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August 27, 2018

United States Nuclear Regulatory Commission
Regional Administrator – Region II
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Serial No.: 18-309
NRA/GDM
Docket No.: 50-280
License No.: DPR-32

VIRGINIA ELECTRIC AND POWER COMPANY (DOMINION ENERGY VIRGINIA)
SURRY POWER STATION UNIT 1
CYCLE 29 STARTUP PHYSICS TESTS REPORT

As required by Surry Power Station (Surry) Technical Specification 6.6.A.1, enclosed is the Surry Unit 1 Cycle 29 Startup Physics Tests Report. The report summarizes the results of the physics testing program performed prior to and following initial criticality of Cycle 29 on May 30, 2018. The results of the physics tests were within the applicable Technical Specifications limits.

If you have any questions or require additional information, please contact Mr. Gary Miller at (804) 273-2771.

Sincerely,

B. L. Stanley, Director
Nuclear Regulatory Affairs
Dominion Energy Services, Inc. for
Virginia Electric and Power Company

Enclosure: Surry Unit 1 Cycle 29 Startup Physics Tests Report

Commitments made in this letter: None

IE26
NRR

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Surry Power Station

Serial No. 18-309
Docket No. 50-280

Enclosure

SURRY UNIT 1 CYCLE 29
STARTUP PHYSICS TESTS REPORT

August 2018

Virginia Electric and Power Company
(Dominion Energy Virginia)
Surry Power Station Unit 1

CLASSIFICATION/DISCLAIMER

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

This report presents the analysis and evaluation of the physics tests that were performed to verify that the Surry Unit 1 Cycle 29 core could be operated safely and makes an initial evaluation of the performance of the core. This report was performed in accordance with DNES-AA-NAF-NCD-5007, Rev. 3 [Ref. 17]. It is not the intent of this report to discuss the particular methods of testing or to present the detailed data taken. Standard testing techniques and methods of data analysis were used. The test data, results, and evaluations, together with the detailed startup procedures, are on file at Surry Power Station. Therefore, only a cursory discussion of these items is included in this report. The analyses presented include a brief summary of each test, a comparison of the test results with design predictions, and an evaluation of the results.

The Surry Unit 1 Cycle 29 startup physics tests results and evaluation sheets are included in Appendix B to provide additional information on the startup test results. Each data sheet provides the following information: 1) test identification, 2) test results, 3) acceptance criteria and whether they were met (if applicable), 4) date and time of the test, and 5) preparer/ reviewer initials. These sheets provide a compact summary of the startup test results in a consistent format. The entries for the design values were based on calculations performed by Dominion Energy Virginia's Nuclear Engineering and Fuel Group. The acceptance criteria are based on design tolerances or applicable Technical Specifications (TS) and Core Operating Limits Report (COLR) limits.

SECTION 1 — INTRODUCTION AND SUMMARY

On April 21, 2018, Unit No. 1 of Surry Power Station completed Cycle 28 and began refueling [Ref. 1]. During this refueling, 65 of the 157 fuel assemblies in the core were replaced with fresh Batch S1/31A, S1/31B and S2/30B assemblies [Ref. 8]. The Surry 1 Cycle 29 (S1C29) core consists of 8 sub-batches of fuel: three fresh batches (S1/31A, S1/31B and S2/30B), three once-burned batches (S1/30A, S1/30B and S1/30C), and two twice-burned batches (S1/29C and S2/28B). S1C29 utilizes the 15x15 Upgrade (Upgrade) Fuel Design for all but 8 of the fuel assemblies (which make up batch S1/30C). The remaining 8 assemblies are Lead Test Assemblies (LTAs) of the AREVA AGORA-5A-I (AGORA) design that are being loaded for their second cycle of irradiation [Ref. 1].

Fuel batches S1/29C, S1/30A, S1/30B, S1/31A, S1/31B, S2/28B and S2/30B are of the Westinghouse Upgrade fuel design which includes ZIRLO (I-spring) structural mid grids with balanced mixing vane pattern, three ZIRLO Intermediate Flow Mixing (IFM) grids, "tube-in-tube" guide thimbles, the use of optimized ZIRLO fuel clad that improves corrosion resistance and oxidation of the bottom portion of the fuel clad to improve debris resistance, Robust Protective Grids (RPG), and modified Debris Filter Bottom Nozzles (mDFBN). In addition, except for S2/28B, these batches of the Upgrade fuel design utilize the Westinghouse Integral Nozzle (WIN) top nozzle design [Ref. 8].

The fresh Upgrade fuel uses Westinghouse's Integral Fuel Burnable Absorber (IFBA) product as the burnable absorber. The IFBA design involves the application of a thin coating of ZrB_2 on the fuel pellet surface during fabrication. Pellets with the IFBA coating are placed in specific symmetric patterns in each fresh assembly, typically affecting from 16 to 148 rods per assembly. The top and bottom 6 inches of the fuel pellet stack in the IFBA rods will contain pellets that have no IFBA coating, and have a hole in the center (annular). This additional void space helps accommodate the helium gas that accumulates from neutron absorption in ZrB_2. IFBA rods generate more internal gas during operation because neutron absorption in the ZrB_2 coating creates helium gas in addition to the fission gas created during irradiation of the fuel. Therefore, the initial pressure is set lower so the internal pressure early in lifetime may be lower [Ref. 5].

Surry 1 batch 30C is of the AREVA AGORA fuel design. The top grids of the assemblies are a High Thermal Performance (HTP) design fabricated from M5 material. The mid-grids are AFA-3G vaned mixing grids, which are bimetallic grids utilizing M5 strips and Inconel 718 springs. The mid-span mixing grids (MSMG) are M5 vaned mixing grids placed on spans 3 through 5 on the assembly. The MSMG are similar to the IFM grids used in the other batches of this cycle and are located at approximately the same elevations as the IFMs. The bottom grid is an Inconel 718 HMP (High Mechanical Performance) grid. The fuel rod cladding is composed of M5 material and the guide tubes and instrument tubes are composed of Q12 (zirconium alloy) and are of the MONOBLOC design [Ref. 1].

The AREVA AGORA LTAs utilize gadolinia (Gd_2O_3) as a burnable poison integral to the fuel. Each LTA contains 28 gadolinia rods, 12 at 12% and 16 at 6%, with 6 inch cutback regions at the top and bottom of the fuel. The cutback regions are the same enrichment as non-gadolinia rods. The gadolinia rods are subject to the 5:1 enrichment penalty (5% reduction in U-235 for each weight percent of gadolinia) from the nominal enrichment.

Cycle 29 loads Secondary Source Assemblies (SSAs) in core locations H04 and H12 to improve Source Range Detector response. Each assembly consists of six source rods containing antimony and beryllium pellets encapsulated in a double layer of stainless steel cladding. There are no thimble-plugging devices in S1C29. The cycle design report [Ref. 1] provides a more detailed description of the Cycle 29 core.

The S1C29 full core loading plan [Ref. 8 and Ref. 11] is given in Figure 1.1, and the beginning of cycle fuel assembly burnups [Ref. 6] are given in Figure 1.2. The incore moveable detector locations used for the flux map analyses [Ref. 7] are identified in Figure 1.3. Figure 1.4 identifies the location and number of control rods in the Cycle 29 core [Ref. 1].

According to the Startup Physics logs, the Cycle 29 core achieved initial criticality on May 30, 2018 at 06:48 [Ref. 14]. Prior to and following criticality, startup physics tests were performed as outlined in Table 1.1. This cycle used the Reactivity Measurement and Analysis System (RMAS) to perform startup physics testing. Note that RMAS v.7 [Ref. 9] was used for

S1C29 Startup Physics Testing. The tests performed are the same as in previous cycles. A summary of the test results follows.

The measured drop time of each control rod was within the 2.40 second Technical Specification [Ref. 4] limit, as well as the 1.68 second 15x15 Upgrade Fuel administrative limit [Ref. 10]. Control rod banks SA, SB, A, C, and D are located in Upgrade fuel assemblies. Control rod bank B rods are located in the eight AGORA assemblies.

Individual control rod bank worths were measured using the rod swap technique [Ref. 2]. For the purpose of this test, a bank was defined as 'fully inserted' when it was 2 steps off the bottom of the core [Ref. 13]. The sum of the individual measured control rod bank worths was 1.8% lower than the design prediction. The reference bank (Control Bank B) worth was 1.1% lower than its design prediction. Control rod banks with design predictions greater than 600 pcm were within ±3.0% of the design predictions. For individual banks worth 600 pcm or less (only Control Bank A fits this category), the difference was 7.7 pcm above the design prediction. These results are within the design tolerances of ±15% for individual banks worth more than 600 pcm (±10% for the reference bank worth), ±100 pcm for individual banks worth 600 pcm or less, and ±10% for the sum of the individual control rod bank worths.

Measured critical boron concentrations for two control bank configurations, all rods out (ARO) and Reference Bank (B-bank) in, were within the design tolerances and the Technical Specification criterion [Ref. 4] that the overall core reactivity balance shall be within ±1% Δk/k of the design prediction. The boron worth coefficient measurement (the differential boron worth, DBW) was 1.2% lower than the design prediction, which is within the design tolerance of ±10%.

The measured isothermal temperature coefficient (ITC) for the all-rods-out (ARO) configuration was 0.190 pcm/°F lower than the design prediction. This result is within the design tolerance of ±2.0 pcm/°F [Ref. 14].

The zero power physics testing results met the criteria established in reference 18 permitting the first flux map to be performed up to 50% power (versus 30% power if the criteria were not met).

Core power distributions were within established design tolerances. The measured assembly power distributions were within the design tolerance of $\pm 15\%$ for assemblies with power <0.9 and $\pm 10\%$ for assemblies with power ≥ 0.9. A 6.7% maximum difference occurred in the 27.15% power map. The heat flux hot channel factors, $F_Q(Z)$, and enthalpy rise hot channel factors, $F^N_{\Delta H}$, were within the limits of the COLR [Ref. 8]. All power flux maps were within the maximum incore power tilt design tolerance of 2% (QPTR $\leq$ 1.02).

The Reactor Coolant Pump (RCP) start sequence is as follows: 'B' RCP started on 5/21 at 05:43, 'C' RCP started on 5/22 at 20:50, 'B' RCP stopped on 5/22 at 21:32, 'B' RCP started on 5/27 at 02:23 and 'A' RCP started on 5/27 at 21:36 [Appendix A].

The total RCS Flow was successfully verified as being greater than 273,000 gpm and greater than the limit in the COLR (274,000 gpm), as required by Surry Technical Specifications [Ref. 4]. The total RCS Flow at nominal conditions was measured as 289,496 gpm.

In summary, all startup physics test results were acceptable. Detailed results, specific design tolerances, and acceptance criteria for each measurement are presented in the following sections of this report.

Table 1.1

SURRY UNIT 1 – CYCLE 29
CHRONOLOGY OF TESTS

Test	Date	Time	Power	Reference Procedure
Hot Rod Drop-Hot Full Flow	05/29/18	10:03	HSD	1-NPT-RX-014
Reactivity Computer Checkout	05/30/18	09:49	HZP	1-NPT-RX-008
Boron Endpoint – ARO	05/30/18	09:49	HZP	1-NPT-RX-008
Zero Power Testing Range	05/30/18	09:53	HZP	1-NPT-RX-008
Boron Worth Coefficient	05/30/18	13:18	HZP	1-NPT-RX-008
Temperature Coefficient – ARO	05/30/18	10:12	HZP	1-NPT-RX-008
Bank B Worth	05/30/18	11:45	HZP	1-NPT-RX-008
Boron Endpoint – B in	05/30/18	13:18	HZP	1-NPT-RX-008
Bank A Worth – Rod Swap	05/30/18	13:17	HZP	1-NPT-RX-008
Bank C Worth – Rod Swap	05/30/18	13:17	HZP	1-NPT-RX-008
Bank SA Worth – Rod Swap	05/30/18	13:17	HZP	1-NPT-RX-008
Bank D Worth – Rod Swap	05/30/18	13:17	HZP	1-NPT-RX-008
Bank SB Worth – Rod Swap	05/30/18	13:17	HZP	1-NPT-RX-008
Total Rod Worth	05/30/18	13:17	HZP	1-NPT-RX-008
Flux Map – less than 50% Power* Peaking Factor Verification & Power Range Calibration	05/31/18	10:00	27.15%	1-NPT-RX-002 1-NPT-RX-008 1-NPT-RX-005 1-GEP-RX-001
Flux Map – 65% - 75% Power Peaking Factor Verification & Power Range Calibration	06/01/18	03:35	70.52%	1-NPT-RX-002 1-NPT-RX-008 1-NPT-RX-005 1-GEP-RX-001
Flux Map – 95% - 100% Power Peaking Factor Verification & Power Range Calibration	06/06/18	13:00	99.87%	1-NPT-RX-002 1-NPT-RX-008 1-NPT-RX-005 1-GEP-RX-001
RCS Flow Measurement	06/04/18	06:30	HFP	1-NPT-RX-009

* Results of zero power physics testing required the first flux map to be performed up to 50% power (versus 30% power if specified criteria were not met).

Figure 1.1

SURRY UNIT 1 – CYCLE 29 CORE LOADING MAP

SURRY UNIT 1 - CYCLE 29
FULL CORE LOADING PLAN
REVISION NO. 0

ETE-NAF-2017-0126 REV. 0
ATTACHMENT 1
PAGE 1 of 1

VEP-NES-NAF

NORTH ↑

	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R
15							351	630	357						
14					638	RCC 412	541	RCC 549	548	RCC 405	635				
13				343	537	563	RCC 505	464	RCC 501	560	535	344			
12			345	RCC 551	507	RCC AG8	430	SS11 447	425	RCC AG4	512	RCC 554	348		
11		643	534	513	RCC 404	440	517	451	522	436	RCC 401	502	540	639	
10		RCC 406	564	RCC AG3	435	RCC 529	459	RCC 530	456	RCC 531	438	RCC AG2	557	RCC 411	
9	356	546	RCC 504	424	518	458	RCC 427	442	RCC 428	457	520	421	RCC 514	543	353
8 (270°)	633	RCC 550	462	444	450	RCC 532	443	858	441	RCC 525	445	448	463	RCC 553	644
7	354	542	RCC 506	431	521	453	RCC 423	449	RCC 432	454	519	429	RCC 503	544	355
6		RCC 407	561	RCC AG6	434	RCC 526	460	RCC 527	455	RCC 528	437	RCC AG5	562	RCC 409	
5		636	536	515	RCC 402	433	524	452	523	439	RCC 403	511	538	642	
4			349	RCC 556	510	RCC AG1	426	SS10 446	422	RCC AG7	508	RCC 555	347		
3				346	539	559	RCC 509	461	RCC 516	558	533	342			
2					640	RCC 408	547	RCC 552	545	RCC 410	631				
1							352	637	350						

180°

INCORE DEVICE DESCRIPTIONS:
RCC- FULL LENGTH CONTROL ROD
SSXX - SECONDARY SOURCE ASSEMBLY

Prepared By: D. G. Livingston Date: 10/24/17
Reviewed By: S.B. Rosenfelder Date: 10/24/17
Approved By: A.H. Nicholson Date: 10/25/17
Concurrence By: Brad Williamson Date: 10/25/17
Approved By: M LAPRADE Date: 10/25/17

Figure 1.2

SURRY UNIT 1 – CYCLE 29
BEGINNING OF CYCLE FUEL ASSEMBLY BURNUPS (GWD/MTU)

MEASURED
PREDICTED

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1							40.79	40.44	40.22							1
							40.49	40.46	40.45							
2					40.97	24.64	0.00	0.00	0.00	24.47	40.70					2
					40.77	24.55	0.00	0.00	0.00	24.55	40.84					
3				31.92	0.00	0.00	0.00	24.83	0.00	0.00	0.00	32.17				3
				31.88	0.00	0.00	0.00	25.03	0.00	0.00	0.00	31.88				
4			31.89	0.00	0.00	21.47	19.89	20.90	20.12	21.74	0.00	0.00	32.20			4
			31.89	0.00	0.00	21.74	19.88	20.86	19.86	21.74	0.00	0.00	31.90			
5		40.87	0.00	0.00	23.76	19.91	0.00	24.15	0.00	20.07	24.06	0.00	0.00	40.88		5
		40.86	0.00	0.00	23.96	19.89	0.00	24.01	0.00	19.92	23.96	0.00	0.00	40.81		
6		24.34	0.00	21.84	20.18	0.00	24.36	0.00	24.41	0.00	19.82	21.93	0.00	24.65		6
		24.51	0.00	21.79	19.91	0.00	24.47	0.00	24.46	0.00	19.87	21.78	0.00	24.51		
7	40.36	0.00	0.00	20.11	0.00	24.65	20.54	23.79	20.47	24.45	0.00	19.84	0.00	0.00	40.69	7
	40.48	0.00	0.00	19.89	0.00	24.45	20.41	24.02	20.41	24.45	0.00	19.90	0.00	0.00	40.52	
8	40.33	0.00	24.88	21.02	24.06	0.00	23.94	0.00	24.43	0.00	23.92	20.93	24.94	0.00	40.29	8
	40.36	0.00	25.03	20.89	24.02	0.00	24.01	0.00	24.01	0.00	24.02	20.89	25.03	0.00	40.39	
9	40.76	0.00	0.00	19.76	0.00	24.42	20.48	23.89	20.34	24.95	0.00	19.80	0.00	0.00	40.31	9
	40.52	0.00	0.00	19.90	0.00	24.45	20.41	24.02	20.41	24.45	0.00	19.89	0.00	0.00	40.48	
10		24.55	0.00	22.20	19.68	0.00	24.58	0.00	24.42	0.00	19.86	21.84	0.00	24.28		10
		24.51	0.00	21.78	19.87	0.00	24.46	0.00	24.47	0.00	19.91	21.79	0.00	24.51		
11		40.91	0.00	0.00	24.29	20.00	0.00	24.51	0.00	19.86	23.90	0.00	0.00	40.68		11
		40.78	0.00	0.00	23.96	19.92	0.00	24.01	0.00	19.89	23.96	0.00	0.00	40.85		
12			31.89	0.00	0.00	21.65	20.07	20.68	20.09	21.50	0.00	0.00	31.82			12
			31.90	0.00	0.00	21.75	19.86	20.87	19.88	21.74	0.00	0.00	31.89			
13				31.77	0.00	0.00	0.00	24.92	0.00	0.00	0.00	31.87				13
				31.88	0.00	0.00	0.00	25.03	0.00	0.00	0.00	31.88				
14					40.72	24.53	0.00	0.00	0.00	24.78	40.91					14
					40.83	24.55	0.00	0.00	0.00	24.55	40.77					
15							40.24	40.50	40.35							15
							40.45	40.43	40.49							

Figure 1.3

SURRY UNIT 1 – CYCLE 29
AVAILABLE INCORE MOVEABLE DETECTOR LOCATIONS

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1								MD							
2										MD					
3				MD			MD	MD				MD			
4					+ MD			MD		MD					
5			MD		MD		MD				MD	MD		MD	
6					MD			MD		MD					
7			MD				MD		MD			+ MD		+ MD	
8	MD		MD		MD					MD			MD	MD	
9					MD				MD	MD					MD
10			MD				MD					MD		MD	
11					MD			MD		MD	MD				
12			MD				MD					MD	MD		
13								+ MD		MD					
14					MD				MD						
15							MD								

MD - Moveable Detector
\+ - Locations Not Used For Any Map

Figure 1.4

SURRY UNIT 1 – CYCLE 29
CONTROL ROD LOCATIONS

180°

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
																1
						A		D		A						2
							SA		SA							3
				C		B				B		C				4
					SB						SB					5
		A		B		D		C		D		B		A		6
			SA				SB		SB				SA			7
90°		D				C				C				D		8 (270°)
			SA				SB		SB				SA			9
		A		B		D		C		D		B		A		10
					SB						SB					11
				C		B				B		C				12
							SA		SA							13
						A		D		A						14
																15

0°

D = Control Bank D
C = Control Bank C
B = Control Bank B
A = Control Bank A

SB = Shutdown Bank SB
SA = Shutdown Bank SA

SECTION 2 — CONTROL ROD DROP TIME MEASUREMENTS

The drop time of each control rod was measured at hot shutdown (HSD) with three reactor coolant pumps in operation (full flow) and with T_{ave} greater than or equal to 530 °F per 1-NPT-RX-014. This verified the time to entry of a rod into the dashpot region was less than or equal to the maximum allowed by Technical Specification 3.12.C.1 [Ref. 4].

Surry Unit 1 Cycle 29 used the Rod Drop Measurement Instrument (RDMI) to gather and analyze the rod drop data [Ref. 12]. The methodology acquires data using the secondary RPI coil terminals (/3 & /4) on the Computer Enhanced Rod Position Indication (CERPI) racks for each rod. Data is immediately saved to a comma-separated value file.

A typical rod drop trace for S1C29 is shown in Figure 2.1. The measured drop time for each control rod is recorded on Figure 2.2. The slowest, fastest and average drop times are summarized in Table 2.1. Figure 2.3 shows slowest, fastest, and average drop times for Surry 1 Cycles 18-29. Technical Specification 3.12.C.1 [Ref. 4] specifies a maximum rod drop time to dashpot entry of 2.4 seconds for all rods. Note that AREVA AGORA fuel assemblies are loaded in Control Bank B. These test results satisfied this Technical Specification limit as well as the Westinghouse 15x15 Upgrade administrative limit [Ref. 10] of 1.68 seconds. In addition, rod bounce was observed at the end of each trace demonstrating that no control rod stuck in the dashpot region. Compared to the rod drop results from S1C28, the fastest rod drop time decreased by 0.02 seconds, the average rod drop time decreased by 0.01 seconds, and the slowest rod time decreased by 0.01 seconds.

Table 2.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
HOT ROD DROP TIME SUMMARY

ROD DROP TIME TO DASHPOT ENTRY

SLOWEST ROD	FASTEST ROD	AVERAGE TIME
B-06 1.45 sec.	K-04, K-12 1.29 sec	1.35 sec.

Figure 2.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
TYPICAL ROD DROP TRACE

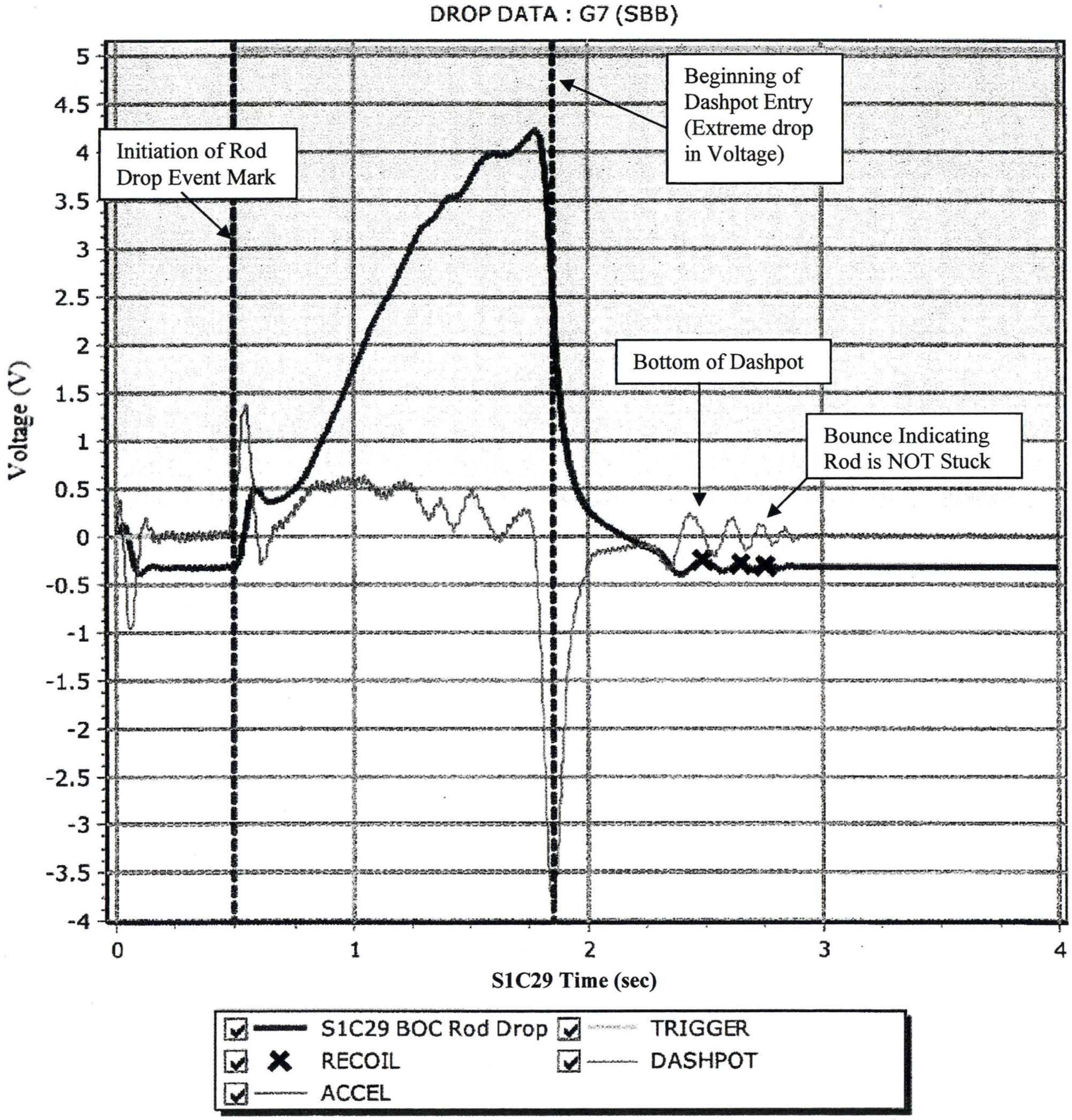


Figure 2.2

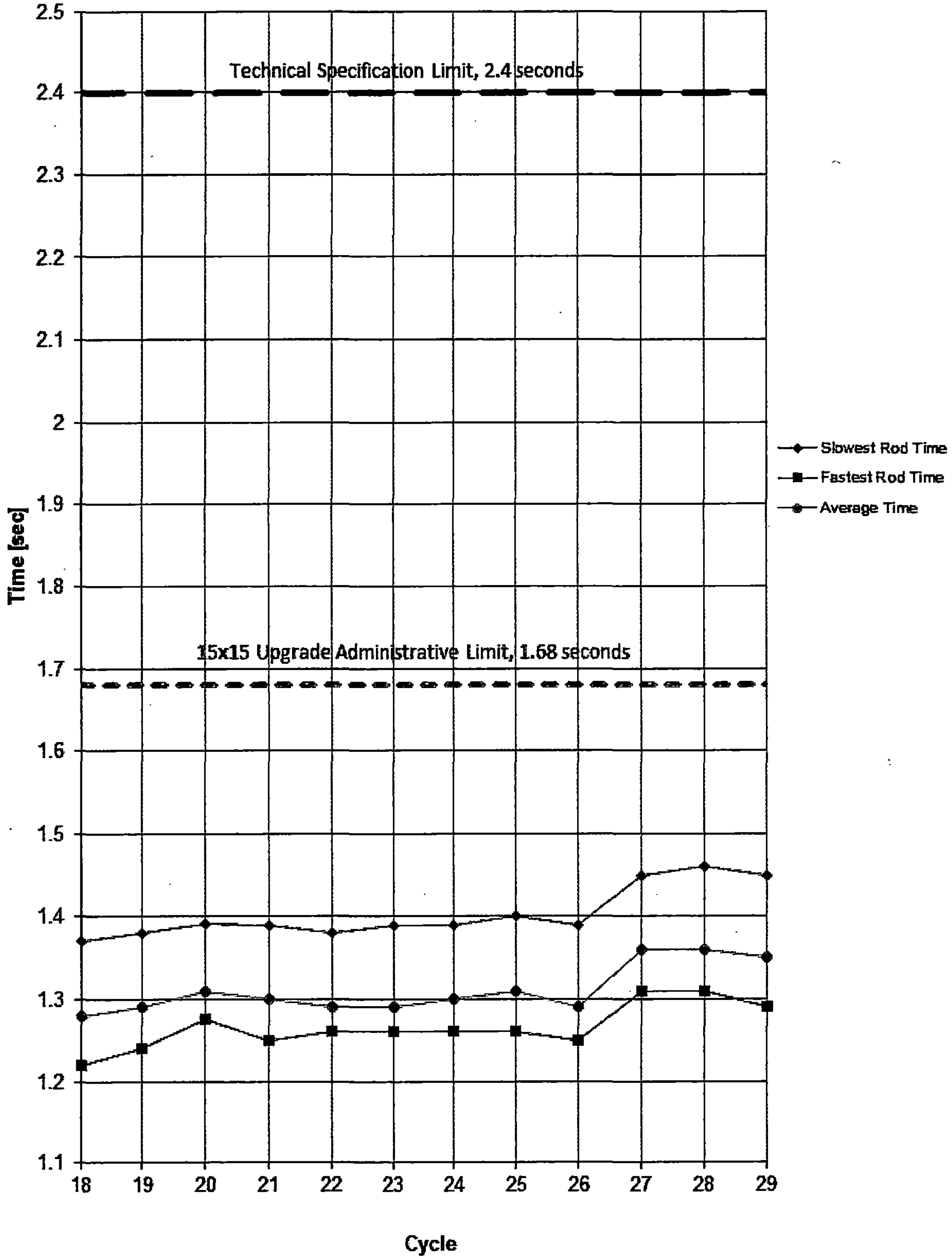
SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
ROD DROP TIME – HOT FULL FLOW CONDITIONS

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
															1
					1.36		1.33		1.34						2
						1.35		1.36							3
			1.35		1.29				1.31		1.39				4
				1.35						1.36					5
	1.34		1.30		1.34		1.35		1.36		1.30		1.45		6
		1.35				1.38		1.36				1.34			7
	1.44				1.35				1.43				1.37		8
		1.37				1.35		1.38				1.37			9
	1.34		1.32		1.34		1.34		1.37		1.32		1.38		10
				1.34						1.35					11
			1.33		1.29				1.32		1.39				12
						1.37		1.34							13
					1.39		1.36		1.39						14
															15

x.xx ==> Rod drop time to dashpot entry (sec.)

Figure 2.3

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
ROD DROP TIMES TRENDING



SECTION 3 — CONTROL ROD BANK WORTH MEASUREMENTS

Control rod bank worths were measured for the control and shutdown banks using the rod swap technique [Ref. 2]. The initial step of the rod swap method diluted the predicted most reactive control rod bank (hereafter referred to as the reference bank) into the core and measured its reactivity worth using conventional test techniques. The reactivity changes resulting from the reference bank movements were recorded continuously by the reactivity computer and were used to determine the differential and integral worth of the reference bank. For Cycle 29, Control Bank B was used as the reference bank. Surry 1 targeted a dilution rate of 1100 pcm/hr for the reference bank measurement.

During a previous startup physics testing campaign, a control rod became stuck on the bottom eventually forcing a reactor trip to fix the problem. The solution to this issue for startup physics testing was to avoid requiring control rods to be manually inserted to 0 steps. To accomplish this, an evaluation of the startup physics testing process was performed [Ref. 13], concluding that the definition of fully inserted for control rod positions used in startup physics testing could be changed from 0 steps withdrawn to a range of 0 to 2 steps withdrawn. The S1C29 startup physics testing campaign used 2 steps withdrawn for all conditions requiring control rods to be manually fully inserted.

After completion of the reference bank reactivity worth measurement, the reactor coolant system temperature and boron concentration were stabilized with the reactor near critical and the reference bank near its full insertion. Initial statepoint data (core reactivity and moderator temperature) for the rod swap maneuver were next obtained with the reference bank at its fully inserted position and all other banks fully withdrawn.

Test bank swaps proceed in sequential order from the bank with the smallest worth to the bank with the largest worth. The second test bank should have a predicted worth higher than the first bank in order to ensure the first bank will be moved fully out before the second bank is fully inserted. The rod swap maneuver was performed by withdrawing the previous test bank (or reference bank for the first maneuver) several steps and then inserting the next test bank to balance the reactivity of the bank withdrawal. This sequence was repeated until the previous test

bank was fully withdrawn and the current test bank was nearly inserted. The next step was to swap the rest of the test bank in by balancing the reactivity with the withdrawal of the reference bank until the test bank was fully inserted and the reference bank was positioned such that the core was near the initial statepoint condition. This measured critical position (MCP) of the reference bank with the test bank fully inserted was used to determine the integral reactivity worth of the test bank.

The core reactivity, moderator temperature, and differential worth of the reference bank were recorded with the reference bank at the MCP. The rod swap maneuver was repeated for all test banks. Note that after the final test bank was fully inserted, the test bank was swapped with the reference bank until the reference bank was fully inserted and the last test bank was fully withdrawn. Here the final statepoint data for the rod swap maneuver was obtained (core reactivity and moderator temperature) in order to verify the reactivity drift was within procedural limitations for the rod swap test.

A summary of the test results is given in Table 3.1. As shown in this table and the Startup Physics Test Summary Sheets given in Appendix B, the individual measured bank worths for the control and shutdown banks were within the design tolerance of ±10% for the reference bank, ±15% for test banks of worth greater than 600 pcm, and ±100 pcm for test banks of worth less than or equal to 600 pcm. The sum of the individual measured rod bank worths was 1.8% lower than the design prediction. This is well within the design tolerance of ±10% for the sum of the individual control rod bank worths.

The integral and differential reactivity worths of the reference bank (Control Bank B) are shown in Figures 3.1 and 3.2, respectively. The design predictions [Ref. 1] and the measured data are plotted together in order to illustrate their agreement. In summary, the measured rod worth values were found to be satisfactory.

Table 3.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
CONTROL ROD BANK WORTH SUMMARY

BANK	MEASURED WORTH (PCM)	PREDICTED WORTH (PCM)	PERCENT DIFFERENCE (%) (M-P)/P X 100
B – Reference	1170.9	1184.0	-1.1%
A	242.7	235.0	7.7 pcm*
C	915.0	924.5	-1.0%
SA	859.0	875.7	-1.9%
D	986.5	1015.4	-2.8%
SB	1110.7	1145.6	-3.0%
Total Bank Worth	5284.8	5380.2	-1.8%

*Note: For bank worth < 600 pcm, worth difference = (M - P).

Figure 3.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
CONTROL BANK B INTEGRAL ROD WORTH - HZP
ALL OTHER RODS WITHDRAWN

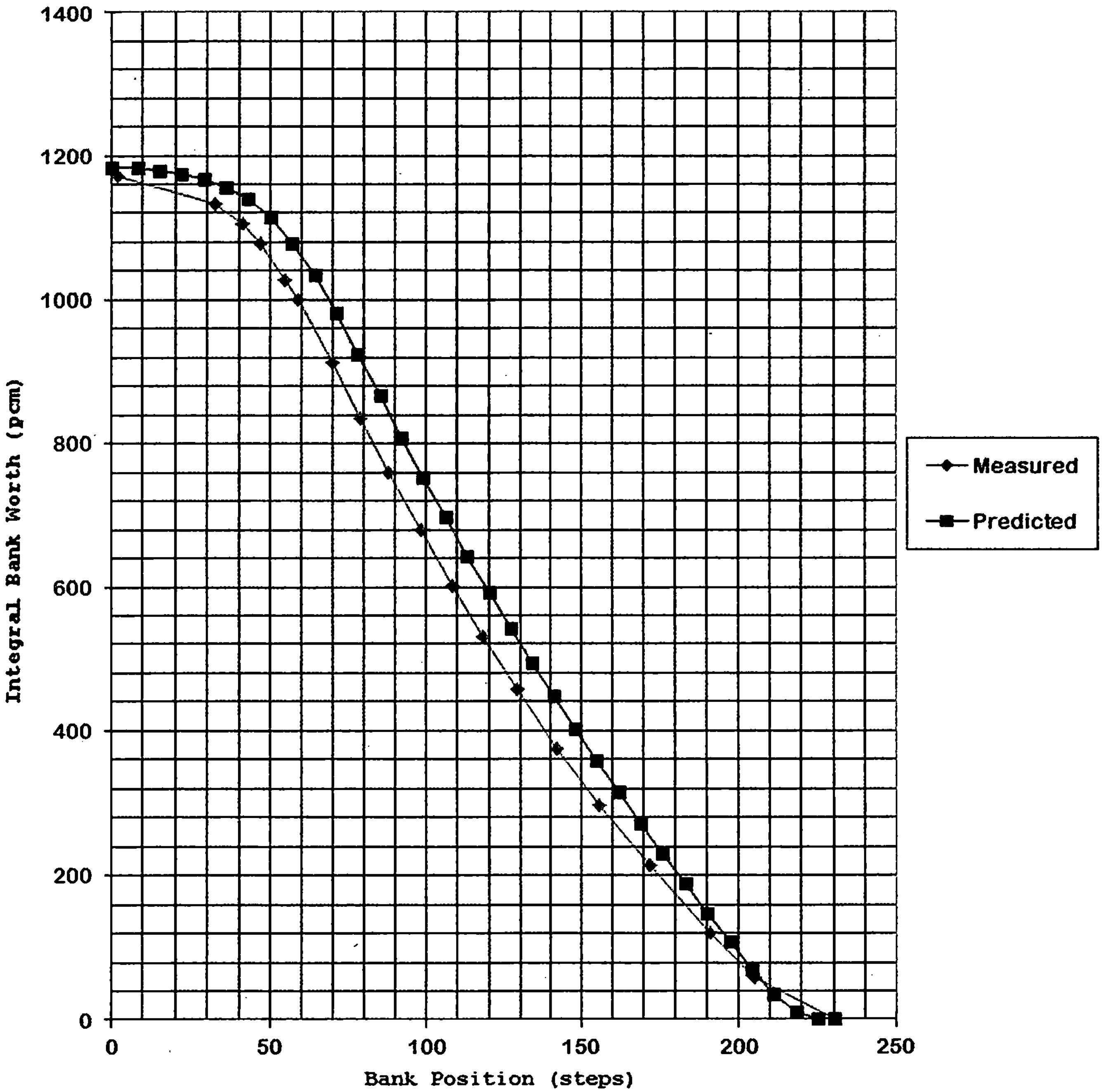
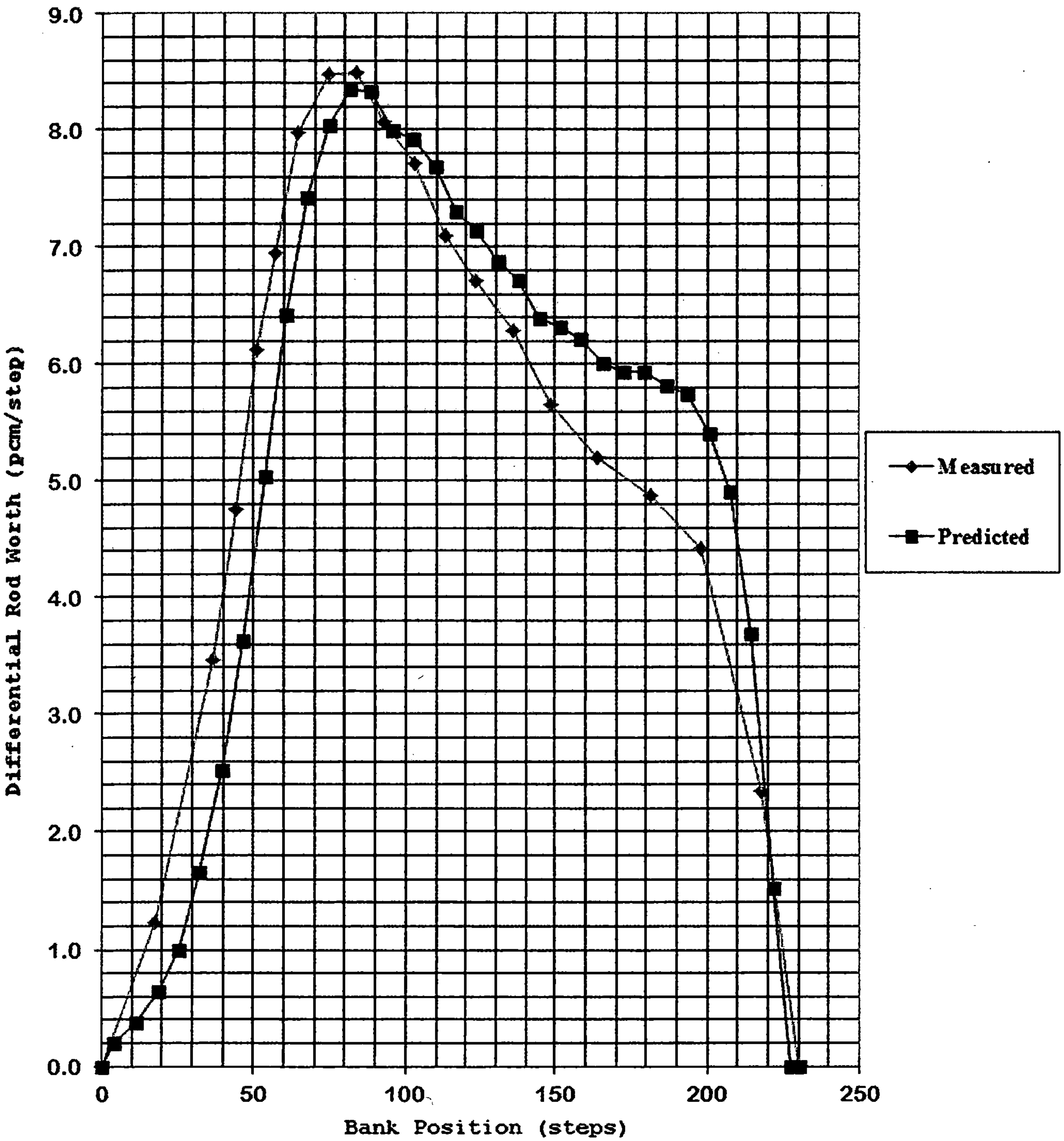


Figure 3.2

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
CONTROL BANK B DIFFERENTIAL ROD WORTH - HZP
ALL OTHER RODS WITHDRAWN



SECTION 4 — BORON ENDPOINT AND WORTH MEASUREMENTS

Boron Endpoint

With the reactor critical at hot zero power (HZP), reactor coolant system (RCS) boron concentrations were measured at selected rod bank configurations to enable a direct comparison of measured boron endpoints with design predictions. For each critical boron concentration measurement, the RCS conditions were stabilized with the control banks at or very near a selected endpoint position. Adjustments to the measured critical boron concentration values were made to account for off-nominal control rod position and moderator temperature, as necessary.

The results of these measurements are given in Table 4.1. As shown in this table and in the Startup Physics Test Summary Sheets given in Appendix B, the measured critical boron endpoint values were within their respective design tolerances. The ARO endpoint comparison to the predicted value met the requirements of Technical Specification 4.10.A [Ref. 4] regarding core reactivity balance. In summary, the boron endpoint results were satisfactory.

Boron Worth Coefficient

The measured boron endpoint values provide stable statepoint data from which the boron worth coefficient or differential boron worth (DBW) was determined. By relating each endpoint concentration to the integrated rod worth present in the core at the time of the endpoint measurement, the value of the DBW over the range of boron endpoint concentrations was obtained.

A summary of the measured and predicted DBW is shown in Table 4.2. As indicated in this table and in Appendix B, the measured DBW was well within the design tolerance of $\pm 10\%$. In summary, the measured boron worth coefficient was satisfactory.

Table 4.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
BORON ENDPOINTS SUMMARY

Control Rod Configuration	Measured Endpoint (ppm)	Predicted Endpoint (ppm)	Difference M-P (ppm)
ARO	1495.7	1489.0	6.7
B Bank In	1342.5	1342.7*	-0.2

* The predicted endpoint for the B Bank In configuration was adjusted for the difference between the measured and predicted values of the endpoint taken at the ARO configuration as shown in the boron endpoint Startup Physics Test Summary Sheet in Appendix B.

Table 4.2

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
BORON WORTH COEFFICIENT

Measured Boron Worth (pcm/ppm)	Predicted Boron Worth (pcm/ppm)	Percent Difference (%) (M-P)/P x 100
-7.65	-7.74	-1.2%

SECTION 5 — TEMPERATURE COEFFICIENT MEASUREMENT

The Isothermal Temperature Coefficient (ITC) at the ARO condition is measured by controlling the RCS temperature with the steam dump valves to the condenser, establishing a constant heatup or cooldown rate by adjusting feed and letdown flow rates, and monitoring the resulting reactivity changes on the reactivity computer.

Reactivity was measured during the RCS heat up of 3.55 °F, followed by the RCS cool down of 2.91 °F. Reactivity and temperature data were taken from the reactivity computer. Using the statepoint method, the temperature coefficient was determined by dividing the change in reactivity by the change in RCS temperature.

The predicted and measured ITC values are compared in Table 5.1. As can be seen from this summary and from the Startup Physics Test Summary Sheet given in Appendix B, the measured ITC value was within the design tolerance of ±2 pcm/°F. The calculated moderator temperature coefficient (MTC), which is calculated using a measured ITC of -2.258 pcm/ °F, a predicted Doppler temperature coefficient (DTC) of -1.65 pcm/ °F, and a measurement uncertainty of +0.5 pcm/ °F, is -0.108 pcm/ °F. It thus satisfies the COLR criteria [Ref. 8] that indicates MTC at HZP be less than or equal to +6.0 pcm/ °F.

Table 5.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
ISOTHERMAL TEMPERATURE COEFFICIENT SUMMARY

BANK POSITION (STEPS)	TEMPERATURE RANGE (°F)		BORON CONCENTRATION (ppm)	ISOTHERMAL TEMPERATURE COEFFICIENT (PCM/°F)				
	LOWER LIMIT	UPPER LIMIT		HEAT-UP	COOL-DOWN	AVG. MEAS	PRED	DIFFER (M-P)
D/200	546.61	550.17	1488.3	-2.018	-2.498	-2.258	-2.067	-0.190

SECTION 6 — POWER DISTRIBUTION MEASUREMENTS

The core power distributions were measured using the moveable incore detector flux mapping system. This system consists of five fission chamber detectors which traverse fuel assembly instrumentation thimbles in up to 50 core locations. Figure 1.3 shows the available locations monitored by the moveable detectors for Cycle 29 power ascension flux maps. For each traverse, the detector voltage output is continuously monitored on a recorder, and scanned for 610 discrete axial points. Full core, three-dimensional power distributions are determined from this data using a Dominion-modified version of the Combustion Engineering computer program, CEBRZ/CECOR [Ref. 3, Ref. 15]. CECOR couples the measured voltages with predetermined analytic power-to-flux ratios in order to determine the power distribution for the whole core. The CECOR GUI (Ref. 16) was used as an interface to CEBRZ and CECOR.

A list of the full-core flux maps [Ref. 7] taken during the startup test program and the measured values of the important power distribution parameters are given in Table 6.1. A comparison of these measured values with their COLR limits is given in Table 6.2. Flux map 1 was taken at 27.15% power to verify the radial power distribution (RPD) predictions at low power and to ensure there is no evidence that supports the possibility of a core misload or dropped rod. Figure 6.1 shows the measured RPDs from this flux map. Flux maps 2 and 3 were taken at 70.52% and 99.87% power, respectively, with different control rod configurations. These flux maps were taken to check at-power design predictions and to measure core power distributions at various operating conditions. The radial power distributions for these maps are given in Figures 6.2 and 6.3.

The radial power distributions for the maps given in Figures 6.1, 6.2 and 6.3 show that the measured relative assembly power values deviated from the design predictions by at most ±6.7% in the 27.15% power map, ±4.7% in the 70.52% power map and ±4.0% in the 99.87% power map. The maximum positive quadrant power tilt for the three maps were 1.57%, 0.99% and 1.17%, respectively. These power tilts are within the design tolerance of 2%.

The measured $F_Q(Z)$ and $F_{\Delta H}^N$ peaking factor values for the at-power flux maps were within the limits of the COLR [Ref. 8]. Flux Maps 1, 2 and 3 were used for power range detector calibration or to confirm existing calibrations.

In conclusion, the power distribution measurement results are considered acceptable with respect to the design tolerances, the accident analysis acceptance criteria, and the COLR [Ref. 8]. It is therefore anticipated that the core will continue to operate safely throughout Cycle 29.

Table 6.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
INCORE FLUX MAP SUMMARY

Map Description	Map No.	Date	Burnup MWD/MTU	Power (%)	Bank D Steps	Peak $F_Q(Z)$ Hot Channel Factor (1)			$F^N_{\Delta H}$ Hot (2) Channel Factor		Core F_Z Max		Core Tilt (3)		Axial Offset (%)	No. Of Thimbles
						Assy	Axial Point	$F_Q(Z)$	Assy	$F^N_{\Delta H}$	Axial Point	F_Z	Max	Loc		
Low Power	1	05/31/18	1.0	27.15	168	L-9	30	2.238	L-7	1.553	27	1.358	1.0157	SW	2.109	46
Int. Power (4)	2	06/01/18	13.8	70.52	196	L-9	30	1.943	L-7	1.501	27	1.211	1.0099	SW	2.328	46
Hot Full Power	3	06/06/18	188.0	99.87	229	L-9	30	1.893	L-9	1.486	30	1.172	1.0114	SW	0.824	46

NOTES: Hot spot locations are specified by giving assembly locations (e.g., H-8 is the center-of-core assembly) and core height (in the "Z" direction the core is divided into 61 axial points starting from the top of the core). These flux maps were used for power range detector calibration or were used to confirm existing calibrations.

(1) $F_Q(Z)$ includes a total uncertainty of 8%.

(2) $F^N_{\Delta H}$ includes no uncertainty.

(3) CORE TILT - defined as the average quadrant power tilt from CECOR. "Max" refers to the maximum positive core tilt (QPTR > 1.0000).

(4) Int. Power – intermediate power flux map.

Table 6.2

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
COMPARISION OF MEASURED POWER DISTRIBUTION
PARAMETERS WITH THEIR CORE OPERATING LIMITS

	Peak $F_Q(Z)$ Hot Channel Factor				$F^N_{\Delta H}$ Hot Channel Factor		
Map No.	Meas.	Limit	Node	Margin* (%)	Meas.	Limit	Margin* (%)
1	2.238	5.000	30	55.2	1.553	1.992	22.1
2	1.943	3.545	30	45.2	1.501	1.780	15.7
3	1.893	2.503	30	24.4	1.486	1.636	9.1

The measured $F_Q(Z)$ hot channel factors include 8% total uncertainty. Measured $F^N_{\Delta H}$ data includes no uncertainty.

* Margin (%) = 100*(Limit – Meas.) / Limit

Figure 6.1 — ASSEMBLYWISE POWER DISTRIBUTION
27.15% POWER

ASSEMBLY RELATIVE POWER FRACTIONS
Top value = Measured, middle value = Analytical, bottom value = % Delta
% Delta = (M - A)x100/A

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.229	0.276	0.231						
							0.234	0.282	0.237						
							-2.26	-2.11	-2.56						
2					0.298	0.539	0.885	0.877	0.886	0.546	0.295				
					0.298	0.546	0.906	0.906	0.909	0.548	0.298				
					-0.11	-1.31	-2.26	-3.24	-2.49	-0.28	-0.90				
3				0.456	1.023	1.131	1.217	1.071	1.207	1.121	1.004	0.442			
				0.433	1.016	1.141	1.242	1.128	1.244	1.143	1.018	0.434			
				5.25	0.64	-0.91	-2.02	-5.06	-3.00	-1.93	-1.35	1.78			
4			0.447	1.018	1.235	1.141	1.279	1.260	1.277	1.129	1.206	0.992	0.431		
			0.435	1.001	1.228	1.151	1.306	1.298	1.311	1.154	1.229	1.001	0.435		
			2.85	1.74	0.58	-0.84	-2.04	-2.90	-2.57	-2.20	-1.90	-0.90	-0.94		
5		0.310	1.064	1.251	1.144	1.243	1.342	1.246	1.352	1.229	1.116	1.223	1.014	0.302	
		0.301	1.025	1.234	1.150	1.256	1.375	1.275	1.383	1.259	1.150	1.234	1.025	0.301	
		2.92	3.80	1.41	-0.53	-1.07	-2.37	-2.31	-2.21	-2.40	-2.97	-0.88	-1.07	0.23	
6		0.563	1.174	1.175	1.268	1.197	1.181	1.281	1.179	1.177	1.239	1.145	1.139	0.546	
		0.556	1.157	1.164	1.265	1.201	1.195	1.302	1.199	1.202	1.264	1.163	1.156	0.555	
		1.18	1.44	0.97	0.27	-0.31	-1.17	-1.65	-1.67	-2.04	-2.01	-1.51	-1.51	-1.59	
7	0.241	0.931	1.268	1.345	1.410	1.207	1.255	1.212	1.248	1.181	1.369	1.310	1.242	0.904	0.234
	0.241	0.928	1.268	1.335	1.397	1.203	1.257	1.222	1.255	1.200	1.392	1.332	1.267	0.926	0.240
	0.16	0.28	0.01	0.77	0.95	0.35	-0.17	-0.82	-0.57	-1.57	-1.62	-1.64	-1.98	-2.39	-2.48
8	0.288	0.932	1.154	1.366	1.325	1.319	1.223	1.246	1.207	1.282	1.277	1.331	1.126	0.898	0.284
	0.291	0.928	1.155	1.351	1.294	1.307	1.223	1.255	1.223	1.307	1.294	1.351	1.155	0.928	0.291
	-0.93	0.39	-0.10	1.08	2.40	0.91	0.02	-0.73	-1.34	-1.93	-1.33	-1.49	-2.49	-3.26	-2.57
9	0.241	0.935	1.282	1.349	1.403	1.210	1.258	1.213	1.233	1.197	1.391	1.329	1.258	0.917	0.242
	0.240	0.926	1.267	1.332	1.392	1.200	1.255	1.222	1.257	1.203	1.397	1.335	1.268	0.927	0.241
	0.46	1.01	1.20	1.27	0.81	0.80	0.25	-0.74	-1.89	-0.47	-0.43	-0.47	-0.80	-1.07	0.59
10		0.566	1.186	1.188	1.287	1.219	1.211	1.296	1.185	1.198	1.272	1.175	1.165	0.562	
		0.556	1.157	1.163	1.264	1.202	1.199	1.302	1.195	1.201	1.265	1.164	1.157	0.556	
		1.87	2.51	2.15	1.82	1.40	0.98	-0.47	-0.80	-0.22	0.59	0.95	0.70	1.11	
11		0.310	1.059	1.270	1.186	1.279	1.390	1.259	1.367	1.247	1.179	1.261	1.045	0.306	
		0.301	1.025	1.234	1.150	1.259	1.383	1.275	1.375	1.256	1.150	1.234	1.025	0.301	
		2.89	3.30	2.94	3.16	1.58	0.53	-1.25	-0.59	-0.71	2.51	2.22	1.93	1.69	
12			0.464	1.035	1.262	1.174	1.320	1.300	1.311	1.160	1.254	1.038	0.455		
			0.435	1.001	1.229	1.154	1.312	1.298	1.307	1.151	1.228	1.001	0.435		
			6.74	3.37	2.70	1.69	0.59	0.17	0.30	0.77	2.15	3.67	4.68		
13				0.447	1.045	1.165	1.261	1.140	1.257	1.155	1.035	0.446			
				0.434	1.018	1.143	1.244	1.128	1.242	1.141	1.016	0.433			
				2.99	2.65	1.93	1.33	1.04	1.23	1.22	1.92	2.91			
14					0.313	0.560	0.926	0.924	0.931	0.557	0.303				
					0.298	0.548	0.910	0.906	0.906	0.546	0.298				
					5.15	2.16	1.71	1.99	2.80	1.93	1.84				
15							0.243	0.288	0.240						
							0.237	0.282	0.234						
							2.34	2.06	2.59						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 1.6 ANALYTICAL AXIAL OFFSET = 4.821 %
STANDARD DEVIATION = 1.128 MEASURED AXIAL OFFSET = 2.109 %

Summary:

QPTR:		
	0.9986	0.9819
	1.0157	1.0038

Figure 6.2 — ASSEMBLYWISE POWER DISTRIBUTION
70.52% POWER

ASSEMBLY RELATIVE POWER FRACTIONS
Top value = Measured, middle value = Analytical, bottom value = % Delta
% Delta = (M - A)x100/A

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.251	0.305	0.254						
							0.257	0.313	0.260						
							-2.18	-2.71	-2.18						
2					0.312	0.561	0.920	0.945	0.924	0.573	0.311				
					0.313	0.568	0.941	0.975	0.944	0.570	0.313				
					-0.40	-1.24	-2.18	-3.12	-2.07	0.53	-0.53				
3				0.465	1.022	1.131	1.218	1.082	1.213	1.127	1.010	0.450			
				0.447	1.020	1.140	1.241	1.135	1.243	1.142	1.021	0.447			
				4.06	0.21	-0.83	-1.84	-4.69	-2.45	-1.31	-1.03	0.67			
4			0.454	1.010	1.217	1.134	1.267	1.247	1.264	1.127	1.200	0.995	0.445		
			0.448	1.001	1.216	1.141	1.282	1.271	1.286	1.143	1.217	1.002	0.448		
			1.30	0.94	0.06	-0.61	-1.20	-1.92	-1.69	-1.43	-1.40	-0.66	-0.58		
5		0.318	1.041	1.225	1.134	1.242	1.342	1.234	1.341	1.234	1.116	1.216	1.018	0.313	
		0.315	1.025	1.220	1.143	1.249	1.349	1.248	1.357	1.250	1.143	1.220	1.025	0.315	
		1.02	1.58	0.43	-0.81	-0.56	-0.52	-1.10	-1.16	-1.28	-2.37	-0.33	-0.64	-0.62	
6		0.578	1.159	1.153	1.250	1.238	1.185	1.270	1.187	1.236	1.241	1.140	1.139	0.568	
		0.576	1.152	1.150	1.254	1.241	1.189	1.279	1.192	1.242	1.254	1.149	1.151	0.575	
		0.29	0.58	0.27	-0.29	-0.22	-0.32	-0.73	-0.43	-0.47	-1.04	-0.82	-1.02	-1.28	
7	0.262	0.956	1.262	1.309	1.375	1.200	1.244	1.202	1.247	1.188	1.352	1.289	1.241	0.938	0.257
	0.264	0.957	1.259	1.303	1.366	1.194	1.239	1.201	1.236	1.191	1.362	1.301	1.258	0.955	0.262
	-0.91	-0.15	0.23	0.48	0.62	0.48	0.42	0.12	0.90	-0.26	-0.71	-0.91	-1.33	-1.75	-1.83
8	0.312	0.985	1.144	1.323	1.286	1.294	1.207	1.232	1.198	1.271	1.255	1.304	1.133	0.966	0.315
	0.321	0.992	1.155	1.315	1.262	1.282	1.201	1.231	1.201	1.282	1.262	1.315	1.155	0.991	0.321
	-2.75	-0.71	-0.91	0.61	1.94	0.94	0.51	0.07	-0.25	-0.85	-0.53	-0.81	-1.94	-2.47	-1.95
9	0.260	0.956	1.264	1.312	1.374	1.202	1.244	1.199	1.226	1.198	1.368	1.304	1.253	0.947	0.263
	0.262	0.955	1.258	1.301	1.362	1.191	1.237	1.201	1.239	1.194	1.366	1.303	1.259	0.957	0.264
	-0.66	0.11	0.48	0.84	0.92	0.91	0.54	-0.15	-1.08	0.33	0.15	0.06	-0.51	-1.08	-0.46
10		0.581	1.170	1.165	1.271	1.255	1.204	1.278	1.184	1.241	1.265	1.166	1.159	0.576	
		0.575	1.151	1.149	1.254	1.242	1.192	1.279	1.189	1.241	1.254	1.149	1.152	0.576	
		0.99	1.62	1.41	1.36	1.06	1.02	-0.09	-0.43	0.02	0.88	1.49	0.59	-0.01	
11		0.320	1.046	1.243	1.167	1.265	1.363	1.237	1.344	1.241	1.165	1.242	1.040	0.318	
		0.315	1.025	1.220	1.143	1.250	1.357	1.248	1.349	1.249	1.143	1.220	1.025	0.315	
		1.57	2.02	1.86	2.11	1.20	0.46	-0.90	-0.39	-0.65	1.91	1.81	1.42	0.79	
12			0.465	1.022	1.238	1.156	1.294	1.271	1.284	1.146	1.235	1.028	0.460		
			0.448	1.002	1.217	1.143	1.286	1.271	1.282	1.141	1.216	1.001	0.448		
			3.71	2.02	1.69	1.15	0.62	0.04	0.17	0.47	1.54	2.66	2.67		
13				0.455	1.036	1.155	1.252	1.141	1.248	1.149	1.033	0.456			
				0.447	1.021	1.142	1.243	1.135	1.241	1.140	1.020	0.447			
				1.88	1.51	1.14	0.72	0.50	0.53	0.82	1.25	1.97			
14					0.319	0.576	0.951	0.981	0.949	0.573	0.316				
					0.313	0.570	0.944	0.976	0.941	0.568	0.313				
					2.03	1.00	0.72	0.56	0.89	0.92	0.99				
15							0.261	0.315	0.259						
							0.260	0.314	0.258						
							0.21	0.40	0.57						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 1.1
STANDARD DEVIATION = 0.809
ANALYTICAL AXIAL OFFSET = 3.860 %
MEASURED AXIAL OFFSET = 2.328 %

Summary:

QPTR:		
	0.9977	0.9893
	1.0099	1.0032

Figure 6.3 — ASSEMBLYWISE POWER DISTRIBUTION
99.87% POWER

ASSEMBLY RELATIVE POWER FRACTIONS
Top value = Measured, middle value = Analytical, bottom value = % Delta
% Delta = (M - A)x100/A

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.262 0.270 -2.78	0.318 0.331 -4.03	0.265 0.273 -2.98						
2					0.315 0.318 -1.05	0.565 0.575 -1.69	0.924 0.947 -2.40	0.977 1.008 -3.11	0.925 0.950 -2.60	0.566 0.576 -1.74	0.314 0.318 -1.34				
3				0.455 0.449 1.35	0.996 1.004 -0.82	1.111 1.127 -1.41	1.205 1.229 -1.92	1.088 1.133 -3.95	1.201 1.231 -2.40	1.109 1.129 -1.73	0.993 1.005 -1.23	0.450 0.450 -0.08			
4			0.453 0.450 0.62	0.987 0.988 -0.10	1.187 1.199 -1.02	1.119 1.132 -1.13	1.249 1.267 -1.41	1.236 1.255 -1.48	1.252 1.271 -1.46	1.119 1.134 -1.28	1.185 1.199 -1.13	0.982 0.988 -0.61	0.447 0.450 -0.60		
5		0.322 0.320 0.63	1.020 1.009 1.05	1.203 1.202 0.05	1.133 1.140 -0.57	1.242 1.252 -0.77	1.329 1.346 -1.26	1.231 1.242 -0.90	1.341 1.352 -0.78	1.243 1.253 -0.81	1.125 1.141 -1.41	1.198 1.202 -0.35	1.001 1.009 -0.83	0.315 0.320 -1.53	
6		0.581 0.582 -0.13	1.138 1.137 0.07	1.140 1.140 -0.00	1.254 1.257 -0.26	1.290 1.291 -0.10	1.201 1.203 -0.14	1.283 1.285 -0.17	1.207 1.205 0.17	1.291 1.291 0.02	1.250 1.257 -0.58	1.131 1.139 -0.70	1.123 1.136 -1.11	0.572 0.581 -1.52	
7	0.273 0.276 -1.20	0.956 0.961 -0.57	1.239 1.246 -0.58	1.289 1.287 0.18	1.369 1.360 0.64	1.217 1.208 0.73	1.263 1.248 1.18	1.219 1.209 0.86	1.267 1.246 1.67	1.210 1.205 0.42	1.353 1.357 -0.31	1.274 1.284 -0.79	1.226 1.245 -1.55	0.939 0.959 -2.04	0.268 0.274 -2.02
8	0.328 0.339 -3.36	1.017 1.023 -0.62	1.146 1.151 -0.47	1.306 1.298 0.65	1.278 1.255 1.82	1.305 1.288 1.30	1.224 1.209 1.22	1.253 1.242 0.85	1.217 1.209 0.68	1.292 1.288 0.31	1.254 1.255 -0.10	1.287 1.298 -0.86	1.125 1.150 -2.19	0.992 1.023 -3.00	0.330 0.339 -2.65
9	0.272 0.274 -0.60	0.960 0.959 0.13	1.251 1.245 0.51	1.299 1.284 1.13	1.380 1.357 1.69	1.224 1.205 1.59	1.265 1.246 1.49	1.218 1.209 0.72	1.246 1.248 -0.18	1.213 1.208 0.42	1.363 1.360 0.22	1.284 1.286 -0.18	1.234 1.246 -0.99	0.945 0.961 -1.64	0.272 0.276 -1.39
10		0.586 0.581 0.86	1.151 1.136 1.29	1.155 1.139 1.41	1.278 1.257 1.64	1.314 1.292 1.70	1.234 1.205 2.42	1.294 1.285 0.73	1.205 1.203 0.14	1.294 1.291 0.25	1.266 1.257 0.75	1.148 1.140 0.74	1.137 1.137 0.02	0.578 0.582 -0.73	
11		0.325 0.320 1.46	1.026 1.009 1.70	1.221 1.202 1.62	1.160 1.141 1.68	1.271 1.254 1.36	1.366 1.352 1.04	1.237 1.242 -0.37	1.344 1.346 -0.13	1.247 1.252 -0.38	1.163 1.140 2.01	1.219 1.202 1.38	1.018 1.009 0.89	0.321 0.320 0.28	
12			0.465 0.450 3.37	1.006 0.988 1.82	1.217 1.200 1.43	1.147 1.134 1.17	1.281 1.271 0.81	1.258 1.255 0.26	1.270 1.267 0.22	1.135 1.132 0.30	1.213 1.199 1.20	1.008 0.988 1.98	0.460 0.450 2.25		
13				0.457 0.450 1.49	1.018 1.005 1.31	1.140 1.129 0.97	1.240 1.231 0.70	1.138 1.133 0.42	1.233 1.229 0.36	1.128 1.127 0.10	1.012 1.004 0.79	0.456 0.449 1.48			
14					0.322 0.318 1.41	0.581 0.576 0.94	0.955 0.950 0.50	1.014 1.009 0.45	0.954 0.947 0.69	0.578 0.575 0.45	0.320 0.318 0.73				
15							0.270 0.273 -1.07	0.332 0.331 0.38	0.272 0.270 0.61						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 1.1
STANDARD DEVIATION = 0.811
ANALYTICAL AXIAL OFFSET = 0.345 %
MEASURED AXIAL OFFSET = 0.824 %

Summary:

QPTR:		
	0.9956	0.9906
	1.0114	1.0024

SECTION 7 — CONCLUSIONS

Table 7.1 summarizes the results associated with Surry Unit 1 Cycle 29 startup physics testing program. As noted herein, all test results were acceptable and within associated design tolerances, Technical Specifications limits, or COLR limits. The AREVA AGORA LTAs show no signs of anomalous behavior and are performing as expected. It is anticipated that, based on the results associated with the S1C29 startup physics testing program, the Surry 1 core will continue to operate safely throughout Cycle 29.

Table 7.1

SURRY UNIT 1 – CYCLE 29 STARTUP PHYSICS TESTS
STARTUP PHYSICS TESTING RESULTS SUMMARY

Parameter	Measured (M)	Predicted (P)	Diff (M-P) or (M-P)/P,%	Design Tolerance
Critical Boron Concentration (HZP ARO), ppm	1495.7	1489.0	6.7	39.1
Critical Boron Concentration (HZP Ref Bank in), ppm	1342.5	1342.7	-0.2	±25
Isothermal Temp Coefficient (HZP ARO), pcm/F	-2.258	-2.067	-0.19	±2
Differential Boron Worth (HZP ARO), pcm/ppm	-7.65	-7.74	-1.2%	±10%
Reference Bank Worth (B-bank, dilution), pcm	1170.9	1184.0	-1.1%	±10%
A-bank Worth (Rod Swap), pcm	242.7	235.0	7.7	±100
C-bank Worth (Rod Swap), pcm	915.0	924.5	-1.0%	±15%
SA-bank Worth (Rod Swap), pcm	859.0	875.7	-1.9%	±15%
D-bank Worth (Rod Swap), pcm	986.5	1015.4	-2.8%	±15%
SB-bank Worth (Rod Swap), pcm	1110.7	1145.6	-3.0%	±15%
Total Bank Worth, pcm	5284.8	5380.2	-1.8%	±10%
S1C29 Testing Time:		**8.0**	**hrs**	
[criticality 05/30/2018 @ 06:48 to end of testing 05/30/2018 @ 14:45]				
Last 5 Surry Startups:				
S2C28 testing time:		7.0	hrs	
S1C28 testing time:		5.8	hrs	
S2C27 testing time:		7.6	hrs	
S1C27 testing time:		5.6	hrs	
S2C26 testing time:		7.2	hrs	

SECTION 8 — REFERENCES

1. M. M. Giffen, "Surry Unit 1, Cycle 29 Design Report", Engineering Technical Evaluation ETE-NAF-20180052, Rev. 0, May 2018.

2. T. S. Psuik, "Control Rod Reactivity Worth Determination By The Rod Swap Technique," Topical Report VEP-FRD-36-Rev. 0.3-A, February 2015.

3. C. J. Wells and J. G. Miller, "The CEBRZ Flux Map Data Processing Code for a Movable In-core Detector System," Engineering Technical Evaluation ETE-NAF-2011-0004, Rev. 0, March 2011.

4. Surry Units 1 and 2 Technical Specifications.

5. R. W. Twitchell, "Operational Impact of the Implementation of Westinghouse Integral Fuel Burnable Absorber (IFBA) and the Removal of Flux Suppression Inserts (FSIs) for Surry Unit 1 Cycle 21," Technical Report NE-1466, Rev. 0, January 2006.

6. D. B. Livingston, "Surry Unit 1, Cycle 29 TOTE, Core Follow, and Accounting Calculations", Calculation PM-1958, Rev. 0, May 2018.

7. K. L. Kennett, "Surry Unit 1 Cycle 29 Flux Map Analysis", Calculation PM-1959, Rev. 0, and Addenda A - B, May & June 2018.

8. D. T. Smith, "Reload Safety Evaluation Surry 1 Cycle 29 Pattern ZEU," EVAL-ENG-RSE-S1C29, Rev. 0, April 2018.

9. M. P. Shanahan, "Implementation of RMAS version 7 at Surry Unit 1 and 2," Engineering Technical Evaluation ETE-NAF-2014-0021, Rev. 0, May 2014.

10. B. J. Vitiello and G. L. Darden, "Implementation of the Westinghouse 15x15 Upgrade Fuel Design at Surry Units 1 and 2," Engineering Technical Evaluation ETE-NAF-2010-0080, Rev. 0, January 2011.

11. D. B. Livingston, "Surry Unit 1 Cycle 29 Full Core Loading Plan," Engineering Technical Evaluation ETE-NAF-2017-0126, Rev. 0, October 2017.

12. D. J. Agnew, "Rod Drop Test Computer Users Guide and SQA Paperwork," Engineering Technical Evaluation ETE-NAF-2014-0118, Rev. 0, April 2015.

13. A. H. Nicholson, "Justification For Defining 0 To 2 Steps Withdrawn As Fully Inserted When Measuring Control And Shutdown Banks During The Surry Startup Physics Testing Program," Engineering Transmittal ET-NAF-06-0046, Rev. 0, April, 2006.

14. S. B. Rosenfelder, "Surry Unit 1 Cycle 29 Startup Physics Testing Logs and Results," Memorandum MEMO-NCD-20180020, Rev. 0, May 2018.

15. S. R. Ehrensberger, "The CECOR Flux Map Analysis Code Version 3.4 Additional Software Requirements and Design," Engineering Technical Evaluation ETE-NAF-2018-0021, Rev. 0, March 2018.

16. S. R. Ehrensberger, "Implementation of CECOR Software System Using CECOR v3.4 and CECOR-GUI v1.7," Engineering Technical Evaluation ETE-NAF-2018-0034, Rev. 0, March 2018.,

17. Nuclear Engineering Standard DNES-AA-NAF-NCD-5007, Rev. 3, "Startup Physics Tests Results Reporting."

18. T. S. Psuik, "Implementation of Changes to the Allowable Power Level for the Initial Startup Flux Map for Surry Units 1 and 2," Engineering Technical Evaluation ETE-NAF-2015-0007, Rev. 0, April 2015.

APPENDIX A — RCP STARTUP ORDER

(Generation - 6)

From: (Generation - 6)
Sent: Monday, June 11, 2018 8:55 AM
To: (Generation - 6)
Subject: FW: RCP Start Order

From: (Generation - 3)
Sent: Wednesday, June 06, 2018 10:00 AM
To: (Generation - 6)
Cc: (Generation - 6)
Subject: RCP Start Order

'B' RCP Started 5/21 05:43
'C' RCP Started 5/22 20:50
'B'' RCP Stopped 5/22 21:32
'B' RCP Started 5/27 02:23
'A' RCP Started 5/27 21:36

Reactor Engineer
Surry Power Station

Dominion Energy
Phone:
E-mail:

APPENDIX B — STARTUP PHYSICS TEST SUMMARY SHEETS

Surry Power Station Unit 1 Cycle 29 Startup Physics Test Summary Sheet - Formal Tests (Page 1 of 6)

Measured Value	Design Criteria	Acceptance Criteria	Design Criteria Met	Acceptance Criteria Met	Date/ Time of Test	Preparer/ Reviewer
Zero Power Testing Range Determination						
ZPTR= 2e-9 to 1e-7 amps	background < ZPTR < POAH background = 2.918e-11 amps POAH= 2.432e-7 amps	N/A	✓ Yes ___ No	N/A	09:53 5/30/18	MNG/ BRK
Reactivity Computer Checkout						
ρ_c=+57.850/-43.918 pcm (measured reactivity) ρ_t=+58.178/-44.510 pcm (predicted reactivity) %D = {(ρc - ρt)/ρt} x 100% %D = -.569%/-1.77%	$\lvert\{(\rho_c - \rho_t)/\rho_t\}\rvert \times 100\% \leq 4.0\ \%$[1] Pre-critical Bench Test Results +120/-100 pcm The allowable range is set to the larger of the measured results or the pre-critical bench test. Allowable range +120/-100 pcm	N/A	✓ Yes ___ No	N/A	5/30/18 09:49	MNG/ BRK
Critical Boron Concentration - ARO						
$(C_B)^M_{ARO}$= 1495.7 ppm (Adj. To design conds.)	$(C_B)_{ARO}$=[2] 1489 ± 39.1 ppm or 300 pcm $\Delta(C_B)_{ARO}=(C_B)^M_{ARO} - (C_B)_{ARO}$ = 6.7 ppm	$\lvert\alpha C_B \times \Delta(C_B)_{ARO}\rvert \leq 1000$ pcm [T.S. 4.10.A] αC_B=[2] -7.67 pcm/ppm	✓ Yes ___ No	✓ Yes ___ No	09:49 5/30/18	MNG/ BRK
Isothermal Temperature Coefficient - ARO						
$(\alpha_T^{ISO})^M_{ARO}$ = -2.258 pcm/°F	$(\alpha_T^{ISO})_{ARO}$ =[2] -2.067 ± 2 pcm/°F $(\alpha_T^{ISO})^M_{ARO} - (\alpha_T^{ISO})_{ARO}$ = -0.190 pcm/°F	$\alpha_T^{ISO} \leq \alpha_M^{lim} - \alpha_T^{mod} + \alpha_T^{DOP}$ $\alpha_T^{ISO} \leq 3.850$ pcm/°F where: (α_M^{lim}); 6.0 pcm/°F [COLR 3.4] (α_T^{unc})[1]; 0.5 pcm/°F (α_T^{DOP})[2]; -1.65 pcm/°F	✓ Yes ___ No	✓ Yes ___ No	5/30/18 10:12	MNG/ BRK
Control Bank B Worth Measurement, Rod Swap Reference Bank						
$I_B^{REF,M}$= 1170.871 pcm	I_B^{REF}=[2] 1184 ± 10% 100x(Meas. - Des.)/Des. = -1.1 %	N/A	✓ Yes ___ No	N/A	5/30/18 11:45	MNG/ BRK

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0052, Rev. 0
3.) ETE-NAF-2018-0051, Rev. 0

Surry Power Station Unit 1 Cycle 29 Startup Physics Test Summary Sheet - Formal Tests (Page 2 of 6)

Measured Value	Design Criteria	Acceptance Criteria	Design Criteria Met	Acceptance Criteria Met	Date/ Time of Test	Preparer/ Reviewer
Critical Boron Concentration - B-Bank In						
$(C_B)^M{}_B$= 1342.5 ppm	$(C_B)_B$=[2] 1336 +$\Delta(C_B)_{ARO}$ ± 25 ppm $\Delta(C_B)_{ARO}$= 6.7 ppm (from above) $(C_B)_B$= 1342.7 ± 25 ppm $(C_B)^M{}_B - (C_B)_B$ = -0.2 ppm	N/A	✓ Yes ___ No	N/A	5/30/18 13:18	MMG/ BRK
HZP Boron Worth Coefficient Measurement						
$(\alpha C_B)^M$= -7.65 pcm/ppm	αC_B =[2] -7.74 ± 0.77 pcm/ppm $\Delta\alpha C_B = (\alpha C_B)^M - (\alpha C_B)$ = 0.09 pcm/ppm	N/A	✓ Yes ___ No	N/A	5/30/18 13:18	MMG/ BRK
Control Bank A Worth Measurement, Rod Swap						
$I_A{}^{RS}$= 242.7 pcm	$(I_A{}^{RS})$[3]= 235.0 ± 100 pcm Meas. - Des.. = 7.7 pcm	N/A	✓ Yes ___ No	N/A	5/30/18 13:17	BRK/ MMG
Shutdown Bank A Worth Measurement, Rod Swap						
$I_{SA}{}^{RS}$= 859.0 pcm	$(I_{SA}{}^{RS})$[3]= 875.7 ± 15% 100x(Meas. - Des.)/Des. = -1.9 %	N/A	✓ Yes ___ No	N/A	5/30/18 13:17	BRK/ MMG
Control Bank C Worth Measurement, Rod Swap						
$I_C{}^{RS}$= 915.0 pcm	$(I_C{}^{RS})$[3]= 924.5 ± 15% 100x(Meas. - Des.)/Des. = -1.0 %	N/A	✓ Yes ___ No	N/A	5/30/18 13:17	BRK/ MMG
Control Bank D Worth Measurement, Rod Swap						
$I_D{}^{RS}$= 986.5 pcm	$(I_D{}^{RS})$[3]= 1015.4 ± 15% 100x(Meas. - Des.)/Des. = -2.8 %	N/A	✓ Yes ___ No	N/A	5/30/18 13:17	BRK/ MMG
Shutdown Bank B Worth Measurement, Rod Swap						
$I_{SB}{}^{RS}$= 1110.7 pcm	$(I_{SB}{}^{RS})$[3]= 1145.6 ± 15% 100x(Meas. - Des.)/Des. = -3.0 %	N/A	✓ Yes ___ No	N/A	5/30/18 13:17	BRK/ MMG
Total Rod Worth, Rod Swap						
I_{Total}= 5284.8 pcm	(I_{total})[3]= 5380.2 ± 10% 100x(Meas. - Des.)/Des. = -1.8 %	N/A	✓ Yes ___ No	N/A	5/30/18 13:17	BRK/ MMG

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0052, Rev. 0
3.) ETE-NAF-2018-0051, Rev. 0

Surry Power Station Unit 1 Cycle 29 Startup Physics Test Summary Sheet - Formal Tests (Page 3 of 6)

Measured Value	Design Criteria	Acceptance Criteria	Design Criteria Met	Acceptance Criteria Met	Date/ Time of Test	Preparer/ Reviewer
M/D Flux Map: Power ≤ 50%						
Map Power Level (% Full Power) = 27.15						
Max Relative Assembly Power, %DIFF (M-P)/P					5/31/18 10:00	JAC RAH 5/31/18
%DIFF= -5.1 % for Pi ≥0.9 6.7 % for P_i<0.9	±10% for P_i ≥0.9 ±15% for P_i<0.9 (P_i = assy power)[1,2]	N/A	✓ Yes ___ No	N/A		
Nuclear Enthalpy Rise Hot Channel Factor, FΔH(N)						
FΔH(N)= 1.553	N/A	FΔH(N)≤1.635(1+0.3(1-P)) [COLR 3.7]	N/A	✓ Yes ___ No		
Total Heat Flux Hot Channel Factor, FQ(Z)						
Peak $F_Q(Z)$ Hot Channel Factor= 2.238	N/A	$F_Q(Z)$≤5*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.0157	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A	↓	

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0052, Rev. 0
3.) ETE-NAF-2018-0051, Rev. 0

Surry Power Station Unit 1 Cycle 29 Startup Physics Test Summary Sheet - Formal Tests (Page 4 of 6)

Measured Value	Design Criteria	Acceptance Criteria	Design Criteria Met	Acceptance Criteria Met	Date/ Time of Test	Preparer/ Reviewer
M/D Flux Map, 65% ≤ Power ≤ 75%						
Map Power Level (% Full Power) = 70.52						
Max Relative Assembly Power, %DIFF (M-P)/P					6/1/18 03:35	KLK/ TSP
%DIFF= -4.7 % for Pi ≥0.9 4.1 % for P_i<0.9	±10% for P_i ≥0.9 ±15% for P_i<0.9 (P_i = assy power)[1,2]	N/A	✓ Yes ___ No	N/A		
Nuclear Enthalpy Rise Hot Channel Factor, FΔH(N)						
FΔH(N)= 1.501	N/A	FΔH(N)≤1.635(1+0.3(1-P)) [COLR 3.7]	N/A	✓ Yes ___ No		
Total Heat Flux Hot Channel Factor, FQ(Z)						
Peak F_Q(Z) Hot Channel Factor= 1.943	N/A	F_Q(Z)≤(2.5/P)*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.0099	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0052, Rev. 0
3.) ETE-NAF-2018-0051, Rev. 0

Surry Power Station Unit 1 Cycle 29 Startup Physics Test Summary Sheet - Formal Tests (Page 5 of 6)

Measured Value	Design Criteria	Acceptance Criteria	Design Criteria Met	Acceptance Criteria Met	Date/ Time of Test	Preparer/ Reviewer
M/D Flux Map, 95% ≤ Power ≤ 100%						
Map Power Level (% Full Power) = 99.87						
Max Relative Assembly Power, %DIFF (M-P)/P					6/6/18 13:00	WMC DJA
%DIFF= -4.0 % for Pi ≥0.9 -4.0 % for P_i<0.9	±10% for P_i ≥0.9 ±15% for P_i<0.9 (P_i = assy power)[1,2]	N/A	✓ Yes ___ No	N/A		
Nuclear Enthalpy Rise Hot Channel Factor, FΔH(N)						
FΔH(N)= 1.486	N/A	FΔH(N)≤1.635(1+0.3(1-P)) [COLR 3.7]	N/A	✓ Yes ___ No		
Total Heat Flux Hot Channel Factor, FQ(Z)						
Peak $F_Q(Z)$ Hot Channel Factor= 1.893	N/A	$F_Q(Z)$≤{2.5/P}*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.0117	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0052, Rev. 0
3.) ETE-NAF-2018-0051, Rev. 0

Surry Power Station Unit 1 Cycle 29 Startup Physics Test Summary Sheet - Formal Tests (Page 6 of 6)

Measured Value	Design Criteria	Acceptance Criteria	Design Criteria Met	Acceptance Criteria Met	Date/ Time of Test	Preparer/ Reviewer
RCS Flow Measurement						
F_{Total}= 289495.6 gpm	N/A	$F_{total} \geq$ 274000 gpm [COLR 3.8]	N/A	✓ Yes ___ No	6/4/18 06:30	DJA / [illegible]

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0052, Rev. 0
3.) ETE-NAF-2018-0051, Rev. 0