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March 5, 2019

United States Nuclear Regulatory Commission
Regional Administrator – Region II
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Atlanta, Georgia 30303-1257

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VIRGINIA ELECTRIC AND POWER COMPANY
SURRY POWER STATION UNIT 2
CYCLE 29 STARTUP PHYSICS TESTS REPORT

As required by Surry Power Station (Surry) Technical Specification 6.6.A.1, enclosed is the Surry Unit 2 Cycle 29 Startup Physics Tests Report. This report summarizes the results of the physics testing program performed prior to and following initial criticality of Cycle 29 on December 5, 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

Commitments made in this letter: None

IE26
NRR

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ENCLOSURE

SURRY UNIT 2 CYCLE 29 STARTUP PHYSICS TESTS REPORT

February 2019

**Virginia Electric and Power Company
(Dominion Energy Virginia)
Surry Power Station Unit 2**

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PREFACE

This report presents the analysis and evaluation of the physics tests that were performed to verify that the Surry Unit 2 Cycle 29 (S2C29) 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. 12]. 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 S2C29 startup physics tests results and evaluation sheets are included as an appendix 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 it was 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's Nuclear Engineering and Fuel Group. The acceptance criteria are based on design tolerances or applicable Technical Specifications and COLR Limits.

Per Surry Technical Specification 6.6.A [Ref. 6], "the report shall address each of the tests identified in the FSAR and shall in general include a description of the measured values of the operating conditions or characteristics obtained during the test program, and a comparison of these values with design predictions and specifications." Per UFSAR Section 3.6.1.1 [Ref. 20], "a detailed series of start-up physics tests are performed," followed by references to core power distribution measurements, i.e., flux maps. The S2C29 Startup Physics Tests Report includes, as required, a description of measured values and a comparison of these values to design predictions of the tests performed during startup testing and the initial power ascension flux maps performed thereafter.

SECTION 1 — INTRODUCTION AND SUMMARY

On October 27, 2018, Unit No. 2 of Surry Power Station completed Cycle 28 and began refueling [Ref. 1]. During this refueling, 84 of the 157 fuel assemblies in the core were replaced with 64 fresh Batch S2/31 assemblies and 20 twice-burned Batch S1/29 assemblies last irradiated in Surry 1 Cycle 28 [Ref. 1]. The Cycle 29 core consists of 9 sub-batches of fuel: three fresh batches (S2/31A, S2/31B and S2/31C), two once-burned batches (S1/30A and S2/30A), and four twice-burned batches (S1/29A, S1/29B, S1/29C and S2/29B). Like the previous cycle, S2C29 will have a full core of the 15x15 Upgrade Fuel Design [Ref. 1]. One batch S2/30A assembly (Assembly 817 in Full-core location M-08) was reconstituted with a single stainless steel rod [Ref. 14].

The Westinghouse Upgrade fuel includes three ZIRLO Intermediate Flow Mixing (IFM) grids for improved thermal-hydraulic performance, ZIRLO (I-spring) structural mid grids with balanced mixing vane pattern, "tube-in-tube" guide thimbles, and 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. The Upgrade fuel used for all batches includes the Westinghouse Robust Protective Grid (RPG), modified Debris Filter Bottom Nozzle (mDFBN) and the Westinghouse Integrated Top Nozzle (WIN) [Ref. 13].

This cycle uses Westinghouse's Integral Fuel Burnable Absorber (IFBA) fuel product. 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].

Cycle 29 loads two Secondary Source Assemblies (SSAs) in core locations H-04 and H-12 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 S2C29. The cycle design report [Ref. 1] provides a more detailed description of the Cycle 29 core.

The S2C29 full core loading plan [Ref. 2] is given in Figure 1.1, and the beginning of cycle fuel assembly burnups [Ref. 18] are given in Figure 1.2. The in-core moveable detector locations used for the flux map analyses [Ref. 11] 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 December 5, 2018 at 11:59 [Ref. 3]. 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 S2C29 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 seconds Technical Specification [Ref. 6] limit, as well as the 1.68 seconds 15x15 Upgrade Fuel administrative limit [Ref. 8].

Individual control rod bank worths were measured using the rod swap technique [Ref. 4]. 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. 10]. The sum of the individual measured control rod bank worths was within -2.2% of the design prediction. The reference bank (Control Bank B) worth was within -1.7% of its design prediction. Control rod banks with design predictions greater than 600 pcm were within -6.7% of the design predictions. Control rod banks with design predictions less than 600 pcm (Control Bank A) were within 18 pcm of the design prediction. These results are within the design tolerances of $\pm$15% for individual banks worth more than 600 pcm ($\pm$10% for the reference bank worth), $\pm$100 pcm for individual banks worth 600 pcm or less, and $\pm$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. 6] that the overall core reactivity balance shall be within $\pm 1\%$ $\Delta k/k$ of the design prediction. The boron worth coefficient measurement was within -1.7% of the design prediction, which is within the design tolerance of $\pm 10\%$.

The measured isothermal temperature coefficient (ITC) for the ARO configuration was within -0.189 pcm/°F of the design prediction. This result is within the design tolerance of ± 2.0 pcm/°F.

All zero power physics testing results met the tighter criteria permitting the first flux map analysis to be performed as high as 50% power (versus 30% power).

The Reactor Coolant Pump (RCP) start sequence is as follows: 'C' RCP started on 12/01/18 at 10:21, 'A' RCP started on 12/01/18 at 15:40, and 'B' RCP started on 12/03/18 at 09:47 [Appendix A].

Core power distributions were all within established design tolerances. The measured assembly power distributions were within $\pm 8.7\%$ of the design predictions, where an 8.7% maximum difference occurred in the 26.94% power map. The heat flux hot channel factors, $F_Q(Z)$, and enthalpy rise hot channel factors, $F_{\Delta H}^{N}$, were within the limits of the COLR [Ref. 13]. The first power ascension flux map was not within the maximum incore quadrant power tilt design tolerance of 2%. (QPTR < 1.02). NEF performed a review to confirm that the measured quadrant tilt for this map was bounded by the current safety analysis [Ref. 13]. The subsequent two power ascension flux maps had power tilts within this design tolerance, so no additional assessment was performed. The tilt is expected to remain within the design tolerance for the remainder of the cycle. The maximum positive in-core quadrant power tilts ranged from 2.87% to 1.57% during the power ascension.

The total RCS Flow was 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. 6]. The total RCS Flow at nominal conditions was measured as 290,012 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 2 – CYCLE 29
CHRONOLOGY OF TESTS

Test	Date	Time	Power	Reference Procedure
Hot Rod Drop-Hot Full Flow	12/04/18	19:50	HSD	2-NPT-RX-014
Reactivity Computer Checkout	12/05/18	13:21	HZP	2-NPT-RX-008
Boron Endpoint – ARO	12/05/18	13:21	HZP	2-NPT-RX-008
Zero Power Testing Range	12/05/18	13:21	HZP	2-NPT-RX-008
Boron Worth Coefficient	12/05/18	14:50	HZP	2-NPT-RX-008
Temperature Coefficient – ARO	12/05/18	13:45	HZP	2-NPT-RX-008
Bank B Worth	12/05/18	14:50	HZP	2-NPT-RX-008
Boron Endpoint – B in	12/05/18	14:50	HZP	2-NPT-RX-008
Bank A Worth – Rod Swap	12/05/18	17:07	HZP	2-NPT-RX-008
Bank C Worth – Rod Swap	12/05/18	17:07	HZP	2-NPT-RX-008
Bank SA Worth – Rod Swap	12/05/18	17:07	HZP	2-NPT-RX-008
Bank SB Worth – Rod Swap	12/05/18	17:07	HZP	2-NPT-RX-008
Bank D Worth – Rod Swap	12/05/18	17:07	HZP	2-NPT-RX-008
Total Rod Worth	12/05/18	17:07	HZP	2-NPT-RX-008
Flux Map – less than 50% Power* Peaking Factor Verification & Power Range Calibration	12/06/18	15:51	26.94%	2-NPT-RX-002 2-NPT-RX-008 2-NPT-RX-005 2-GEP-RX-001
Flux Map – 65% - 75% Power Peaking Factor Verification & Power Range Calibration	12/07/18	15:45	70.57%	2-NPT-RX-002 2-NPT-RX-008 2-NPT-RX-005 2-GEP-RX-001
Flux Map – 95% - 100% Power Peaking Factor Verification & Power Range Calibration	12/11/18	09:52	99.89%	2-NPT-RX-002 2-NPT-RX-008 2-NPT-RX-005 2-GEP-RX-001
RCS Flow Measurement	12/10/18	10:00	HFP	2-NPT-RX-009

* Results of zero power physics testing permitted the first flux map to be performed up to 50% power (versus 30% power if specified criteria were not met). The first flux map was performed below 30% power in anticipation of a required chemistry hold.

Figure 1.1

SURRY UNIT 2 – CYCLE 29 CORE LOADING MAP

SURRY UNIT 2 - CYCLE 29
FULL CORE LOADING PLAN
REVISION NO. 0

ETE-NAF-2018-0065 REV. 0 ATTACHMENT 1
PAGE 1 OF 1

VEP-NES-NAF

NORTH ↑

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							764	301	760						
2					360	RCC 847	938	RCC 946	941	RCC 852	362				
3				331	950	957	RCC 916	810	RCC 919	959	954	328			
4			326	RCC 909	905	RCC 808	815	358 809	814	RCC 803	904	RCC 912	329		
5		364	953	902	RCC 420	844	931	415	926	842	RCC 416	908	951	363	
6		RCC 843	961	RCC 806	851	RCC 914	825	RCC 936	831	RCC 923	853	RCC 804	962	RCC 849	
7	758	943	RCC 921	823	925	830	RCC 837	839	RCC 836	832	929	812	RCC 913	939	762
8 (90°)	307	RCC 940	824	817	419	RCC 934	834	857	835	RCC 935	417	818	816	RCC 948	308
9	761	947	RCC 917	822	928	826	RCC 833	840	RCC 838	829	933	819	RCC 924	945	763
10		RCC 854	960	RCC 801	848	RCC 920	828	RCC 930	827	RCC 918	850	RCC 807	958	RCC 856	
11		359	955	910	RCC 414	846	932	413	927	855	RCC 418	901	956	361	
12			327	RCC 907	903	RCC 805	813	SS9 811	821	RCC 802	906	RCC 911	336		
13				338	952	963	RCC 922	820	RCC 915	964	949	339			
14					365	RCC 841	937	RCC 944	942	RCC 845	358				
15							759	305	757						

0°

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

Prepared By: [signature] S. B. Rosenfelder Date: 05/14/18

Concurrence By: [signature] B. S. Williamson Date: 5/17/18

Reviewed By: [signature] B. R. Kinney Date: 5/14/18

Approved By: [signature] A. H. Nicholson Date: 5/21/18

Approved By: [signature] M. N. LaPrade Date: 5/21/18

Figure 1.2

SURRY UNIT 2 – 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							35.24 35.31	40.66 41.06	35.42 35.27							1
2					40.47 40.51	24.73 24.94	0.00 0.00	0.00 0.00	0.00 0.00	24.80 24.87	40.55 40.51					2
3				41.29 41.41	0.00 0.00	0.00 0.00	0.00 0.00	21.51 21.26	0.00 0.00	0.00 0.00	0.00 0.00	41.59 41.43				3
4			41.90 41.48	0.00 0.00	0.00 0.00	19.82 19.86	19.53 19.51	20.55 20.27	19.68 19.54	19.90 19.90	0.00 0.00	0.00 0.00	41.64 41.46			4
5		41.60 41.40	0.00 0.00	0.00 0.00	23.71 23.45	24.16 24.25	0.00 0.00	23.30 23.38	0.00 0.00	24.02 24.23	23.56 23.48	0.00 0.00	0.00 0.00	41.18 41.30		5
6		24.77 24.81	0.00 0.00	19.94 19.89	24.19 24.21	0.00 0.00	23.75 23.48	0.00 0.00	23.41 23.43	0.00 0.00	24.37 24.25	19.94 19.87	0.00 0.00	24.87 24.89		6
7	35.37 35.24	0.00 0.00	0.00 0.00	19.79 19.53	0.00 0.00	23.31 23.42	24.66 24.64	24.35 24.62	24.69 24.65	23.43 23.47	0.00 0.00	19.51 19.50	0.00 0.00	0.00 0.00	35.27 35.26	7
8	41.36 41.20	0.00 0.00	21.52 21.26	20.18 20.25	23.61 23.41	0.00 0.00	24.52 24.61	21.49 21.61	24.52 24.62	0.00 0.00	23.40 23.42	20.27 20.25	21.30 21.25	0.00 0.00	41.12 41.20	8
9	35.05 35.24	0.00 0.00	0.00 0.00	19.45 19.51	0.00 0.00	23.89 23.47	24.37 24.65	24.73 24.62	24.55 24.63	23.46 23.41	0.00 0.00	19.45 19.53	0.00 0.00	0.00 0.00	35.70 35.25	9
10		24.79 24.90	0.00 0.00	19.92 19.86	24.09 24.25	0.00 0.00	23.50 23.43	0.00 0.00	23.45 23.48	0.00 0.00	24.04 24.21	19.98 19.89	0.00 0.00	24.56 24.82		10
11		41.13 41.30	0.00 0.00	0.00 0.00	23.47 23.49	24.26 24.23	0.00 0.00	23.44 23.37	0.00 0.00	24.33 24.25	23.46 23.45	0.00 0.00	0.00 0.00	41.22 41.40		11
12			41.52 41.46	0.00 0.00	0.00 0.00	20.25 19.90	19.48 19.54	20.13 20.27	19.36 19.51	20.01 19.86	0.00 0.00	0.00 0.00	41.37 41.48			12
13				41.43 41.42	0.00 0.00	0.00 0.00	0.00 0.00	21.23 21.26	0.00 0.00	0.00 0.00	0.00 0.00	41.16 41.41				13
14					40.54 40.51	24.78 24.87	0.00 0.00	0.00 0.00	0.00 0.00	25.13 24.94	40.09 40.51					14
15							35.35 35.25	40.75 41.06	35.32 35.30							15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 1.3

SURRY UNIT 2 – CYCLE 29
AVAILABLE INCORE MOVEABLE DETECTOR LOCATIONS

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

MD - Moveable Detector
\+ - Location not used for any map.

Figure 1.4

SURRY UNIT 2 – 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		270° 8
			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 2-NPT-RX-014. This verified that 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. 6].

S2C29 used the Rod Drop Measurement Instrument (RDMI) to gather and analyze the rod drop data [Ref. 7]. The rod drop times were measured by withdrawing all banks to their fully withdrawn position and dropping all of the 48 control rods by opening the reactor trip breakers. This allowed the rods to drop into the core as they would during a plant trip.

The current 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. Further details about the RDMI can be found in Reference 7.

A typical rod drop trace for S2C29 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 2 cycles 20-29. Technical Specification 3.12.C.1 [Ref. 6] specifies a maximum rod drop time to dashpot entry of 2.4 seconds for all rods. These test results satisfied this Technical Specification limit as well as the administrative limit [Ref. 8] 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. The average rod drop time of 1.36 seconds for S2C29 increased slightly from 1.35 seconds for S2C28.

Table 2.1

SURRY UNIT 2 – CYCLE 29 STARTUP PHYSICS TESTS
HOT ROD DROP TIME SUMMARY

ROD DROP TIME TO DASHPOT ENTRY

SLOWEST ROD	FASTEST ROD(S)	AVERAGE TIME
G-13 1.47 sec.	L-05/K-04 1.32 sec.	1.36 sec.

Figure 2.1

SURRY UNIT 2 – CYCLE 29 STARTUP PHYSICS TESTS
TYPICAL ROD DROP TRACE

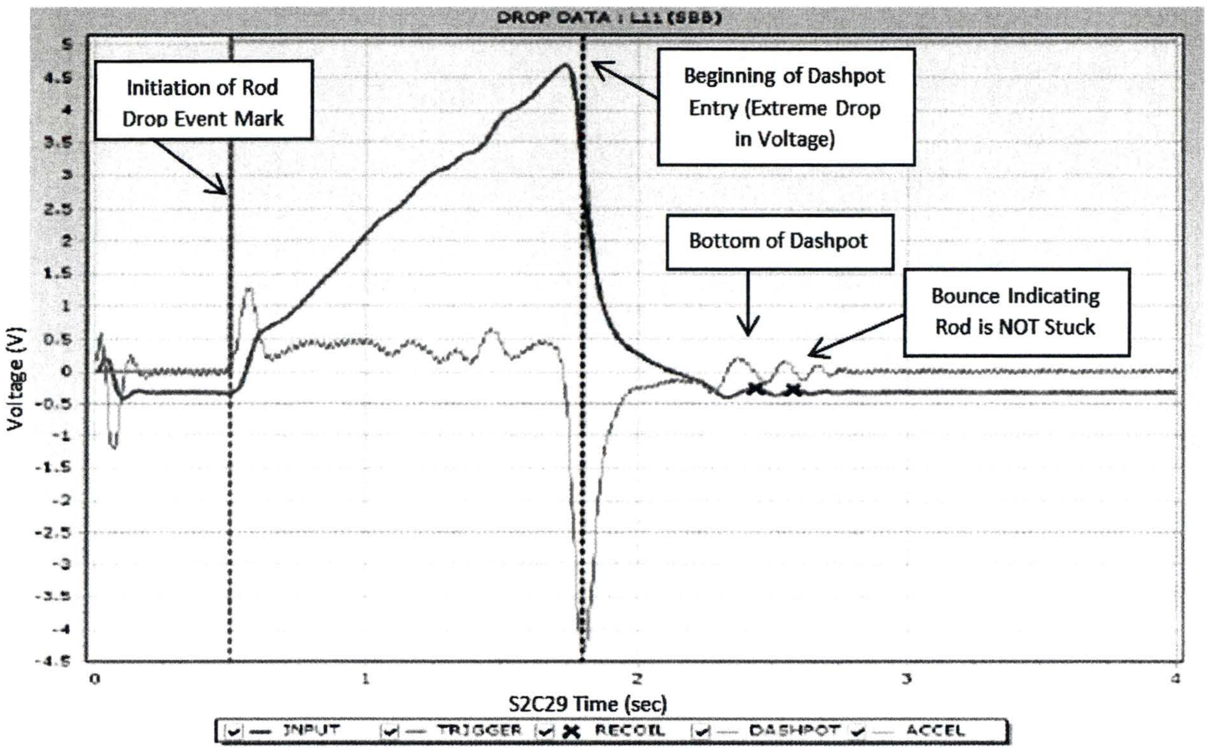


Figure 2.2

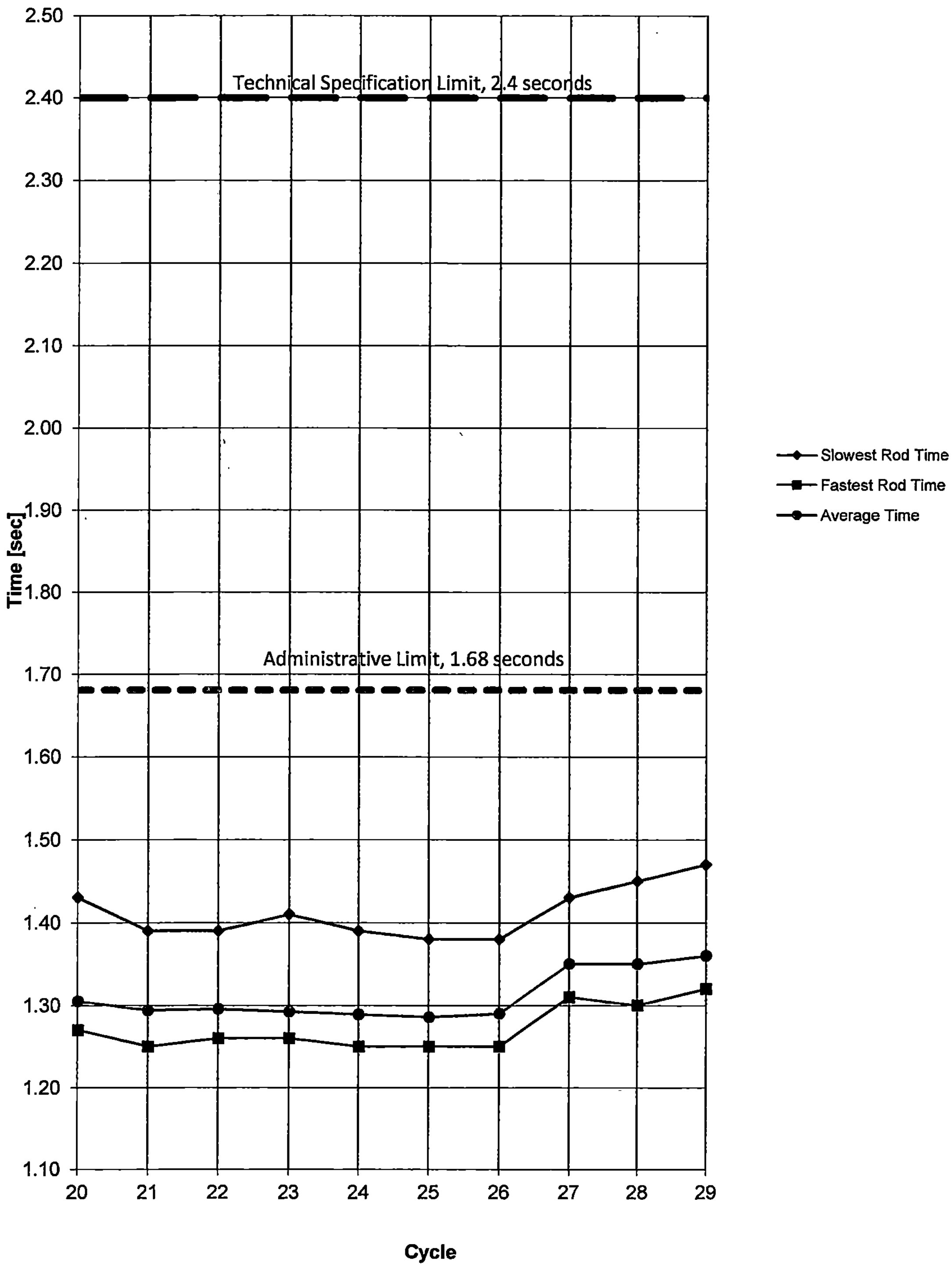
SURRY UNIT 2 – CYCLE 29 STARTUP PHYSICS TESTS
ROD DROP TIME – HOT FULL FLOW CONDITIONS

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1															
2						1.356		1.344		1.350					
3							1.346		1.352						
4				1.342		1.322				1.370		1.360			
5					1.322						1.354				
6		1.330		1.348		1.344		1.350		1.428		1.332		1.430	
7			1.344				1.370		1.380				1.354		
8		1.338				1.342				1.340				1.380	
9			1.358				1.364		1.370				1.334		
10		1.358		1.332		1.362		1.354		1.374		1.346		1.374	
11					1.344						1.368				
12				1.338		1.342				1.342		1.352			
13							1.340		1.466						
14						1.388		1.340		1.364					
15															

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

Figure 2.3

SURRY UNIT 2 – 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. 4]. 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 2 targeted a dilution rate around 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. 10], 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 S2C29 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 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 reference 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 Tests Summary Sheets provided 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 within -2.2% of 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 2 – 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	1365	1389	-1.7%
A	276	258	18 pcm*
C	731	781	-6.4%
SA	1000	973	+2.7%
SB	998	1070	-6.7%
D	1085	1107	-1.9%
Total Bank Worth	5456	5578	-2.2%

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

Figure 3.1

SURRY UNIT 2 – CYCLE 29 STARTUP PHYSICS TESTS
CONTROL BANK B INTEGRAL ROD WORTH - HZP
ALL OTHER RODS WITHDRAWN

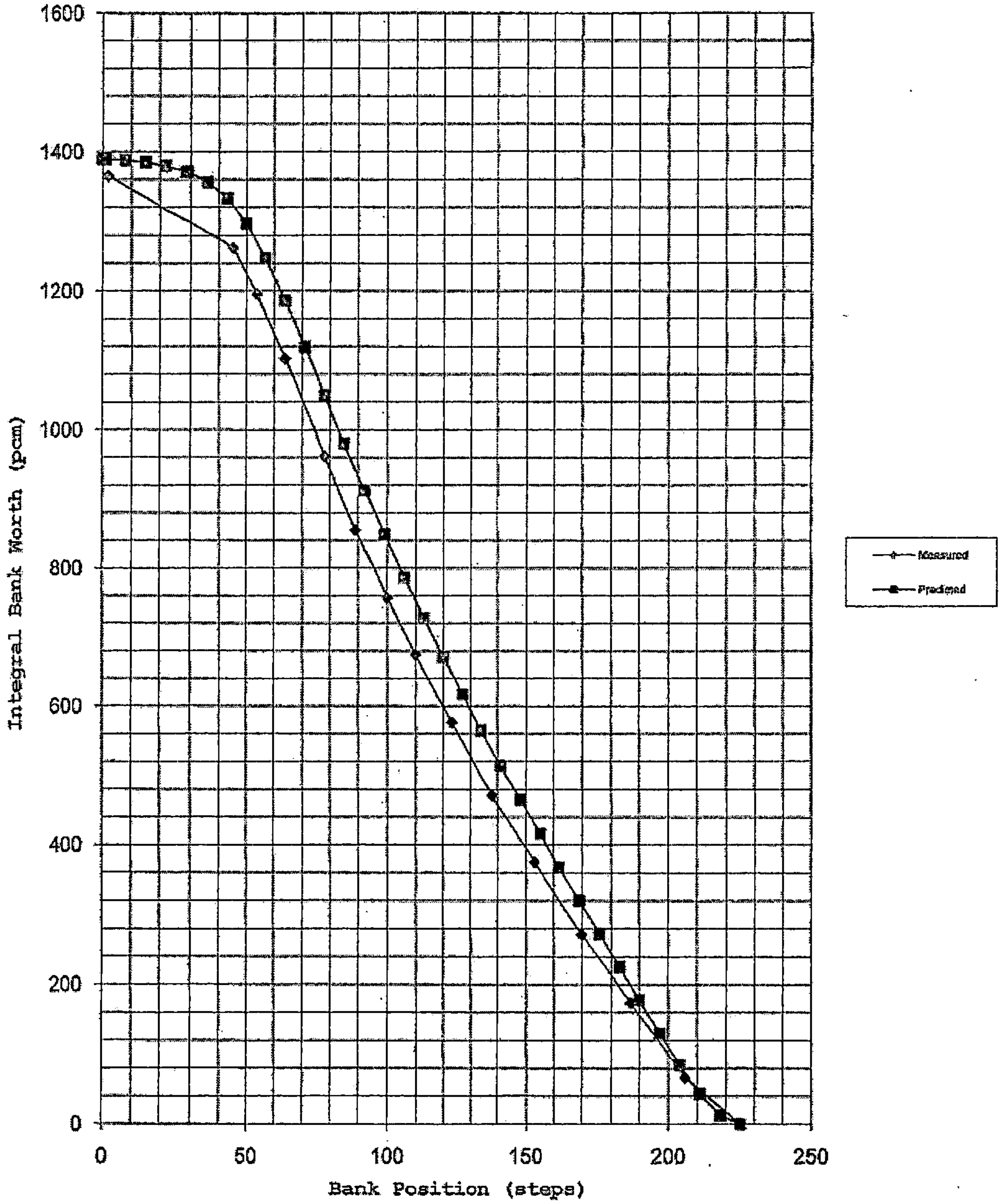
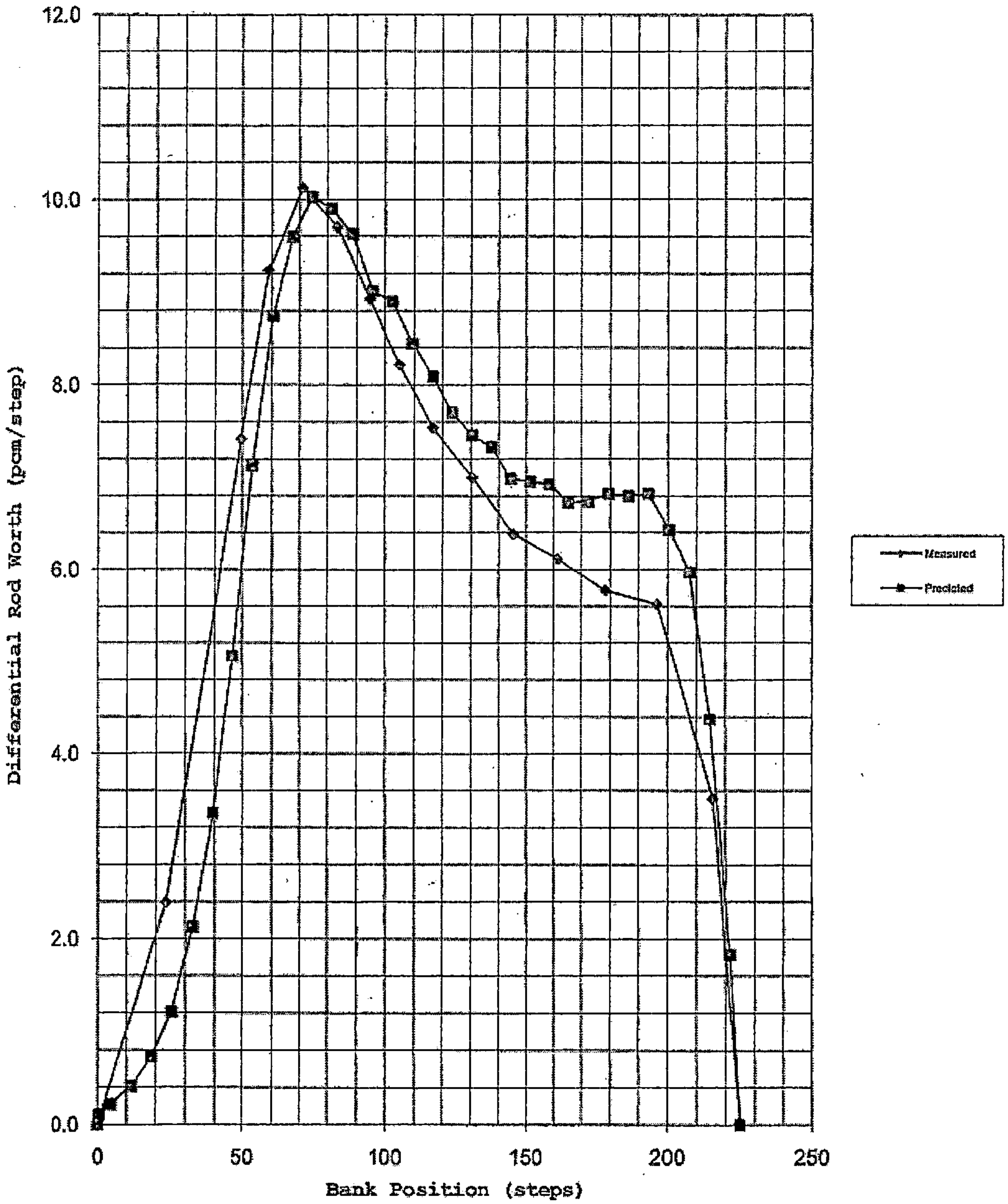


Figure 3.2

SURRY UNIT 2 – 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 Tests Summary Sheets provided 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. 6] 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 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 2 – CYCLE 29 STARTUP PHYSICS TESTS
BORON ENDPOINTS SUMMARY

Control Rod Configuration	Measured Endpoint (ppm)	Predicted Endpoint (ppm)	Difference M-P (ppm)
ARO	1556	1545	+11
B Bank In	1376.6	1377*	-0.4

* 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 Tests Summary Sheet in Appendix B.

Table 4.2

SURRY UNIT 2 – CYCLE 29 STARTUP PHYSICS TESTS
BORON WORTH COEFFICIENT

Measured Boron Worth (pcm/ppm)	Predicted Boron Worth (pcm/ppm)	Percent Difference $\frac{(M-P)}{P} \times 100$ (%)
-7.63	-7.76	-1.7

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 3.41 °F, followed by the RCS cool down of 2.87 °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 Tests Summary Sheet provided in Appendix B, the measured ITC value was within the design tolerance of $\pm$2 pcm/°F. The calculated moderator temperature coefficient (MTC), which is calculated using a measured ITC of -2.019 pcm/°F, a predicted doppler temperature coefficient (DTC) of -1.66 pcm/°F, and a measurement uncertainty of +0.5 pcm/°F, is +0.141 pcm/°F. It thus satisfies the COLR criteria [Ref. 13] which indicates MTC at HZP be less than or equal to +6.0 pcm/°F.

Table 5.1

SURRY UNIT 2 – CYCLE 29 STARTUP PHYSICS TESTS
ISOTHERMAL TEMPERATURE COEFFICIENT SUMMARY

BANK POSITION (STEPS)	TEMPERATURE RANGE (°F)		BORON CONCENTRATION (ppm)	ISOTHERMAL TEMPERATURE COEFFICIENT (PCM/°F)				
	LOWER	UPPER		HEAT-UP	COOL-DOWN	AVG. MEAS	PRED	DIFFER (M-P)
D/207	546.29	549.73	1550.0	-2.154	-1.883	-2.019	-1.830	-0.189

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 49 available locations monitored by the moveable detectors for Cycle 29 power ascension flux maps. As noted in Figure 1.3, one thimble location (R8) was determined to be unusable during the incore checkout and was not attempted during the 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. 15, Ref. 16]. 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. 17) was used as an interface to CEBRZ and CECOR.

A list of the full-core flux maps [Ref. 11] 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 26.94% 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 70.57%, and 99.89% 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, respectively.

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 ±8.7% in the 26.94% power map, ±5.3% in the 70.57% power map, and ±5.2% in the 99.89% power map. The maximum positive incore quadrant power tilts for the three maps were 2.87%, 1.78%, and 1.57%, respectively. The tilt from the 26.94% power map was reviewed to confirm that the 2.87% measured quadrant tilt was bounded by the current safety analysis [Ref. 13]. The remaining power tilts were 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. 13]. Flux Maps 1 through 3 were used for power range detector calibration or to confirm existing calibrations.

Due to the reconstituted rod in Assembly 817 (full-core location M-08), a reduced $F_{\Delta H}^N$ limit of 1.619 (1% less than the nominal value of 1.635; at 100% power) was imposed. This is tracked in the monthly flux maps as "Fuel Type 2". Through the first three power ascension maps, the $F_{\Delta H}^N$ has not been limiting in Assembly 817 for either maximum peaking or minimum margin to the limit. These are denoted in Table 6.2 with (M-08).

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. 13]. It is therefore anticipated that the core will continue to operate safely throughout Cycle 29.

Table 6.1

SURRY UNIT 2 – 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)			$F_{\Delta H}^N$ Hot (2) Channel Factor		Core F_Z Max		Core Tilt (3)		Axial Offset (%)	No. Of Thimbles
						Assy	Axial Point	$F_Q(Z)$	Assy	$F_{\Delta H}^N$	Axial Point	F_Z	Max	Loc		
Low Power	1	12/06/18	2.0	26.94	169	H-13	27	2.318	J-12	1.584	26	1.377	1.0287	SW	4.887	49
Int. Power (4)	2	12/07/18	17.0	70.57	197	J-12	26	1.998	J-12	1.528	26	1.224	1.0178	SW	3.620	49
Hot Full Power	3	12/11/18	138.0	99.89	224	J-12	30	1.892	J-12	1.497	30	1.183	1.0157	SW	1.615	49

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) $F_{\Delta H}^N$ 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 2 – CYCLE 29 STARTUP PHYSICS TESTS
COMPARISION OF MEASURED POWER DISTRIBUTION
PARAMETERS WITH THEIR CORE OPERATING LIMITS

	Peak $F_Q(Z)$ Hot Channel Factor				$F_{\Delta H}^N$ Hot Channel Factor		
Map No.	Meas.	Limit	Node	Margin* (%)	Meas.	Limit	Margin* (%)
1	2.318	5.000	27	53.6	1.584	1.993	20.5
(M-08)	N/A				1.546	1.974	21.7
2	1.998	3.543	26	43.6	1.528	1.779	14.1
(M-08)	N/A				1.495	1.762	15.1
3	1.892	2.503	30	24.4	1.497	1.636	8.4
(M-08)	N/A				1.470	1.620	9.2

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

(M-08) is the $F_{\Delta H}^N$ data for Assembly 817 (reconstituted assembly) only.

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

Figure 6.1 — ASSEMBLYWISE POWER DISTRIBUTION
26.94% 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							0.264	0.293	0.267						
							0.274	0.299	0.274						
							-3.58	-1.98	-2.59						
2					0.266	0.555	0.941	1.014	0.955	0.568	0.270				
					0.276	0.579	0.980	1.044	0.983	0.582	0.277				
					-3.71	-4.07	-3.93	-2.87	-2.88	-2.42	-2.68				
3				0.327	0.877	1.070	1.187	1.268	1.215	1.088	0.885	0.330			
				0.334	0.910	1.117	1.246	1.297	1.253	1.122	0.912	0.334			
				-2.01	-3.61	-4.18	-4.76	-2.21	-3.05	-3.06	-2.98	-1.33			
4			0.327	0.931	1.255	1.271	1.300	1.293	1.325	1.286	1.257	0.933	0.326		
			0.335	0.959	1.299	1.327	1.366	1.367	1.380	1.332	1.299	0.957	0.333		
			-2.35	-2.94	-3.41	-4.19	-4.86	-5.38	-4.00	-3.48	-3.24	-2.56	-1.96		
5		0.270	0.900	1.268	1.166	1.178	1.172	1.112	1.190	1.187	1.167	1.271	0.897	0.268	
		0.274	0.918	1.307	1.217	1.232	1.235	1.173	1.241	1.235	1.214	1.300	0.910	0.272	
		-1.34	-1.92	-2.97	-4.20	-4.42	-5.12	-5.20	-4.08	-3.90	-3.88	-2.22	-1.48	-1.31	
6		0.582	1.117	1.313	1.191	1.120	1.111	1.085	1.133	1.119	1.199	1.311	1.120	0.595	
		0.588	1.135	1.346	1.244	1.170	1.171	1.158	1.173	1.169	1.237	1.337	1.127	0.584	
		-1.03	-1.58	-2.48	-4.29	-4.27	-5.13	-6.31	-3.37	-4.27	-3.04	-1.92	-0.65	1.92	
7	0.278	0.996	1.267	1.388	1.227	1.141	1.108	1.129	1.181	1.146	1.219	1.366	1.269	1.046	0.291
	0.278	0.998	1.275	1.406	1.257	1.179	1.165	1.164	1.165	1.176	1.248	1.389	1.266	0.994	0.278
	0.14	-0.21	-0.61	-1.29	-2.37	-3.26	-4.85	-2.98	1.34	-2.54	-2.32	-1.69	0.26	5.25	4.52
8	0.306	1.069	1.341	1.421	1.183	1.147	1.139	1.197	1.139	1.107	1.166	1.405	1.316	1.078	0.310
	0.303	1.062	1.325	1.420	1.192	1.166	1.167	1.225	1.167	1.166	1.192	1.420	1.325	1.062	0.303
	0.84	0.68	1.22	0.08	-0.74	-1.60	-2.41	-2.29	-2.39	-5.07	-2.19	-1.07	-0.68	1.51	2.32
9	0.282	1.010	1.290	1.406	1.247	1.174	1.156	1.148	1.124	1.160	1.250	1.409	1.282	1.011	0.284
	0.278	0.994	1.266	1.389	1.248	1.176	1.165	1.164	1.165	1.179	1.257	1.406	1.275	0.998	0.278
	1.34	1.66	1.91	1.19	-0.05	-0.21	-0.79	-1.40	-3.48	-1.60	-0.55	0.20	0.58	1.31	1.99
10		0.601	1.169	1.373	1.263	1.187	1.184	1.169	1.172	1.173	1.259	1.370	1.155	0.601	
		0.584	1.127	1.337	1.237	1.169	1.173	1.158	1.171	1.170	1.244	1.346	1.134	0.588	
		2.97	3.77	2.70	2.14	1.51	0.90	0.95	0.12	0.30	1.20	1.76	1.87	2.26	
11		0.282	0.949	1.351	1.267	1.278	1.282	1.220	1.267	1.250	1.257	1.354	0.948	0.282	
		0.272	0.910	1.300	1.214	1.235	1.241	1.173	1.235	1.232	1.216	1.306	0.917	0.274	
		3.62	4.30	3.90	4.38	3.47	3.33	4.00	2.57	1.45	3.40	3.65	3.36	3.10	
12			0.359	1.001	1.359	1.391	1.443	1.436	1.428	1.382	1.360	1.025	0.361		
			0.333	0.957	1.299	1.332	1.380	1.367	1.366	1.327	1.299	0.959	0.335		
			7.68	4.61	4.60	4.45	4.55	5.06	4.57	4.16	4.73	6.87	7.66		
13				0.350	0.957	1.180	1.326	1.391	1.326	1.182	0.959	0.355			
				0.334	0.912	1.122	1.253	1.297	1.246	1.117	0.910	0.334			
				4.80	4.90	5.20	5.86	7.27	6.45	5.82	5.39	6.24			
14					0.294	0.615	1.047	1.120	1.065	0.620	0.293				
					0.277	0.582	0.983	1.044	0.980	0.579	0.276				
					6.03	5.75	6.47	7.32	8.67	7.00	6.09				
15							0.296	0.322	0.297						
							0.274	0.299	0.274						
							8.17	7.78	8.34						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 3.2
STANDARD DEVIATION = 1.985

Summary:

Map No: S2-29-01
Control Rod Position:
D Bank at 169 Steps

Date: 12/06/2018

$F_Q(Z)$ = 2.318

$F^N_{\Delta H}$ = 1.584

F_Z = 1.377

Burnup = 2.0 MWD/MTU

Power: 26.94%

QPTR:		
	0.9698	0.9767
	1.0287	1.0249

Axial Offset (%) = +4.887

Figure 6.2 — ASSEMBLYWISE POWER DISTRIBUTION
70.57% POWER

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

Row	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.292	0.328	0.295						
							0.298	0.329	0.298						
							-1.99	-0.16	-0.95						
2					0.283	0.583	0.984	1.092	0.997	0.597	0.287				
					0.289	0.598	1.008	1.108	1.010	0.601	0.290				
					-2.21	-2.46	-2.39	-1.46	-1.24	-0.68	-1.19				
3				0.341	0.893	1.082	1.198	1.277	1.226	1.100	0.900	0.344			
				0.345	0.912	1.112	1.239	1.291	1.244	1.115	0.913	0.345			
				-1.17	-2.06	-2.65	-3.31	-1.05	-1.48	-1.36	-1.40	-0.36			
4			0.340	0.938	1.252	1.268	1.297	1.288	1.317	1.283	1.252	0.942	0.340		
			0.345	0.955	1.274	1.300	1.335	1.332	1.347	1.304	1.275	0.954	0.344		
			-1.52	-1.73	-1.74	-2.45	-2.86	-3.28	-2.24	-1.64	-1.84	-1.29	-1.13		
5		0.283	0.903	1.254	1.169	1.196	1.196	1.129	1.200	1.202	1.165	1.263	0.903	0.282	
		0.286	0.917	1.280	1.202	1.228	1.225	1.162	1.231	1.230	1.200	1.275	0.911	0.284	
		-1.05	-1.54	-2.00	-2.79	-2.57	-2.34	-2.82	-2.52	-2.25	-2.91	-0.98	-0.84	-0.73	
6		0.600	1.111	1.291	1.198	1.189	1.148	1.123	1.149	1.195	1.207	1.291	1.109	0.600	
		0.604	1.123	1.313	1.236	1.221	1.180	1.159	1.182	1.220	1.231	1.306	1.117	0.602	
		-0.68	-1.03	-1.71	-3.05	-2.62	-2.71	-3.07	-2.77	-2.09	-1.95	-1.14	-0.67	-0.35	
7	0.301	1.019	1.257	1.355	1.225	1.164	1.133	1.129	1.128	1.153	1.214	1.339	1.249	1.021	0.302
	0.301	1.020	1.260	1.366	1.242	1.186	1.167	1.162	1.167	1.184	1.235	1.352	1.253	1.018	0.301
	-0.07	-0.11	-0.23	-0.78	-1.40	-1.89	-2.93	-2.84	-3.37	-2.60	-1.68	-1.00	-0.32	0.28	0.28
8	0.332	1.122	1.312	1.378	1.178	1.156	1.146	1.193	1.134	1.125	1.161	1.373	1.316	1.127	0.334
	0.332	1.120	1.311	1.378	1.176	1.165	1.164	1.216	1.164	1.165	1.176	1.378	1.311	1.120	0.332
	0.14	0.18	0.10	0.02	0.13	-0.77	-1.52	-1.93	-2.58	-3.44	-1.27	-0.34	0.35	0.65	0.62
9	0.302	1.024	1.262	1.362	1.242	1.186	1.163	1.152	1.149	1.184	1.243	1.374	1.270	1.030	0.305
	0.301	1.018	1.253	1.352	1.235	1.184	1.167	1.162	1.167	1.186	1.242	1.366	1.259	1.020	0.301
	0.40	0.61	0.74	0.76	0.60	0.19	-0.34	-0.84	-1.54	-0.14	0.04	0.56	0.84	0.93	1.20
10		0.609	1.136	1.326	1.249	1.234	1.190	1.166	1.184	1.227	1.247	1.335	1.140	0.612	
		0.602	1.117	1.306	1.231	1.220	1.182	1.159	1.180	1.221	1.236	1.313	1.123	0.604	
		1.21	1.73	1.56	1.46	1.15	0.70	0.57	0.34	0.51	0.93	1.68	1.53	1.39	
11		0.290	0.933	1.304	1.231	1.258	1.258	1.187	1.245	1.242	1.219	1.310	0.938	0.292	
		0.284	0.911	1.275	1.199	1.230	1.231	1.162	1.225	1.228	1.202	1.279	0.917	0.286	
		1.94	2.37	2.29	2.70	2.30	2.22	2.14	1.67	1.15	1.38	2.39	2.30	2.03	
12			0.361	0.981	1.312	1.344	1.396	1.376	1.373	1.333	1.310	0.999	0.363		
			0.344	0.954	1.275	1.304	1.347	1.332	1.335	1.300	1.274	0.955	0.345		
			4.93	2.86	2.91	3.04	3.65	3.29	2.82	2.55	2.84	4.56	5.28		
13				0.355	0.941	1.152	1.292	1.346	1.286	1.150	0.942	0.358			
				0.345	0.913	1.115	1.244	1.291	1.239	1.112	0.912	0.345			
				2.90	3.07	3.39	3.87	4.29	3.76	3.43	3.24	3.89			
14					0.297	0.621	1.050	1.156	1.056	0.622	0.299				
					0.290	0.601	1.011	1.108	1.008	0.598	0.289				
					2.29	3.40	3.91	4.35	4.76	4.03	3.54				
15							0.310	0.344	0.312						
							0.298	0.329	0.298						
							4.16	4.46	4.55						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 1.9
STANDARD DEVIATION = 1.240

Summary:

Map No: S2-29-02
Control Rod Position:
D Bank at 197 Steps

Specificat12/07/2018
$F_Q(Z)$ = 1.998
$F^N_{\Delta H}$ = 1.528
F_Z = 1.224
Burnup = 17.0 MWD/MTU

Power: 70.57%

QPTR:		
	0.9819	0.9839
	1.0178	1.0164

Axial Offset (%) = +3.620

Figure 6.3 — ASSEMBLYWISE POWER DISTRIBUTION
99.89% 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
							0.304	0.341	0.306						
1							0.309	0.345	0.309						
							-1.70	-1.06	-1.03						
					0.288	0.591	0.991	1.121	1.000	0.597	0.291				
2					0.295	0.604	1.011	1.135	1.013	0.606	0.295				
					-2.24	-2.14	-1.98	-1.25	-1.28	-1.56	-1.20				
				0.341	0.885	1.075	1.196	1.270	1.218	1.092	0.896	0.346			
3				0.349	0.905	1.101	1.227	1.280	1.232	1.104	0.906	0.349			
				-2.30	-2.23	-2.38	-2.56	-0.79	-1.10	-1.01	-1.08	-0.96			
			0.343	0.926	1.227	1.252	1.286	1.283	1.309	1.278	1.239	0.933	0.344		
4			0.350	0.946	1.254	1.281	1.317	1.313	1.328	1.285	1.254	0.945	0.348		
			-1.89	-2.10	-2.13	-2.26	-2.34	-2.28	-1.46	-0.55	-1.18	-1.23	-1.16		
		0.288	0.894	1.231	1.158	1.201	1.202	1.139	1.211	1.214	1.170	1.238	0.893	0.283	
5		0.292	0.909	1.258	1.194	1.231	1.229	1.164	1.234	1.233	1.192	1.254	0.904	0.290	
		-1.28	-1.60	-2.14	-2.98	-2.45	-2.19	-2.11	-1.84	-1.51	-1.87	-1.26	-1.25	-2.49	
		0.605	1.098	1.271	1.204	1.240	1.170	1.146	1.172	1.245	1.215	1.273	1.095	0.602	
6		0.609	1.111	1.293	1.238	1.269	1.197	1.172	1.199	1.268	1.233	1.287	1.106	0.607	
		-0.70	-1.13	-1.72	-2.76	-2.30	-2.23	-2.24	-2.25	-1.85	-1.46	-1.11	-0.98	-0.90	
	0.312	1.020	1.242	1.334	1.228	1.184	1.153	1.146	1.144	1.176	1.222	1.324	1.233	1.014	0.311
7	0.312	1.021	1.246	1.345	1.244	1.203	1.181	1.173	1.181	1.201	1.238	1.333	1.240	1.019	0.311
	-0.09	-0.13	-0.32	-0.80	-1.28	-1.61	-2.39	-2.27	-3.10	-2.05	-1.28	-0.71	-0.58	-0.46	-0.01
	0.347	1.148	1.301	1.357	1.178	1.171	1.163	1.207	1.152	1.153	1.167	1.352	1.297	1.154	0.348
8	0.347	1.145	1.297	1.356	1.177	1.178	1.175	1.223	1.175	1.178	1.177	1.356	1.297	1.145	0.346
	0.12	0.25	0.28	0.04	0.11	-0.56	-1.04	-1.34	-1.92	-2.15	-0.84	-0.29	-0.03	0.77	0.62
	0.313	1.025	1.248	1.341	1.245	1.206	1.183	1.169	1.168	1.203	1.245	1.350	1.251	1.027	0.312
9	0.312	1.019	1.239	1.333	1.238	1.201	1.181	1.173	1.181	1.203	1.244	1.345	1.246	1.021	0.312
	0.29	0.57	0.69	0.60	0.56	0.43	0.14	-0.32	-1.12	0.04	0.10	0.36	0.39	0.56	-0.09
		0.613	1.120	1.303	1.249	1.285	1.217	1.185	1.205	1.278	1.248	1.309	1.122	0.612	
10		0.607	1.105	1.287	1.233	1.268	1.199	1.172	1.197	1.269	1.238	1.293	1.111	0.609	
		1.02	1.34	1.21	1.33	1.32	1.54	1.09	0.66	0.69	0.83	1.23	0.99	0.57	
		0.294	0.920	1.276	1.216	1.258	1.262	1.193	1.251	1.248	1.208	1.281	0.926	0.296	
11		0.290	0.904	1.254	1.192	1.233	1.234	1.164	1.229	1.231	1.194	1.258	0.909	0.292	
		1.37	1.75	1.74	2.04	2.06	2.29	2.45	1.75	1.38	1.14	1.79	1.86	1.21	
			0.360	0.966	1.283	1.318	1.369	1.352	1.351	1.310	1.282	0.978	0.368		
12			0.348	0.945	1.254	1.285	1.326	1.313	1.317	1.282	1.254	0.946	0.350		
			3.56	2.19	2.31	2.56	3.11	2.98	2.57	2.21	2.21	3.38	5.20		
				0.357	0.928	1.135	1.273	1.328	1.268	1.132	0.929	0.360			
13				0.349	0.906	1.104	1.232	1.279	1.227	1.101	0.905	0.349			
				2.33	2.42	2.79	3.31	3.84	3.33	2.79	2.62	3.08			
					0.299	0.624	1.047	1.178	1.054	0.625	0.303				
14					0.295	0.606	1.013	1.135	1.011	0.604	0.295				
					1.49	2.91	3.36	3.82	4.27	3.47	2.87				
							0.319	0.357	0.322						
15							0.310	0.345	0.309						
							2.82	3.62	4.13						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 1.6
STANDARD DEVIATION = 1.023

Summary:

Map No: S2-29-03
Control Rod Position:
D Bank at 224 Steps

Date: 12/11/2018
$F_Q(Z)$ = 1.892
$F^N_{\Delta H}$ = 1.497
F_Z = 1.183
Burnup = 138.0 MWD/MTU

Power: 99.89%

QPTR:		
	0.9834	0.9865
	1.0157	1.0144

Axial Offset (%) = +1.615

SECTION 7 — CONCLUSIONS

Table 7.1 summarizes the results associated with Surry Unit 2 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. Based on the results associated with the S2C29 startup physics testing program, it is anticipated that the Surry 2 core will continue to operate safely throughout Cycle 29.

The reconstituted assembly in full-core location in M-08 is not leading the core in peaking or minimum margin to the limit and will continue to be monitored throughout Cycle 29.

Table 7.1

SURRY UNIT 2 – 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	1556	1545	11	±39
Critical Boron Concentration (HZP Ref Bank in), ppm	1376.6	1377	-0.4	±28
Isothermal Temp Coefficient (HZP ARO), pcm/F	-2.019	-1.830	-0.189	±2
Differential Boron Worth (HZP ARO), pcm/ppm	-7.63	-7.76	-1.7%	±10%
Reference Bank Worth (B-bank, dilution), pcm	1365	1389	-1.7%	±10%
A-bank Worth (Rod Swap), pcm	276	258	18	±100
C-bank Worth (Rod Swap), pcm	731	781	-6.4%	±15%
SA-bank Worth (Rod Swap), pcm	1000	973	2.7%	±15%
SB-bank Worth (Rod Swap), pcm	998	1070	-6.7%	±15%
D-bank Worth (Rod Swap), pcm	1085	1107	-1.9%	±15%
Total Bank Worth, pcm	5456	5578	-2.2%	±10%
S2C29 Testing Time:		**6.5 Hrs**		
[criticality 12/05/2018 @ 11:59 to end of testing 12/05/2018 @ 18:27]				
Recent Startups:				
S1C29 testing time:		8.0 hrs		
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		
S1C26 testing time:		7.8 hrs		

SECTION 8 — REFERENCES

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2. S. B. Rosenfelder, "Surry Unit 2 Cycle 29 Full Core Loading Plan", Engineering Technical Evaluation ETE-NAF-2018-0065, Rev. 0, May 2018.
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15. 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.
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19. 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.
20. Surry Power Station Updated Final Safety Analysis Report.

APPENDIX A — RCP STARTUP ORDER

12/1/2018 09:50
Initial RCP Start: 2-RC-P-1C iaw 2-OP-RC-001

0952 Load shed in ENABLE

0959 Bearing Lift Pump started. White light lit

1011 All personnel on station in Containment for start of 2-RC-P-1C

1016 Engineering personnel are monitoring vibes and prepared for start of 2-RC-P-1C

1021 Started 2-RC-P-1C. All parameters SAT.

1023 Secured Bearing Lift Pump
SPS Unit 2 Control Room Log CASEY, SEAN
12/1/2018 12:21: "C" RCS Loop flow indicators have been vented by I&C. HUMPHRIES, JOSHUA A

12/1/2018 14:57
2-RC-P-1A UPDATE:

2-EP-BKR-25A3 is in TEST IAW 2-OP-RC-001.

1500 2-RC-P-1A1 ("A" RCP Brg Lift pump) started.

1505 2-EP-BKR-25A3 closed in TEST.

1507 2-EP-BKR-25A3 opened in TEST.

1525 2-EP-BKR-25A3 racked to CONNECT.

1530 Ops on station in containment.

1536 Everyone on station in containment.

1540 Started 2-RC-P-1A.

1542 Secured 1-RC-P-1A1 ("A" RCP Brg Lift pump).
SPS Unit 2 Control Room Log FORD, WALTER JOE

12/3/2018 09:40
All PMTs required for 200°F Mode Change are complete. Permission has been granted to raise RCS temperature > 200°F. Commence heating up from 193°F to >200°F.

0947 Started "B" RCP IAW 2-OP-RC-001. All RCPs are now running.

0959 U2 has left Cold Shutdown and has entered Intermediate Shutdown. Current heatup rate is 34°F/Hr.

1039 Stabilized RCS temperature at 210°F for Engineering cross-cals.

1044 Engineering cross-cals are complete. Recommence heating up to 340-345°F.
SPS Unit 2 Control Room Log HUMPHRIES, JOSHUA A
12/3/2018 12:00: RCS temperature is 248°F and rising. Rate of heatup is 30°F/Hr (maximum attainable rate). HUMPHRIES, JOSHUA A

APPENDIX B— STARTUP PHYSICS TESTS SUMMARY SHEETS

Surry Power Station Unit 2 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= 2.0 E-9 to 1.0 E-7 amps	background < ZPTR < POAH background = 2.5337 E-11 amps (N-35) POAH= 2.253 E-7 amps	N/A	✓ Yes ___ No	N/A	12/05/18 1321	SBB KLK
Reactivity Computer Checkout						
ρ_o= +49.901/-56.692 pcm (measured reactivity) ρ_t= +50.093/-57.83 pcm (predicted reactivity) %D = {(pc - pt)/pt} x 100% %D = -0.38% / -1.95%	$\|((\rho_o - \rho_t)/\rho_t)\| \times 100\% \leq 4.0\%$[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	12/05/18 1321	SBB KLK
Critical Boron Concentration - ARO						
$(C_B)^M_{ARO}$= 1556 ppm (Adj. To design conds.)	$(C_B)_{ARO}$=[2] 1545 ± 39 ppm or 300 pcm $\Delta(C_B)_{ARO}=(C_B)^M_{ARO} - (C_B)_{ARO}$= +11 ppm	$\|\alpha C_B \times \Delta(C_B)_{ARO}\| \leq 1000$ pcm [T.S. 4.10.A] αC_B=[2] -7.69 pcm/ppm	✓ Yes ___ No	✓ Yes ___ No	12/05/18 1321	SBB KLK
Isothermal Temperature Coefficient - ARO						
$(\alpha_T^{ISO})^M_{ARO}$ = -2.019 pcm/°F	$(\alpha_T^{ISO})_{ARO}$ =[2] -1.830 ± 2 pcm/°F $(\alpha_T^{ISO})^M_{ARO} - (\alpha_T^{ISO})_{ARO}$ = -0.189 pcm/°F	$\alpha_T^{ISO} \leq \alpha_M^{lim} - \alpha_T^{unc} + \alpha_T^{DOP}$ $\alpha_T^{ISO} \leq 3.840$ pcm/°F where: (α_M^{lim}); 6.0 pcm/°F [COLR 3.4] $(\alpha_T^{unc})^1$; 0.5 pcm/°F $(\alpha_T^{DOP})^2$; -1.66 pcm/°F	✓ Yes ___ No	✓ Yes ___ No	12/05/18 1345	SBB KLK
Control Bank B Worth Measurement, Rod Swap Reference Bank						
$I_B^{REF,M}$= 1365 pcm	I_B^{REF}=[2] 1389 ± 10% 100x(Meas. - Des.)/Des. = -1.7 %	N/A	✓ Yes ___ No	N/A	12/05/18 1450	SBB KLK

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0123, Rev. 0
3.) ETE-NAF-2018-0124, Rev. 0

Surry Power Station Unit 2 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						
$(C_B)^M{}_B$= 1376.6 ppm	$(C_B)_B$=[2] 1366 +$\Delta(C_B)_{ARO}$ ± 28 ppm $\Delta(C_B)_{ARO}$= +11 ppm (from above) $(C_B)_B$= 1377 ± 28 ppm $(C_B)^M{}_B - (C_B)_B$ = -0.4 ppm	N/A	✓ Yes ___ No	N/A	12/05/18 1450	KLK / SBR
HZP Boron Worth Coefficient Measurement						
$(\alpha C_B)^M$= -7.63 pcm/ppm	αC_B =[2] -7.76 ± 0.78 pcm/ppm $\Delta\alpha C_B = (\alpha C_B)^M - (\alpha C_B)$ = 0.13 pcm/ppm	N/A	✓ Yes ___ No	N/A	12/05/18 1450	KLK / SBR
Control Bank A Worth Measurement, Rod Swap						
$I_A{}^{RS}$= 276 pcm	$(I_A{}^{RS})^3$= 258 ± 100 pcm Meas. - Des.. = 18 pcm	N/A	✓ Yes ___ No	N/A	12/05/18 1707	SBR / KLK
Control Bank C Worth Measurement, Rod Swap						
$I_C{}^{RS}$= 731 pcm	$(I_C{}^{RS})^3$= 781 ± 15% 100x(Meas. - Des.)/Des. = -6.4 %	N/A	✓ Yes ___ No	N/A	12/05/18 1707	SBR / KLK
Shutdown Bank A Worth Measurement, Rod Swap						
$I_{SA}{}^{RS}$= 1000 pcm	$(I_{SA}{}^{RS})^3$= 973 ± 15% 100x(Meas. - Des.)/Des. = 2.7 %	N/A	✓ Yes ___ No	N/A	12/05/18 1707	SBR / KLK
Shutdown Bank B Worth Measurement, Rod Swap						
$I_{SB}{}^{RS}$= 998 pcm	$(I_{SB}{}^{RS})^3$= 1070 ± 15% 100x(Meas. - Des.)/Des. = -6.7 %	N/A	✓ Yes ___ No	N/A	12/05/18 1707	SBR / KLK
Control Bank D Worth Measurement, Rod Swap						
$I_D{}^{RS}$= 1085 pcm	$(I_D{}^{RS})^3$= 1107 ± 15% 100x(Meas. - Des.)/Des. = -1.9 %	N/A	✓ Yes ___ No	N/A	12/05/18 1707	SBR / KLK
Total Rod Worth, Rod Swap						
I_{Total}= 5456 pcm	$(I_{total})^3$= 5578 ± 10% 100x(Meas. - Des.)/Des. = -2.2 %	N/A	✓ Yes ___ No	N/A	12/05/18 1707	SBR / KLK

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0123, Rev. 0
3.) ETE-NAF-2018-0124, Rev. 0

ATTACHMENT 7

Surry Power Station Unit 2 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) = 26.94						
Max Relative Assembly Power, %DIFF (M-P)/P					12/5/18 15:51	[initials] / MMG
%DIFF= 8.7 % for $P_i \geq 0.9$ 8.3 % for $P_i < 0.9$	±10% for $P_i \geq 0.9$ ±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)= 1.584	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= 2.318	N/A	$F_Q(Z) \leq 5^*K(Z)$ [COLR 3.7]	N/A	✓ Yes ___ No	↓	↓
Maximum Positive Incore Quadrant Power Tilt					↓	↓
Tilt= 1.0287	≤ 1.02[1]	N/A	___ Yes ✓ No	N/A	↓	↓

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0123, Rev. 0
3.) ETE-NAF-2018-0124, Rev. 0

ATTACHMENT 7

Surry Power Station Unit 2 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) = 70.57						
Max Relative Assembly Power, %DIFF (M-P)/P					12/7/18 15:45	JAL / MMG
%DIFF= 4.8 % for Pi≥0.9 5.3 % 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)= 1.528	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= 1.998	N/A	F_Q(Z)≤(2.5/P)*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No	↓	↓
Maximum Positive Incore Quadrant Power Tilt					↓	↓
Tilt= 1.0178	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A	↓	↓

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0123, Rev. 0
3.) ETE-NAF-2018-0124, Rev. 0

Surry Power Station Unit 2 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) = 99.89						
Max Relative Assembly Power, %DIFF (M-P)/P					12/11/18 09:52	DJA / [illegible]
%DIFF= 4.3 % for Pi≥0.9 5.2 % 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)= 1.497	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= 1.892	N/A	F_Q(Z)≤(2.5/P)*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.057	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0123, Rev. 0
3.) ETE-NAF-2018-0124, Rev. 0

Surry Power Station Unit 2 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}= 290 012 gpm	N/A	$F_{total} \geq$ 274000 gpm [COLR 3.8]	N/A	✓ Yes ___ No	12/10/18 10:00	DJA/ [signature]

References 1.) DNES-AA-NAF-NCD-4015, Rev. 3
2.) ETE-NAF-2018-0123, Rev. 0
3.) ETE-NAF-2018-0124, Rev. 0