for a 14x14 (non-IFM), a 15x15 (IFM and non-IFM), and three 17x17 (IFM and non-IFM) Westinghouse configuration plants, respectively. As these figures show, the assembly exposure does not affect the drop times for the SPC designs.

Figures 18, 19 and 20 show the drag forces for SPC fuel as a function of the assembly exposure for plants with a 14x14, a 15x15, and a 17x17 (same plant as Figure 15) Westinghouse configuration, respectively. Again, there is no trend with burnup. There is more scatter, however, in the 15x15 data due to the method used to perform the drag tests. For the drag tests other than the 15X15 fuel, the rods were withdrawn without guides or external sources of friction. For the 15x15 test, the control rod changeout tool was used for the testing. With this tool, there are alignment guides that can interact with the control rod increasing the friction and the apparent withdrawal force. The larger scatter of the 15x15 drag force testing has been concluded to be the result of this

additional friction. However, even for the 15x15 fuel where these additional friction forces were applied, the measured total drag forces are well within acceptable levels and show no trends with exposure.

7. Results and Conclusion

SPC utilizes appropriate methodology to analyze the fuel designs. Conservatively developed growth models successfully account for the irradiation growth currently being experienced in-reactor. Production and manufacturing constraints placed on materials and finished components assure uniform and predictable behavior. RCCA drop time and drag test information for reactor plants currently utilizing both IFM and non-IFM SPC fuel show no adverse trends.

Considering the review of the SPC design process, manufacturing methodology, the supporting reactor RCCA drop and drag test information, and excellent RCCA insertion history in SPC fuel, it is concluded that SPC fuel designs remain compatible with RCCAs throughout their design lifetime. No rodded burnup restrictions or additional RCCA drop or drag test data are required for SPC PWR fuel.

8. References

1. Presentation, "Root Cause of Incomplete Control Rod Insertions at Westinghouse Reactors," Sumit Ray, Westinghouse Commercial Nuclear Fuel Division.

2. Garzarolli, F., et al., "Effects of High Neutron Fluences on Microstructure and Growth of Zircloy-4," *Zirconium in the Nuclear Industry: Eighth International Symposium, ASTM STP 1023*, L. F. P. Van Swam and C. M. Eucken, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 641-657.

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4. R. A. Copeland to Dr. S. L. Wu (USNRC), "Criteria for PWR Rod and Assembly Growth Correlations," RAC:94:118, August 23, 1994.

5. R. A. Copeland to Dr. S. L. Wu (USNRC), "Responses to NRC Request for Information on EMF-92-116(P)," RAC:94:172, November 16, 1994.

Table 1 SPC Fuel Assembly Characteristics for Westinghouse Reactor Configurations

Characteristic	Value		
	14x14	15x15	17x17
Number of Fuel Rods	179	204	264
Number of Guide Tubes	16	20	24
Instrument Tube	1	1	1
Number of Spacers	7	7	8
Number of Intermediate Flow Mixers (IFMs)	0	3	0 or 3
Fuel Assembly Length, inch	159.71	159.71	159.61
Fuel Rod Pitch, inch	0.556	0.563	0.496

Table 2 SPC Fuel Assembly Characteristics for 14x14 CE Reactor Configurations

Characteristic	Value
Number of Fuel Rods	176
Number of Guide Tubes	5
Number of Spacers	9
Fuel Assembly Length, inch	157.24
Fuel Rod Pitch, inch	0.580

Table 3 SPC Fuel Assembly Characteristics for 15x15 CE Reactor Configurations

Characteristic	Value
Number of Fuel Rods	216
Number of Guide Bars	8
Instrument Tube	1
Number of Spacers	10
Fuel Assembly Length, inch	148.852
Fuel Rod Pitch, inch	0.550

Table 4 Typical 14x14 Guide Tube Dimensions

Item	Westinghouse Value	SPC Value	SPC Delta
Guide Tube OD, inch	0.526	0.541*	0.015
Guide Tube ID, inch	0.492	0.507*	0.015
Clearance with Control Rod (0.431 inch OD), inch	0.061	0.076	0.015
Guide Tube Dashpot OD, inch	0.4815	0.481*	-0.0005
Guide Tube Dashpot ID, inch	0.4465	0.447*	0.0005
Clearance with Control Rod (0.431 inch OD), inch	0.0155	0.016	0.0005

Table 5 Typical 15x15 Guide Tube Dimensions

Item	Westinghouse Value	SPC Value	SPC Delta
Guide Tube OD, inch	0.533	0.544*	0.011
Guide Tube ID, inch	0.499	0.511*	0.012
Clearance with Control Rod (0.443 inch OD), inch	0.056	0.068	0.012
Guide Tube Dashpot OD, inch	0.490	0.489*	-0.001
Guide Tube Dashpot ID, inch	0.455	0.455*	0
Clearance with Control Rod (0.443 inch OD), inch	0.012	0.012	0

* [.]

Table 6 Typical 17x17 Guide Tube Dimensions

Item	Westinghouse Value*	SPC Value	SPC Delta
Guide Tube OD, inch	0.474	0.480**	0.006
Guide Tube ID, inch	0.442	0.448**	0.006
Clearance with Control Rod (0.381 inch OD), inch	0.061	0.067	0.006
Guide Tube Dashpot OD, inch	0.430	0.430**	0
Guide Tube Dashpot ID, inch	0.397	0.397**	0
Clearance with Control Rod (0.381 inch OD), inch	0.016	0.016	0

* Westinghouse V5H fuel assembly design.

** [.]

Figure 1 Typical SPC 17x17 Holddown Spring Force and Guide Tube Strength Characteristics

Figure 2 SPC Drag Test Setup

Figure 3 SPC Drag Test Using a Simulated RCCA and Typical 17x17 Cage Assembly (Test #1, Spacers and IFMs Bracketed)

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