Westinghouse Non-Proprietary Class 3

WCAP-17100-NP
Supplement 1, Revision 0

December 2012

PRA Model for the Westinghouse Shutdown Seal

Supplemental Information for All Domestic Reactor Coolant Pump Models

Westinghouse

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Supplemental Information for All Domestic Reactor Coolant Pump Models

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EXECUTIVE SUMMARY

Westinghouse has developed a Reactor Coolant Pump (RCP) SHIELD® Passive Thermal Shutdown Seal (SDS) that restricts reactor coolant system (RCS) inventory losses to very small leakage rates for a plant event that results in the loss of all RCP seal cooling. The SDS is a thermally actuated, passive device that is integral to the No. 1 insert and is positioned between the No. 1 seal and the No. 1 seal leak-off line to provide a near leak-tight seal once activated. Installation of the SDS will permit a plant to respond to a wide range of events with only an alternating current (AC) independent (e.g., turbine driven or diesel driven) auxiliary feedwater pump available. The possible events include station blackout (SBO), fires that disrupt power supplies, loss of the component cooling water system, and loss of the service water system. Since the SDS will allow negligible RCS inventory losses through the RCP seals, RCS makeup is no longer essential to achieve a stable steady state with the reactor core being cooled.

The SDS deterministic and probabilistic risk assessment (PRA) models for RCP seal performance have been reviewed and approved by the U.S. Nuclear Regulatory Commission (NRC) for the Model 93A RCP, as documented in WCAP-17100-P-A (Reference 1). To apply the deterministic and PRA models to the Westinghouse Model 93, 93A-1, and 100 RCPs, the NRC safety evaluation report (SER) stipulated that the SDS components must be subject to testing similar to that documented for the Model 93A RCP and that the results of such testing must be submitted to NRC for review and approval.

This report provides the results of testing of the SDS design that will be installed in the Model 93, 93A-1 and 100 RCPs. The SDS design for these RCP models is slightly different from the SDS design for the Model 93A RCP in that the sealing surface is the RCP shaft instead of the shaft sleeve. All of the other key features of the SDS design for these RCP models are very similar to the RCP Model 93A. The differences are minimal to accommodate the differences in RCP models as described in this report. The key components of the SDS that are changed for these RCP models were subject to testing to ensure that the reliability was as good as that for the Model 93A RCP SDS. The test results and statistical treatment of the test data for these pump models are documented in this supplement. No additional tests for actuation on a rotating shaft were conducted for the Model 93, 93A-1, and 100 SDS designs.

In addition to the testing of the sealing capability and endurance similar to that presented in WCAP-17100-P-A, testing for 168 hours (seven days) to cover the SDS designs for all of the RCP models was completed to show survivability for that time duration. Following the Fukushima accident, it was projected that a significant safety benefit could be shown if the SDS endurance could be assured for a time period that exceeds the time frames in the current regulatory requirements for station blackout and fire protection (10CFR50.48). The 168 hour value was chosen based on industry discussions in the mid-2011 post-Fukushima time frame.

Finally, this report addresses the Farley post-operational SHIELD seal test in July of 2012, the subsequent forensic investigations and the minor enhancements to improve reliability margins. The results of the forensic investigations concluded that the concept for the Westinghouse SHIELD passive thermal shutdown seal operation remains sound and the benefits remain intact. The analytical models already approved by the NRC in WCAP-17100-P-A, "PRA Model for the Westinghouse Shutdown Seal," as well as those in this report are still valid for all plants with the enhanced SHIELD seal and for the Farley Units with the original design as long as they are not exposed to a dry oxidizing environment after initial installation and operation.

This report is being submitted to NRC for review and approval to facilitate acceptance of regulatory applications that are impacted by RCP seal performance following a loss of all RCP seal cooling for all Westinghouse RCP models currently in use in the USA.

An additional supplemental report is planned to describe the results of testing of the model 93D SDS. Because there are no Model 93D RCPs used in the USA, that report will only be applicable to non-USA plants.

ACKNOWLEDGEMENT

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Camille Zozula and Yves Masset for consultation during the drafting of the 93, 93A-1, and 100 SDS documentation.

Thomas Timmons and Steve Slowik for their expert consultation in preparing this document.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AC	Alternating Current
EDM	Electrical Discharge Machining
FMEA	Failure Modes and Effects Analysis
HAZ	Heat Affected Zone
ID	Inside Diameter
OD	Outside Diameter
NDE	Non-Destructive Examination
NRC	Nuclear Regulatory Commission
ORM	Operator Response Margin
PRA	Probabilistic Risk Assessment
PWR	Pressurized Water Reactor
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
SBO	Station Blackout
SDS	Shutdown Seal
SEM	Scanning Electron Microscope
SER	Safety Evaluation Report
SG	Steam Generator
SNC	Southern Nuclear Operating Company

1 INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

Westinghouse developed a Reactor Coolant Pump (RCP) SHIELD® Passive Thermal Shutdown Seal (SDS) that restricts reactor coolant system (RCS) inventory losses to very small leakage rates during a plant event that results in the loss of all RCP seal cooling. For regulatory applications that rely upon deterministic analyses and PRA modeling when addressing RCP seal behavior in response to a loss of all RCP seal cooling event, the behavior would be significantly different from the previously approved Nuclear Regulatory Commission (NRC) modeling in WCAP-15603, Revision 1-A (Reference 2) and WCAP-16396[1] (Reference 3). To develop deterministic and PRA models that could be approved by the NRC to facilitate acceptance of licensee regulatory applications, significant testing was performed to prove the reliability of the SDS as documented in WCAP-17100-P-A (Reference 1).

The initial testing that was documented in WCAP-17100-P-A was for the SDS to be used with the Model 93A RCP. This RCP model represents over 75% of the Westinghouse RCPs in operation in the USA. The NRC Safety Evaluation Report (SER) for WCAP-17100-P-A limited the approval of the deterministic and PRA models to the Model 93A RCP. In writing the SER, the NRC stated:

> "Currently, the model shall be used to describe the consequences of loss of reactor seal cooling in PRAs after the SDS is installed on Model 93A RCPs. In order to use the PRA model for the other RCPs, e.g., Models 93, 93A-1, 100, etc., the modified SDS components and entire SDS package for those specific RCP models shall be subject to the same tests as described in WCAP-17100-P/NP, Revision 1. The test apparatus(s) shall simulate those specific RCP models. The failure probability value derived from these tests should not exceed the value noted for Model 93A RCPs as provided in WCAP-17100-P/NP, Revision 1. In addition, for Model 100 pumps, Westinghouse had stated that licensees cannot take credit for timely RCP trip on non-SBO loss of seal cooling. For these pumps, Westinghouse shall provide additional guidance to licensees on seal leak-off rates. As stated above in Section 3.5, the NRC staff expects that all additional test data and licensee guidance will be made available for NRC review and approval as part of supplements or revisions to WCAP-17100-P/NP, Revision 1."

This report provides the results of testing of the SDS design that will be installed in the Model 93, 93A-1 and 100 RCPs. This is intended to satisfy the limitations described in the SER for WCAP-17100-P-A. As described below, the SDS design for these RCP models is slightly different from the SDS design for the Model 93A RCP.

In addition to the testing to show sealing endurance similar to that presented in WCAP-17100-P-A, the individual SDS designs for all of the RCP models (including the Model 93A) were subjected to endurance testing for 168 hours (seven days). Following the Fukushima accident, it was projected that a safety benefit could be shown if the SDS endurance could be assured for a time period that exceeds the time frames in the current regulatory requirements for station blackout (10 CFR 50.63) and fire protection (10 CFR 50.48) licensing basis requirements. The 168 hour value was chosen based on industry discussions in the mid-2011 post-Fukushima time frame.

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[1] NRC did not approve WCAP-16396 via SER. Rather, the NRC approved the use of the 21 gpm seal leak rate for deterministic analyses such as 10CFR50.48 coping strategies via IN-2005-14 (Reference 4).

This report is being submitted to the NRC for review and approval of the PRA and deterministic models for RCP seal behavior for loss of seal cooling events, to facilitate acceptance of licensee regulatory applications that are impacted by RCP seal performance following a loss of all RCP seal cooling for all Westinghouse RCP models currently in use in the USA.

1.2 BACKGROUND

1.2.1 SDS Differences among Reactor Coolant Pumps

The operation of the mechanical seal assemblies manufactured by Westinghouse for use in Westinghouse RCPs is consistent among Model 93, 93A, 93A-1, and 100 RCPs. While the RCPs for each of these models may appear to be significantly different, the design of the seal assemblies is similar.

From the perspective of the SDS, the primary difference between RCP Model 93A and the other pump models is the sealing surface. The Model 93A SDS seals against a shaft sleeve, whereas the SDS seals against the shaft itself for the other pump models. The shaft sleeve is an integral part of the Model 93A RCP mechanical seal assembly as it is currently used without the SDS. This results in the following key differences between the Model 93A SDS and the SDS for the other pump models:

a,b,c

1.2.2 RCP Pump Trip Time Windows

The time window available for operator action to trip the RCPs and therefore ensure that the SDS will actuate on a stationary or slowly rotating shaft was presented in subsection 3.2.3.11.7 of

WCAP-17100-P-A based on RCP coastdown data for a Model 93A RCP. The time windows for the other pump models have been re-analyzed with more detailed models.

a,b,c

This method supports the operator response margins for the RCP Model 93A described in Table 3-20 of WCAP-17100-P-A and further supports conclusions discussed in subsection 3.2.3.11.6 of WCAP-17100-P-A.

Table 1-1: Operator Response Margin for Tripping the RCP

RCP Model	Purge Volume PV (gal)	Coastdown Time CD (min)	Slow Rotation Time C (min)	Time From Loss of Seal Cooling to SDS Activation (min)		Operator Response Margin – ORM (min)	
				Minimum (Note 1)	Expected (Note 2)	Minimum	Expected

a,b,c

2 REGULATORY EVALUATION

The proposed PRA and deterministic models for the SDS presented in Sections 3.3 and 3.4 are consistent with those presented in WCAP-17100-P-A and are based on the technical information provided in Section 3. Therefore, the PRA and deterministic models in WCAP-17100-P-A, with the exception of the time window for an operator action to trip an RCP following a loss of all seal cooling, are applicable to the Model 93, 93A, 93A-1, and 100 RCPs. The models for the low leakage characteristics of the SDS can be extended to a time period of 168 hours. The operator action times for tripping an RCP following a loss of all RCP seal cooling should use the information in Table 1-1 of this report in place of Table 3-20 in WCAP-17100-P-A.

3 TECHNICAL EVALUATION

3.1 SHUTDOWN SEAL DESIGN

This supplement to WCAP-17100-P-A considers the SDS design for the Model 93, 93A-1, and 100 RCPs. ^{a,b,c}

To ensure the performance of the SDS for the Model 93, 93A-1 and 100 RCPs, certain tests documented in WCAP-17100-P-A for the RCP Model 93A SDS were repeated for each of the RCP Model 93 SDS and for RCP Model 93A-1 SDS. Since the Model 100 SDS is identical to RCP Model 93A-1 SDS, the tests for RCP Model 93A-1 SDS are also applicable to RCP Model 100 SDS. These tests include:

- Sealing endurance testing to show that the different gaps do not impact performance compared to RCP Model 93A that is documented in subsection 3.2.3.1 of WCAP-17100-P-A.
- Full assembly testing to show that the entire package will actuate and seal with the same reliability as RCP Model 93A SDS that is documented in subsection 3.2.3.4 of WCAP-17100-P-A,
- Axial and lateral movement testing based on the pump's physical differences from RCP Model 93A SDS as documented in subsections 3.2.3.9 and 3.2.3.10 of WCAP-17100-P-A, and

- Scratch testing to develop acceptance criteria for installation of the SDS on existing RCP shafts similar to that documented in subsection 3.2.3.12 of WCAP-17100-P-A.

While testing without failure was achieved for each SDS configuration as discussed above, for statistical analysis relative to endurance testing, only the Model 93A-1 Polymer Ring Endurance testing was credited as it represents the most challenging sealing condition amongst the pump models discussed within this WCAP.

3.2 SDS PERFORMANCE ASSESSMENTS AND TEST RESULTS

The test matrix shown in Table 3-1 was developed based on statistical analysis to support the qualification of the SDS and facilitate installation in RCP Models 93, 93A-1 and 100. Additionally, in response to the Fukushima Daiichi nuclear accident, this testing matrix included additional endurance testing of the RCP Model 93A SDS to 168 hours .

The test equipment for Test Series 2 through 18 is consistent with the testing set-ups as presented in WCAP-17100-P-A. A modified small static testing fixture was developed for endurance testing (Test Series 1) for the extended station blackout as described in subsection 3.2.2. The test results for RCP Models 93, 93A-1, and 100 are presented in this section.

The tests described by this document are intended to qualify the subject SDS designs by demonstrating the statistical reliability of the polymer ring of RCP Model 93, 93A, 93A-1 and 100 SDS designs, qualifying the leak rate of these SDS designs and acquiring data at various off-normal conditions such as those from differential thermal expansion. All testing was performed on a stationary sealing surface (shaft or shaft sleeve mockup). Methodology presented herein is consistent with that documented in WCAP-17100-P-A.

Table 3-1 below identifies the specific tests conducted and Table 3-2 identifies the acceptance criteria specified for each test. [

]^{a,b,c}

[

]^{a,b,c}

[

]^{a,b,c}

a,b,c

a,b,c

Figure 3-1: 93A O-Ring Endurance Testing Depressurization Over 7 Days

Table 3-1: SDS Testing Matrix for RCP Model 93, 93A, 93A-1 and 100

a,b,c

Test Series Number	SDS Model	Test Equipment	Test Condition	Test Duration (hours)[1]	Quantity of Tests[1]

Test matrix notes: a,b,c

[ ]

Table 3-2: SDS Testing Acceptance Criteria

a,b,c

Test Series	SDS Model	SDS Acceptance Criteria

3.2.1 Failure Modes and Effects Analysis

The Failure Modes and Effects Analysis (FMEA) detailed in Table 3-2 of WCAP-17100-P-A was used as a basis for determining the appropriate test plans and design requirements for the RCP Model 93A SDS as well as for RCP Model 93, 93A-1, and 100 SDS.

3.2.2 Test Equipment

The SDS designs for RCP Model 93, 93A-1, and 100 RCPs have been subjected to the same test equipment as the SDS design for the Model 93A RCP, described in WCAP-17100-P-A subsection 3.2.2 for Test Series 2 through 18 shown in Table 3-1 of this supplement. The endurance test fixture for Test Series 1, from Table 3-1, was developed for the extended endurance testing and is based on the small static test fixtures discussed in WCAP-17100-P-A. [

]^{a,b,c}

3.2.3 Test Results

3.2.3.1 Polymer Ring Endurance Test Results (Test Series Number 1):

This test methodology was performed consistent with the Sealing Endurance Tests in subsection 3.2.3.1 of WCAP-17100-P-A. However, the endurance tests performed in this supplement were extended to cover a 168 hour duration to meet the new post-Fukushima design specification. [

]^{a,b,c}

[

]^{a,b,c}

Table 3-3: Polymer Ring Endurance Test Results

a,b,c

TEST NUMBER	TEST START DATE	TEST END DATE	TEST DURATION (HRS)	FINAL TEST TEMPERATURE (°F)

3.2.3.2 93A Shaft Sleeve O-ring Endurance Testing / Secondary Seals (Test Series Number 2)

[

]^{a,b,c}

Subsection 3.2.2.1.1 in WCAP-17100-P-A discusses the test equipment used to qualify RCP Model 93A SDS and Section 3.2.4 in WCAP-17100-P-A discusses the results.

Utilizing the same test equipment, the O-ring endurance tests performed in this supplement were extended to cover a 168 hour duration to meet the new post-Fukushima design specification. [

]^{a,b,c}

Table 3-4: RCP Model 93A SDS, Secondary Sealing (O-ring) Endurance Testing Station Blackout Conditions

a,b,c

Test Number	Number of O-rings Tested per Test Fixture	Test Duration (Hours)	Test Temperature (°F)

3.2.3.3 Full Scale SDS Assembly Activation Testing (Test Series Number 3-18)

Upon completion of the endurance testing, which determined that the polymer ring is capable of creating a leak tight seal for 168 hour duration, further testing was conducted on the large static tester to demonstrate the reliability of the SDS to activate and seal. [

]^{a,b,c}

[

]^{a,b,c}

3.2.3.3.1 Full Scale Activation Tests Results

[

]^{a,b,c}

Table 3-5: RCP Model 93 SDS Large Static Tester Activation Test Results

a,b,c

Test Series[1]	Test Number	Test Type	Upper or Lower Bound Scenario	Activation Temperature (°F)	Test Date	Maximum Post Activation Leak Rate (gpm)

Table 3-6: RCP Model 93A-1 and 100 SDS Large Static Tester Activation Test Results

a,b,c

Test Series[1]	Test Number	Test Type	Upper or Lower Bound Scenario	Activation Temperature (°F)	Test Date	Maximum Post Activation Leak Rate (gpm)

[

] a,b,c

3.2.4 Summary of Testing Results

The ability of the SDS to meet the reliability goals has been demonstrated through testing and analysis of the SDS for all of the RCP models used in the USA. The reliability goals include:

- Passive activation at a No. 1 seal leak-off temperature of [ ]^{a,b,c} to ensure sufficient time for the operators to trip the RCP motors using existing procedures and guidance for the Model 93, 93A and 93A-1 RCPs and to ensure that a significant increase in RCS inventory loss through the RCP seals does not occur prior to activation of the SDS.
- Less than 1 gpm leakage following activation to eliminate the need for immediate manual operator actions to restore RCS makeup to meet regulatory requirements for fire scenarios (10 CFR 50.48) and station blackout scenarios (10 CFR 50.63) and future extended station blackout requirements in response to the post-Fukushima lessons learned.

The test data support a 95% reliability at a 95% confidence level for the SDS, as demonstrated through testing and analysis.

3.3 PRA MODEL

The PRA model documented in WCAP-17100-P-A was approved by the NRC for use in regulatory applications for plant units with Westinghouse RCP Model 93A pumps with the SDS installed in all pumps. The PRA model is supported by test data based on maintaining SBO conditions for 24 hours before performing a cooldown and depressurization of the RCS to conditions for which shutdown heat removal can be used for long term decay heat removal for the next 48 hours.

The test data documented in this supplement supports the removal of the limitation in the NRC SER related to the applicability of the results to the Model 93, 93A-1, and 100 RCPs. The Model 93, 93A, 93A-1 and 100 RCPs represent all of the domestic Westinghouse RCP pump models currently in operation. In addition to the four basic RCP model designations, Westinghouse RCPs can carry an additional identifier to designate differences in some design aspects. An "S" designation refers to the presence of a spool piece between the reactor pump and the motor that facilitates RCP seal inspection and replacement. In pumps with a spool piece, the RCP motor does not have to be lifted from the pump in order to remove the RCP seal package. The seal package is identical for pumps with or without the spool piece. A "CS" designation refers to a cartridge type No. 2 and No. 3 RCP seal. The No. 2 and No. 3 Seals are slightly different in design to allow for easier replacement as an assembly, as opposed to individual components. The remainder of the seal package is identical for pumps with or without the cartridge seal design. The test data documented in this supplement also support the extension of the PRA model to other plant conditions:

- The ability of the SDS to limit RCP seal leakage to very small values for 168 hours (7 days) for all domestic RCP models.
- The ability of the SDS to limit RCP seal leakage to very small values irrespective of the timing of operator actions related to inducing RCS pressure and temperature transients (i.e., testing was done for upper and lower bound RCS pressure and temperature transients).

Because of the close similarity of the SDS for RCP Model 93, 93A-1 and 100 RCPs to the SDS Model 93A RCP, no additional failure modes and effects have been identified. Furthermore, all of the failure modes and effects for the SDS for RCP Model 93A RCP have been determined to be applicable to these additional pump models.

The testing documented in this report supports the conclusion that the PRA model for the SDS should be identical for all domestic Westinghouse RCP models. The PRA model presented in WCAP-17100-P-A is therefore applicable to the SDS when it is installed in all RCPs for Westinghouse RCP Model 93, 93A, 93A-1 and 100. Based on the testing at both upper and lower bounds of RCS conditions, it is further concluded that the PRA model can be applied irrespective of operator actions for RCS cooldown and depressurization, including no operator actions, for up to 168 hours.

[

]^{a,b,c}

This individual failure rate represents simultaneous failure of all RCPs with an SDS installed. Although conservative, this individual failure rate inherently includes common cause failure of the SDS.

3.4 DETERMINISTIC MODEL

The deterministic model documented in WCAP-17100-P-A was approved by the NRC for use in regulatory applications for plant units with Westinghouse RCP Model 93A pumps with the SDS installed in all pumps. The deterministic model is supported by test data based on maintaining SBO conditions for 24 hours before performing a cooldown and depressurization of the RCS to conditions for which shutdown heat removal can be used for long term decay heat removal for the next 48 hours. Thus, the deterministic model is suitable for development and assessment of coping strategies to show compliance with the station blackout and fire protection requirements in Part 50.48 and 50.63 of Title 10 of the Code of Federal Regulations.

The test data documented in this supplement supports the removal of the limitation in the NRC SER related to the applicability of the results to the Model 93, 93A-1, and 100 RCPs. For non-SBO events, this is contingent on modeling of operator actions to trip the RCPs within the allowable time presented in Table 1-1 of this report for each pump model. [

]^{a,b,c}

Therefore, it is concluded that the deterministic model for the SDS should be identical for all domestic Westinghouse RCP models. The deterministic model presented in WCAP-17100-P-A is applicable to the SDS when it is installed in all RCPs for RCP Model 93, 93A, 93A-1 and 100 Westinghouse RCPs. Based on the testing at both upper and lower bounds of RCS conditions, it is further concluded that the deterministic model can be applied irrespective of operator actions for RCS cooldown and depressurization, including no operator actions, for up to 168 hours.

4 LIMITATIONS AND CONDITIONS FOR ACCEPTANCE

4.1 LIMITATIONS

The limitations for the acceptance of the SDS deterministic and PRA models described in WCAP-17100-P-A and this supplement are:

- The SDS is installed in all RCPs in the plant for Westinghouse RCP Model 93, 93A, 93A-1 and 100.
- Review of the applicable operating procedures to confirm that:
  - Operator guidance is provided to promptly trip the RCPs on the loss of all RCP seal cooling.
  - Control room readouts and alarms for loss of all RCP seal cooling are consistent with the assumptions in the PRA model for operator actions.
  - The oil lift pumps are not used in the response to a loss of all seal cooling events.
- The control room readouts and alarms for loss of RCP seal cooling are functionally tested and calibrated.
- The operator actions for tripping an RCP in the event of a loss of all RCP seal cooling for a non-SBO event are consistent with assuring a slowly rotating pump at the time of SDS actuation (e.g., the time provided in Table 1-1 of this report).
- For installation of the SDS on RCPs where the SDS seals directly on the RCP shaft, the shaft will be examined for scratches; any scratch in excess of the acceptance criteria (Section 4.2 of this report) will be evaluated for acceptability prior to installing the SDS.
- Operation of the SDS is within the qualified 9-year service life.

4.2 SDS INSTALLATION ACCEPTANCE CRITERIA

This section describes the acceptance criteria that will be used for the installation of the SDS in RCP Model 93, 93A-1 and 100 Westinghouse RCPs. Because the SDS seals against the shaft for these RCP models, acceptance criteria are required to ensure that the SDS performance meets the functional requirements for leakage and duration for: 1) shaft scratches and flaws, and 2) shaft diameter. The acceptance criteria to be used by Westinghouse for installation of the SDS are discussed in the following paragraphs.

4.2.1 Scratches and Flaws

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a,b,c

Table 4-1: RCP Model 93, 93A-1 and 100 Scratch / Flaw Test Results Summary

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Test Series[1]	Test Number	Shaft Flaw Dimension Width x Depth (inches)	Maximum Post Activation Leak Rate (gpm)

a,b,c

5 FARLEY POST-OPERATIONAL SHIELD SEAL

Westinghouse and Southern Nuclear Operating Company (SNC) partnered to successfully install the first-of-its-kind SHIELD passive thermal shutdown seal in a pilot installation in each Model 93A RCP at the Joseph M. Farley Nuclear Power Plant (Unit 1) near Dothan, Alabama during the plant's October 2010 refueling outage. To confirm the effectiveness of the design, it was agreed to later remove a SHIELD seal for post-operating testing.

A SHIELD seal was removed from one RCP at Farley in April 2012 after one cycle of operation, for post-operating testing. [

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6 SUMMARY AND CONCLUSIONS

The SDS for all domestic Westinghouse RCPs has been thoroughly tested to ensure a high reliability and confidence level that it will restrict RCS inventory losses to very small leakage rates during a plant event that results in the loss of all RCP seal cooling. The SDS that was approved for use on RCP 93A Models can be applied to RCP 93, 93A-1, and 100 Models, because testing has shown the reliability to be consistent with the testing for RCP Model 93A that was documented in WCAP-17100-P-A.

The PRA model for the SDS when installed in any domestic Westinghouse RCP model (RCP Model 93, 93A, 93A-1 and 100) should be the one which was documented and approved by the NRC in WCAP-17100-P-A for the Model 93A RCP. [.]^{a,b,c} This failure rate should be conservatively assumed for the simultaneous failure of the SDS in all pumps in the plant. The low leakage characteristics of the SDS (i.e., less than 1 gpm at nominal RCS hot standby conditions) can be directly modeled for SBO events because the RCP will be stopped or slowly rotating at the time of SDS actuation. For non-SBO events, the low leakage characteristics of the SDS are dependent on successful operator action to trip the RCP within a time window as described in this report. However, an assumed failure to trip the RCP will only result in an RCS leakage rate of 19 gpm per pump (at nominal RCS hot standby conditions) if the SDS has actuated.

The deterministic model for the SDS when installed in any domestic Westinghouse RCP model (RCP Model 93, 93A, 93A-1 and 100) should be the one which was documented and approved by the NRC in WCAP-17100-P-A for the Model 93A RCP. The deterministic model for the SDS when installed in all RCPs in the plant is based on a 95% reliability at a 95% confidence level as supported by the test data documented in this report. The low leakage characteristics of the SDS (i.e., less than 1 gpm at nominal RCS hot standby conditions) can be directly modeled for SBO events because the RCP will be stopped or slowly rotating at the time of SDS actuation. For non-SBO events, the low leakage characteristics of the SDS are dependent on successful operator action to trip the RCP within a time window as described in this report. However, an assumed failure to trip the RCP will only result in an RCS leakage rate of 19 gpm per pump (at nominal RCS hot standby conditions) if the SDS has actuated.

Both the deterministic and the PRA models for the SDS are applicable to a time period of up to 168 hours at nominal hot standby conditions and are independent of any operator actions for RCS cooldown and depressurization or operator actions for restoration of RCP seal injection.

7 REFERENCES

1. WCAP-17100-P-A, Revision 1, "PRA Model for the Westinghouse Shut Down Seal," Robert J. Lutz, Jr., Judy Hodgson, Bruce Howard, August 30, 2011.

2. WCAP-15603, Revision 1-A, "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs," Westinghouse Electric Company, June 2003.

3. WCAP-16396, Revision 0, "Westinghouse Owners Group Reactor Coolant Pump Seal Performance for Appendix R Assessments," Westinghouse Electric Company, January 2005.

4. NRC Information Notice 2005-14, "Fire Protection Findings on Loss of Seal Cooling to Westinghouse Reactor Coolant Pumps," Nuclear Regulatory Commission, June 2005.

APPENDIX A FARLEY POST OPERATIONAL SHIELD SEAL TEST

A.1 BACKGROUND INFORMATION

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A.2 FARLEY SEAL TESTING AND INSPECTION

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a,b,c

a,b,c

Figure A-1 (Page 1 of 3): SHIELD Seal Fault Tree Analysis

a,b,c

Figure A-1 (Page 2 of 3): SHIELD Seal Fault Tree Analysis

a,b,c

Figure A-1 (Page 3 of 3): SHIELD Seal Fault Tree Analysis

Table A-1 Evidence Matrix

a,b,c

#	Scenario	Supporting Evidence	Refuting or Contributing Evidence	Conclusion

Table A-1 Evidence Matrix

a,b,c

#	Scenario	Supporting Evidence	Refuting or Contributing Evidence	Conclusion

Table A-1 Evidence Matrix				
#	Scenario	Supporting Evidence	Refuting or Contributing Evidence	Conclusion

a,b,c

Table A-1 Evidence Matrix

a,b,c

#	Scenario	Supporting Evidence	Refuting or Contributing Evidence	Conclusion

Table A-1 Evidence Matrix

#	Scenario	Supporting Evidence	Refuting or Contributing Evidence	Conclusion

a,b,c

Table A-2: Post-Operation Testing Matrix

a,b,c

#	Test Name	Purpose	Test Description	Conclusions/Observations

Table A-2: Post-Operation Testing Matrix

a,b,c

#	Test Name	Purpose	Test Description	Conclusions/Observations

Table A-2: Post-Operation Testing Matrix

a,b,c

#	Test Name	Purpose	Test Description	Conclusions/Observations
11				
12				
13				
14				
15				

Table A-2: Post-Operation Testing Matrix				
#	Test Name	Purpose	Test Description	Conclusions/Observations

a,b,c

Table A-2: Post-Operation Testing Matrix

a,b,c

#	Test Name	Purpose	Test Description	Conclusions/Observations

A.3 FARLEY SEAL TESTING AND INSPECTION CONCLUSIONS

a,b,c

A.3.1 Thermal Actuator Operated as Designed

a,b,c

A.3.2 Corrosion Products at the Interface Between the Spacer and Piston Ring Ends

a,b,c

a,b,c

a,b,c

A.3.3 Yielding of the Retracting Actuator Raceway Corner

a,b,c

a,b,c

A.3.4 Non-Symmetric Loading From the Spring

a,b,c

A.4 DESIGN ENHANCEMENTS

a,b,c

Table A-3: Design enhancements

Issue	Design Enhancement

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a,b,c

A.4.1 Testing and Qualification of Design Enhancements

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a,b,c

A.4.2 Spacer Pull Tests

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a,b,c

Figure A-2 Pull Test Results for Enhanced Design

A.4.3 Precipitation of Contaminants into the Piston Ring-to-Spacer Interface

a,b,c

A.4.4 Oven Tests

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Table A-4: Oven Test Results for Enhanced Retracting Actuator

a,b,c

Actuator S/N	Mean Activation Temperature (°F)	Standard Deviation (°F)	Actuator S/N	Mean Activation Temperature (°F)	Standard Deviation (°F)

A.4.5 Cam Removal Force Test

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a,b,c

[ ]

Figure A-3 Cam Removal Force Test

A.4.6 Retracting Actuator End-of-cycle Boric Acid Chemistry Soak / Activation Test

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Table A-5: End of Cycle Boric Acid Test Activation Temperatures

a,b,c

Actuator S/N	2500ppb Soak Duration (hours)	Weight (Dry) (grams)	Weight (grams) after 30 hours drying at 155°F	Delta	Actuation Temperature (°F)

A.4.7 Retracting Actuator Activation Test

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a,b,c

Figure A-4: Actuation Temperatures For The Enhanced And Previous Actuator For 50 Activation Tests

A.4.8 Sectioning of Retracting Actuator after Completion of 50 Activation Tests

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A.4.9 Testing in the Static Tester

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Table A-6: Static Activation Tests of Enhanced Design

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Full Scale Static Tester Tests Datasheet				
Test	RA Serial Number	Piston Ring S/N:	Actuation Temperature (°F)	Maximum Leak Rate (gpm)

A.4.10 Summary of Tests Performed on Enhanced Design

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A.5 CONCLUSIONS

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a,b,c