Dominion Resources Services, Inc.
Innsbrook Technical Center
5000 Dominion Boulevard, 2SE, Glen Allen, VA 23060

Dominion®

August 24, 2015

United States Nuclear Regulatory Commission
Regional Administrator – Region II
Marquis One Tower
245 Peachtree Center Ave., NE
Suite 1200
Atlanta, Georgia 30303-1257

Serial No.: 15-432
NLOS/GDM
Docket No.: 50-280
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VIRGINIA ELECTRIC AND POWER COMPANY (DOMINION)
SURRY POWER STATION UNIT 1
CYCLE 27 STARTUP PHYSICS TESTS REPORT

As required by Surry Power Station (Surry) Technical Specification 6.6.A.1, enclosed is the Surry Unit 1 Cycle 27 Startup Physics Tests Report. This report summarizes the results of the physics testing program performed prior to and following initial criticality of Cycle 27 on May 27, 2015. The results of the physics tests were within the applicable Technical Specification limits.

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

Sincerely,

T. R. Huber, Director
Nuclear Licensing and Operations Support
Dominion Resources Services, Inc. for
Virginia Electric and Power Company

Enclosure: Surry Unit 1 Cycle 27 Startup Physics Tests Report

Commitments made in this letter: None

IE26
NRR

cc: U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555-0001

Ms. K. R. Cotton Gross
NRC Project Manager - Surry
U. S. Nuclear Regulatory Commission
One White Flint North
Mail Stop O8 G-9A
11555 Rockville Pike
Rockville, MD 20852-2738

Dr. V. Sreenivas
NRC Project Manager – North Anna
U. S. Nuclear Regulatory Commission
One White Flint North
Mail Stop O8 G-9A
11555 Rockville Pike
Rockville, MD 20852-2738

NRC Senior Resident Inspector
Surry Power Station

Serial No. 15-432
Docket No. 50-280

Enclosure

SURRY UNIT 1 CYCLE 27 STARTUP PHYSICS TESTS REPORT

August 2015

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

CLASSIFICATION/DISCLAIMER

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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 1 Cycle 27 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. 1 [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 27 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's Nuclear Analysis and Fuel Group. The acceptance criteria are based on design tolerances or applicable Technical Specification and COLR Limits.

SECTION 1 — INTRODUCTION AND SUMMARY

On April 19, 2015, Unit No. 1 of Surry Power Station completed Cycle 26 and began refueling [Ref. 1]. During this refueling, 65 of the 157 fuel assemblies in the core were replaced with fresh Batch S1/29 assemblies [Ref. 8]. The Cycle 27 core consists of 8 sub-batches of fuel: three fresh batches (S1/29A, S1/29B and S1/29C), three once-burned batches (S1/28A, S1/28B and S1/28C), and two twice-burned batches (S1/27A and S1/27C). S1C27 will be the third Surry Unit 1 cycle to utilize the 15x15 Upgrade Fuel Design and contains only Upgrade fuel [Ref. 8].

The Westinghouse Upgrade fuel includes ZIRLO (I-spring) structural mid grids with balanced mixing vane pattern, three ZIRLO Intermediate Flow Mixing (IFM) grids, "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 batches S1/28 and S1/29 includes Westinghouse's Robust Protective Grid (RPG) and modified Debris Filter Bottom Nozzle (mDFBN), relative to the Upgrade fuel used for batch S1/27. In addition, S1C27 will be the first Surry cycle to utilize the Westinghouse Integral Nozzle (WIN) top nozzle design [Ref. 8].

This cycle uses Westinghouse's Integral Fuel Burnable Absorber (IFBA) fuel product. The IFBA design involves the application of a thin (0.0003125 inch) 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].

S1C27 also implements the reinsertion of Secondary Source Assemblies (SSAs) to improve Source Range detector indications. Cycle 27 loads two SSAs in core locations H04 and

H12. 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 S1C27. The cycle design report [Ref. 1] provides a more detailed description of the Cycle 27 core.

Two of the three reactor coolant pumps were replaced during the S1C26-S1C27 refueling outage. Further information on this replacement can be found in Reference 20.

The S1C27 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 27 core [Ref. 1].

According to the Startup Physics logs, the Cycle 27 core achieved initial criticality on May 27, 2015 at 00:21 [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 S1C27 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 Surry Unit 1 1.68 second administrative limit [Ref. 10].

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 within –1.2% of the design prediction. The reference bank (Control Bank B) worth was within -2.2% of its design prediction. Control rod banks with design predictions greater than 600 pcm were within -3.5% of the design predictions. For individual banks worth 600 pcm or less (only Control Bank A fits this category), the difference was within –6.8 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. 4] 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 +0.5% 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/^{o}F of the design prediction. This result is within the design tolerance of $\pm$2.0 pcm/^{o}F.

Core power distributions were within established design tolerances. The measured assembly power distributions were within $\pm$4.7% of the design predictions, where a -4.7% maximum difference occurred in the 70.45% 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. 8]. All power flux maps were within the maximum incore power tilt design tolerance of 2% (QPTR $\leq$ 1.02).

The total RCS Flow was successfully verified as being greater than 273,000 gpm and greater than the limit in the COLR (274000 gpm), as required by Surry Technical Specifications [Ref. 4]. RCS Flow was measured at various plant configurations in accordance with the RCS Loop Flows test plan [Ref. 18]. The total RCS Flow at nominal conditions was measured as 289,422 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 27
CHRONOLOGY OF TESTS

Test	Date	Time	Power	Reference Procedure
Hot Rod Drop-Hot Full Flow	05/25/15	20:20	HSD	1-NPT-RX-014
Reactivity Computer Checkout	05/27/15	01:10	HZP	1-NPT-RX-008
Boron Endpoint – ARO	05/27/15	01:10	HZP	1-NPT-RX-008
Zero Power Testing Range	05/27/15	01:10	HZP	1-NPT-RX-008
Boron Worth Coefficient	05/27/15	04:40	HZP	1-NPT-RX-008
Temperature Coefficient – ARO	05/27/15	01:50	HZP	1-NPT-RX-008
Bank B Worth	05/27/15	02:48	HZP	1-NPT-RX-008
Boron Endpoint – B in	05/27/15	04:40	HZP	1-NPT-RX-008
Bank A Worth – Rod Swap	05/27/15	04:45	HZP	1-NPT-RX-008
Bank C Worth – Rod Swap	05/27/15	04:45	HZP	1-NPT-RX-008
Bank SA Worth – Rod Swap	05/27/15	04:45	HZP	1-NPT-RX-008
Bank D Worth – Rod Swap	05/27/15	04:45	HZP	1-NPT-RX-008
Bank SB Worth – Rod Swap	05/27/15	04:45	HZP	1-NPT-RX-008
Total Rod Worth	05/27/15	04:45	HZP	1-NPT-RX-008
Flux Map – less than 50% Power Peaking Factor Verification & Power Range Calibration	05/28/15	02:57	29.01%	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	05/29/15	12:10	70.45%	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	06/04/15	09:00	99.87%	1-NPT-RX-002 1-NPT-RX-008 1-NPT-RX-005 1-GEP-RX-001
RCS Flow Measurement	06/01/15	12:00	HFP	1-NPT-RX-009

Figure 1.1

SURRY UNIT 1 – CYCLE 27
CORE LOADING MAP

SURRY UNIT 1 - CYCLE 27
FULL CORE LOADING PLAN
REVISION NO. 0

VEP-NES-NAF

NORTH ↑

	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R
15							146	153	145						
14					101	RCC 217	350	RCC 363	352	RCC 223	103				
13				142	346	326	RCC 307	246	RCC 301	329	342	143			
12			141	RCC 360	334	RCC 230	202	SS10 257	206	RCC 231	340	RCC 362	144		
11		106	348	337	RCC 216	253	313	261	317	255	RCC 213	332	345	107	
10		RCC 220	331	RCC 229	254	RCC 324	237	RCC 309	233	RCC 318	256	RCC 225	328	RCC 218	
9	152	355	RCC 306	204	319	236	RCC 242	212	RCC 243	239	322	208	RCC 304	354	147
8 (270°)	155	RCC 364	247	260	264	RCC 310	210	325	209	RCC 312	263	259	245	RCC 361	156
7	151	353	RCC 303	205	315	240	RCC 244	211	RCC 248	235	316	201	RCC 302	356	148
6		RCC 222	338	RCC 228	250	RCC 320	234	RCC 311	238	RCC 323	251	RCC 227	339	RCC 221	
5		108	347	330	RCC 214	249	314	262	321	252	RCC 215	335	349	105	
4			140	RCC 365	333	RCC 232	207	SS11 258	203	RCC 226	341	RCC 358	137		
3				139	343	327	RCC 305	241	RCC 308	336	344	138			
2					104	RCC 224	357	RCC 359	351	RCC 219	102				
1							150	154	149						

180°

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

Prepared By: *[signature]* T. S. Psuik Date: 02/11/15

Reviewed By: *[signature]* S. B. Rosenfelder Date: 02/11/15

Approved By: *[signature]* A. H. Nicholson Date: 2/12/15

Concurrence By: *[signature]* A. L. Black Date: 3/5/15

Approved By: *[signature]* M. N. LaPrade Date: 3/5/15

Figure 1.2

SURRY UNIT 1 – CYCLE 27
BEGINNING OF CYCLE FUEL ASSEMBLY BURNUPS (GWD/MTU)

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1							40.61 40.52	40.97 41.01	40.64 40.53					MEASURED PREDICTED		1
2					35.08 35.19	23.92 24.15	0.00 0.00	0.00 0.00	0.00 0.00	23.99 24.14	34.89 35.18					2
3				40.60 40.39	0.00 0.00	0.00 0.00	0.00 0.00	19.98 19.91	0.00 0.00	0.00 0.00	0.00 0.00	40.16 40.38				3
4			40.42 40.37	0.00 0.00	0.00 0.00	23.11 23.19	23.95 23.95	20.44 20.39	24.16 23.95	23.30 23.19	0.00 0.00	0.00 0.00	40.45 40.39			4
5		35.46 35.58	0.00 0.00	0.00 0.00	22.41 22.70	19.68 19.77	0.00 0.00	20.94 20.85	0.00 0.00	19.79 19.79	22.46 22.72	0.00 0.00	0.00 0.00	35.58 35.59		5
6		24.06 24.14	0.00 0.00	23.72 23.15	19.75 19.75	0.00 0.00	24.33 24.16	0.00 0.00	24.14 24.15	0.00 0.00	19.77 19.73	23.11 23.15	0.00 0.00	24.32 24.14		6
7	40.48 40.54	0.00 0.00	0.00 0.00	24.24 23.98	0.00 0.00	24.18 24.16	19.94 19.88	25.08 24.57	19.92 19.91	24.20 24.17	0.00 0.00	23.83 23.98	0.00 0.00	0.00 0.00	40.53 40.53	7
8	41.24 41.01	0.00 0.00	20.21 19.89	20.54 20.39	20.97 20.82	0.00 0.00	24.50 24.57	0.00 0.00	24.35 24.58	0.00 0.00	20.63 20.82	20.49 20.40	20.14 19.89	0.00 0.00	40.91 41.01	8
9	40.78 40.53	0.00 0.00	0.00 0.00	23.95 23.98	0.00 0.00	24.33 24.17	19.95 19.91	24.53 24.57	19.87 19.88	24.20 24.16	0.00 0.00	24.19 23.98	0.00 0.00	0.00 0.00	40.16 40.54	9
10		24.21 24.14	0.00 0.00	23.13 23.15	19.72 19.73	0.00 0.00	24.09 24.15	0.00 0.00	24.70 24.16	0.00 0.00	20.02 19.75	23.38 23.15	0.00 0.00	24.13 24.14		10
11		35.44 35.59	0.00 0.00	0.00 0.00	22.56 22.67	20.02 19.79	0.00 0.00	20.68 20.85	0.00 0.00	19.77 19.77	22.63 22.67	0.00 0.00	0.00 0.00	35.51 35.59		11
12			40.55 40.39	0.00 0.00	0.00 0.00	23.79 23.19	24.03 23.95	20.36 20.39	23.97 23.95	23.23 23.19	0.00 0.00	0.00 0.00	40.36 40.37			12
13				40.40 40.39	0.00 0.00	0.00 0.00	0.00 0.00	20.22 19.91	0.00 0.00	0.00 0.00	0.00 0.00	40.39 40.40				13
14					35.10 35.23	24.13 24.14	0.00 0.00	0.00 0.00	0.00 0.00	23.95 24.15	35.09 35.22					14
15							40.59 40.53	40.83 41.01	40.54 40.53							15

Figure 1.3

SURRY UNIT 1 – CYCLE 27
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 Flux Map 1, 2, or 3
* - Location G7 Used as Calibration Thimble Due to Location J7 Being Unavailable Following Replacement

Figure 1.4

SURRY UNIT 1 – CYCLE 27
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
	D				C				C				D		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

90° (left side, row 8) — 270° (right side, row 8)

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 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. 4].

Surry Unit 1 Cycle 27 is the first cycle to use the Rod Drop Measurement Instrument (RDMI) instead of the rod drop test computer (RDTC) [Ref. 12]. 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 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 12.

A typical rod drop trace for S1C27 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 18-27. Technical Specification 3.12.C.1 [Ref. 4] 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. 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. The rod drop times were slightly slower than S1C26, by an average of 0.07 seconds, which is attributed to use of the new Rod Drop Measurement Instrument (data analyzed for previous cycles with RDMI also gave similar slower rod drop times [Ref. 19]).

Table 2.1

SURRY UNIT 1 – CYCLE 27 STARTUP PHYSICS TESTS
HOT ROD DROP TIME SUMMARY

ROD DROP TIME TO DASHPOT ENTRY

SLOWEST ROD	FASTEST ROD	AVERAGE TIME
P-08 1.45 sec.	M-06 1.31 sec	1.36 sec.

Figure 2.1

SURRY UNIT 1 – CYCLE 27 STARTUP PHYSICS TESTS
TYPICAL ROD DROP TRACE

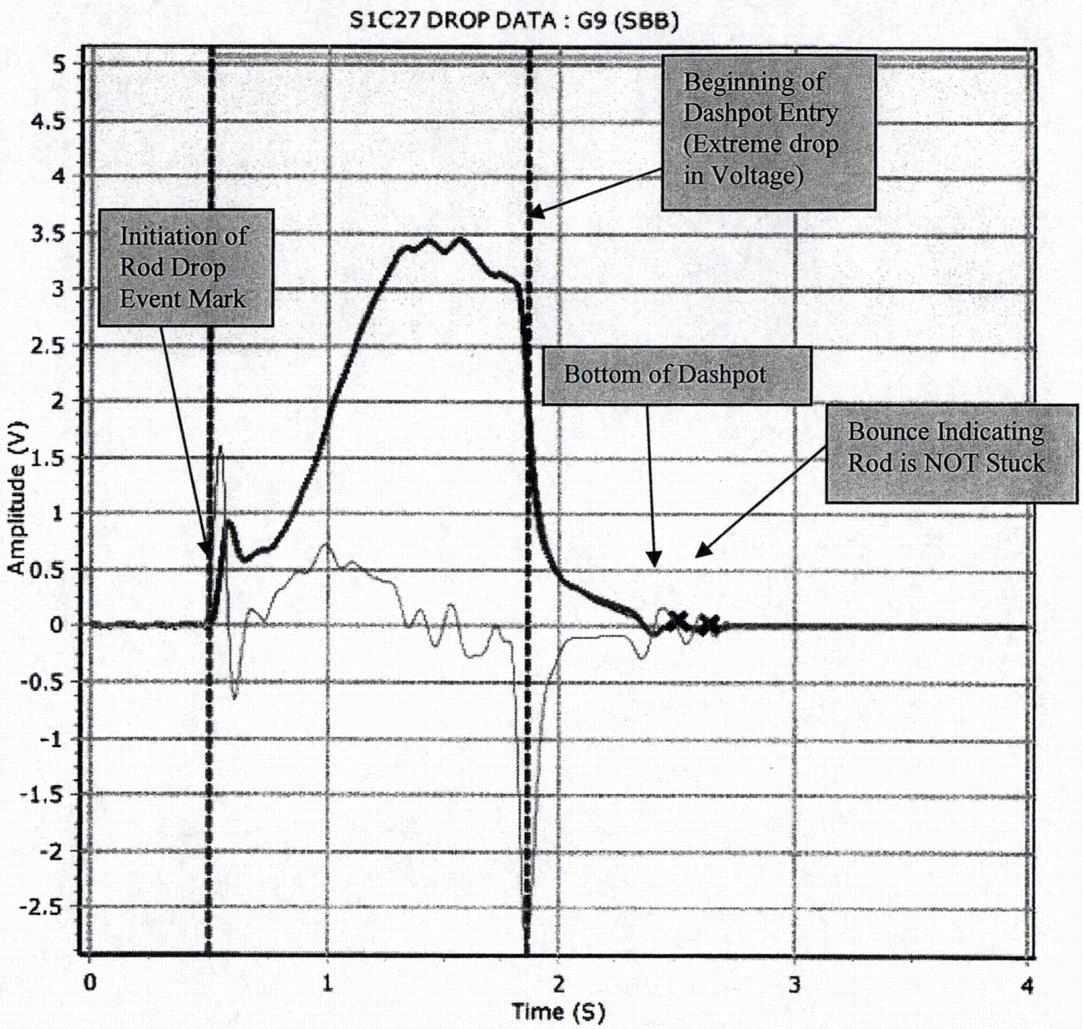


Figure 2.2

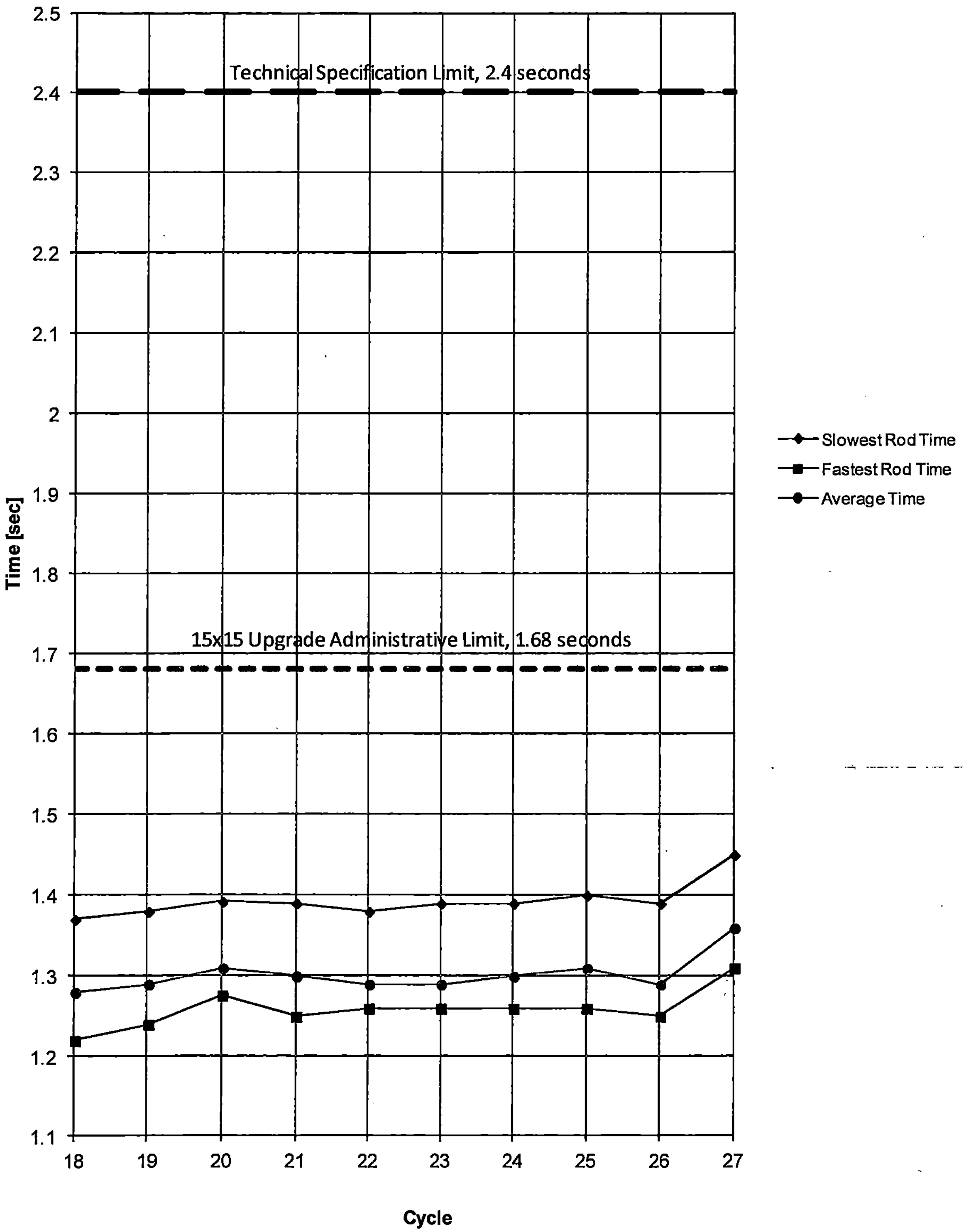
SURRY UNIT 1 – CYCLE 27 STARTUP PHYSICS TESTS
ROD DROP TIME – HOT FULL FLOW CONDITIONS

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
															1
					1.34		1.32		1.35						2
						1.35		1.38							3
			1.35		1.32				1.33		1.39				4
				1.33						1.35					5
	1.33		1.31		1.35		1.35		1.37		1.33		1.43		6
		1.35				1.40		1.35				1.36			7
	1.45				1.37				1.43				1.38		8
		1.39				1.34		1.37				1.36			9
	1.35		1.34		1.34		1.36		1.37		1.35		1.37		10
				1.32						1.33					11
			1.33		1.32				1.35		1.40				12
						1.37		1.37							13
					1.37		1.33		1.38						14
															15

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

Figure 2.3

SURRY UNIT 1 – CYCLE 27 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 27, 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 S1C27 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 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 Test Summary Sheets given in the Appendix, 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 -1.2% 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 1 – CYCLE 27 STARTUP PHYSICS TESTS
CONTROL ROD BANK WORTH SUMMARY

BANK	MEASURED WORTH (PCM)	PREDICTED WORTH (PCM)	PERCENT DIFFERENCE (%) (M-P)/P X 100
B – Reference	1219.4	1247.0	-2.2%
A	250.8	257.6	-6.8 pcm*
C	908.6	908.2	+0.0%
SA	886.3	875.0	+1.3%
D	1044.5	1045.1	-0.1%
SB	1162.7	1204.8	-3.5%
Total Bank Worth	5472.3	5537.7	-1.2%

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

Figure 3.1

SURRY UNIT 1 – CYCLE 27 STARTUP PHYSICS TESTS
CONTROL BANK B INTEGRAL ROD WORTH - HZP
ALL OTHER RODS WITHDRAWN

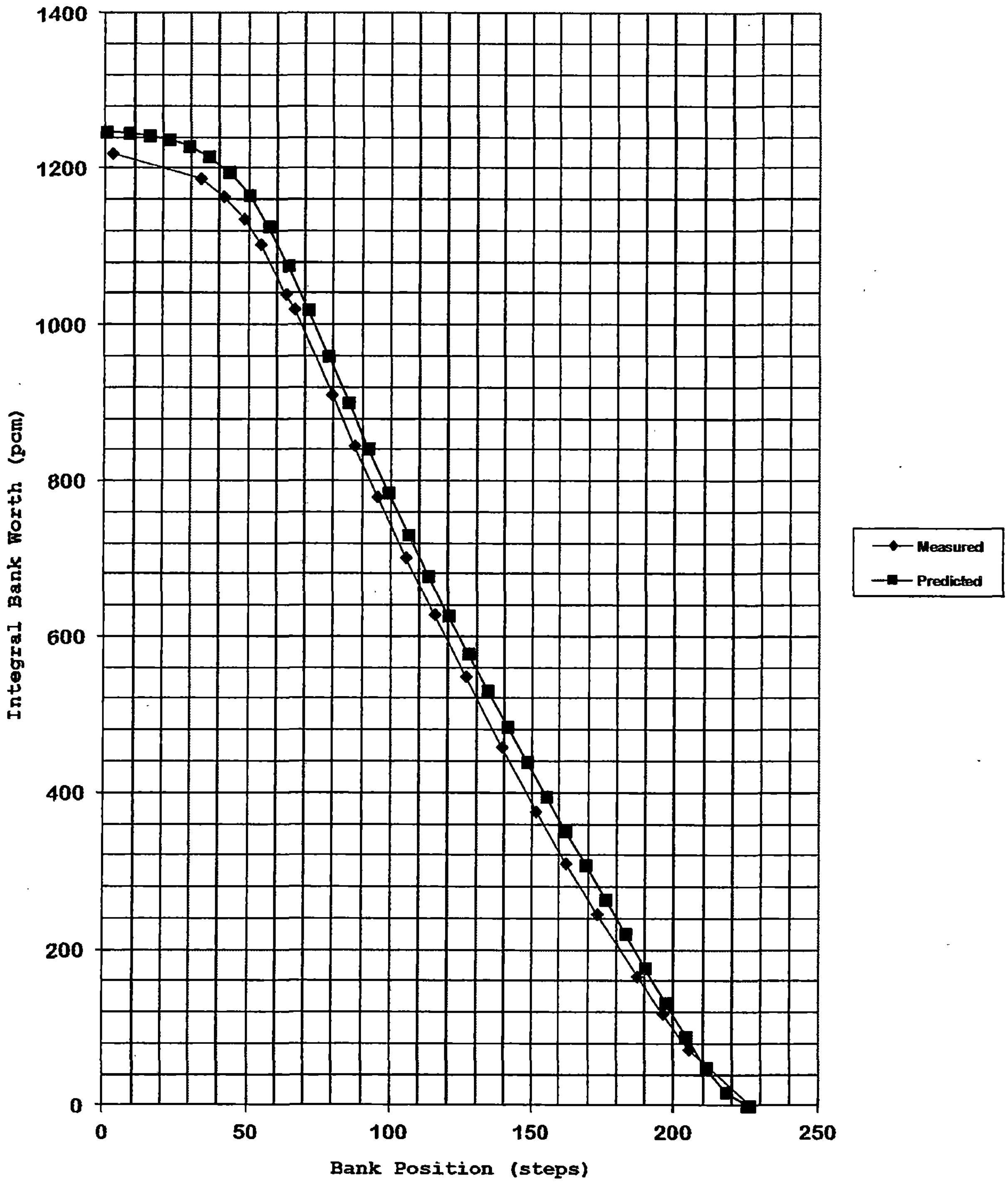
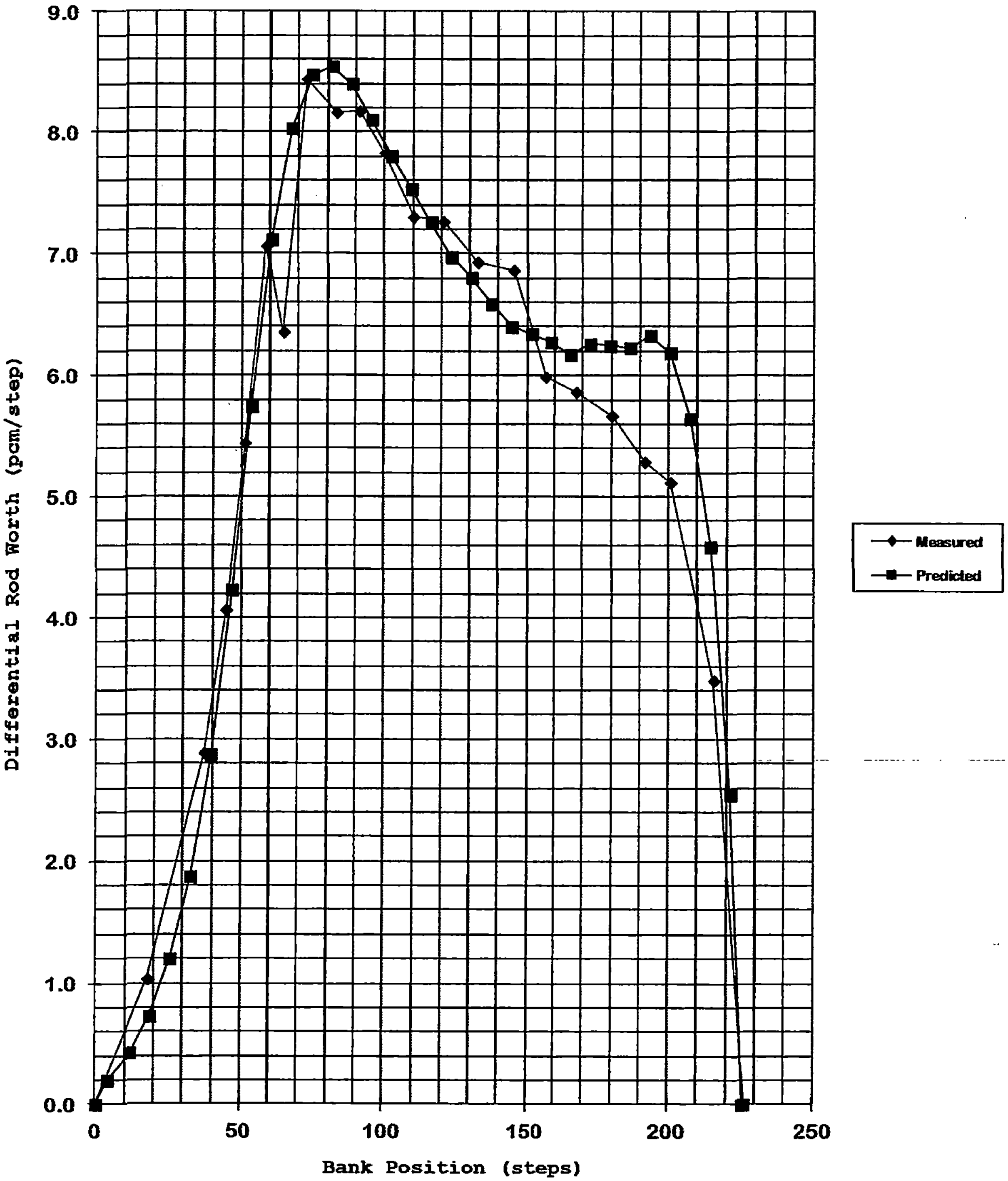


Figure 3.2

SURRY UNIT 1 – CYCLE 27 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 the Appendix, 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 the Appendix, the measured DBW was well within the design tolerance of ±10%. In summary, the measured boron worth coefficient was satisfactory.

Table 4.1

SURRY UNIT 1 – CYCLE 27 STARTUP PHYSICS TESTS
BORON ENDPOINTS SUMMARY

Control Rod Configuration	Measured Endpoint (ppm)	Predicted Endpoint (ppm)	Difference M-P (ppm)
ARO	1472.4	1477.0	-4.6
B Bank In	1312.8	1308.4*	+4.4

* 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 Test Summary Sheet in the Appendix.

Table 4.2

SURRY UNIT 1 – CYCLE 27 STARTUP PHYSICS TESTS
BORON WORTH COEFFICIENT

Measured Boron Worth (pcm/ppm)	Predicted Boron Worth (pcm/ppm)	Percent Difference (%) (M-P)/P x 100
-7.64	-7.60	+0.5%

SECTION 5 — TEMPERATURE COEFFICIENT MEASUREMENT

The 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 3.04 °F, followed by the RCS cool down of 3.02 °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 the Appendix, 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 -2.866 pcm/ °F, a predicted doppler temperature coefficient (DTC) of -1.83 pcm/ °F, and a measurement uncertainty of +0.5 pcm/ °F, is -0.536 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 27 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/206	544.62	547.73	1464	-3.214	-2.517	-2.866	-3.055	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 available locations monitored by the moveable detectors for Cycle 27 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 29.01% 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 70.45% 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 ±4.1% in the 29.01% power map, ±4.7% in the 70.45% power map and ±4.3% in the 99.87% power map. The maximum average quadrant power tilt for the three maps were +0.91%, +0.48% and +0.49%, respectively. These power tilts are within the design tolerance of 2%.

The measured $F_Q(Z)$ and $F^N_{\Delta H}$ 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 27.

Table 6.1

SURRY UNIT 1 – CYCLE 27 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	05/28/15	1.3	29.01	171	M-8	26	2.183	M-8	1.513	26	1.358	1.0091	SW	5.640	46
Int. Power (4)	2	05/29/15	24.8	70.45	197	D-8	25	1.907	M-8	1.467	26	1.214	1.0048	SW	3.532	46
Hot Full Power	3	06/04/15	196.0	99.87	225	D-8	29	1.826	D-8	1.447	29	1.172	1.0045	SW	1.661	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 27 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	2.183	5.000	26	56.3	1.513	1.892	20.0
2	1.907	3.549	25	46.3	1.467	1.698	13.6
3	1.826	2.503	29	27.0	1.447	1.561	7.3

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 29.01% 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							0.243 0.240 1.21	0.290 0.289 0.28	0.242 0.239 1.17						
2					0.303 0.302 0.41	0.570 0.565 0.91	0.954 0.942 1.30	0.980 0.970 1.00	0.947 0.936 1.20	0.573 0.563 1.82	0.304 0.301 0.92				
3				0.364 0.365 -0.38	0.998 0.998 0.00	1.112 1.105 0.61	1.241 1.220 1.68	1.293 1.273 1.57	1.225 1.214 0.94	1.110 1.103 0.62	0.998 0.997 0.09	0.364 0.365 -0.18			
4			0.366 0.367 -0.14	0.964 0.969 -0.48	1.212 1.218 -0.52	1.212 1.212 -0.02	1.217 1.210 0.58	1.336 1.319 1.28	1.226 1.218 0.66	1.215 1.213 0.16	1.212 1.218 -0.47	0.964 0.969 -0.55	0.364 0.367 -0.73		
5		0.303 0.303 -0.16	1.008 1.006 0.16	1.217 1.225 -0.65	1.206 1.225 -1.55	1.297 1.307 -0.75	1.251 1.265 -1.08	1.341 1.337 0.32	1.270 1.270 -0.01	1.304 1.308 -0.32	1.209 1.224 -1.25	1.215 1.223 -0.63	0.997 1.006 -0.90	0.297 0.303 -1.95	
6		0.566 0.572 -1.08	1.109 1.120 -1.03	1.224 1.228 -0.32	1.323 1.318 0.40	1.161 1.167 -0.48	1.212 1.214 -0.14	1.319 1.308 0.87	1.210 1.216 -0.52	1.161 1.167 -0.54	1.305 1.316 -0.86	1.217 1.226 -0.72	1.111 1.121 -0.88	0.569 0.574 -0.92	
7	0.240 0.244 -1.82	0.939 0.956 -1.77	1.210 1.240 -2.40	1.239 1.245 -0.49	1.292 1.289 0.22	1.224 1.223 0.08	1.322 1.325 -0.24	1.184 1.193 -0.76	1.287 1.324 -2.78	1.203 1.220 -1.39	1.269 1.283 -1.10	1.227 1.237 -0.83	1.236 1.247 -0.85	0.954 0.962 -0.83	0.243 0.245 -0.78
8	0.287 0.295 -2.68	0.979 0.992 -1.30	1.296 1.307 -0.87	1.384 1.381 0.25	1.378 1.362 1.19	1.323 1.318 0.37	1.193 1.195 -0.15	1.162 1.176 -1.15	1.169 1.195 -2.14	1.299 1.318 -1.48	1.348 1.362 -0.99	1.369 1.381 -0.88	1.297 1.307 -0.76	0.976 0.992 -1.58	0.290 0.295 -1.67
9	0.244 0.245 -0.35	0.962 0.962 0.03	1.254 1.247 0.60	1.248 1.237 0.91	1.296 1.283 1.02	1.227 1.220 0.57	1.324 1.324 0.00	1.180 1.193 -1.13	1.281 1.325 -3.33	1.216 1.223 -0.57	1.277 1.289 -0.96	1.230 1.245 -1.19	1.224 1.241 -1.34	0.940 0.956 -1.68	0.235 0.245 -4.10
10		0.583 0.574 1.52	1.149 1.121 2.54	1.246 1.227 1.58	1.333 1.316 1.29	1.173 1.167 0.51	1.224 1.216 0.65	1.305 1.308 -0.24	1.200 1.214 -1.18	1.152 1.167 -1.31	1.309 1.319 -0.75	1.205 1.229 -1.96	1.102 1.120 -1.59	0.562 0.572 -1.74	
11		0.309 0.304 1.62	1.025 1.006 1.86	1.243 1.224 1.58	1.246 1.226 1.61	1.324 1.309 1.12	1.281 1.271 0.82	1.349 1.337 0.87	1.263 1.265 -0.12	1.293 1.307 -1.10	1.239 1.226 1.05	1.216 1.226 -0.79	0.993 1.006 -1.29	0.299 0.303 -1.33	
12			0.369 0.367 0.60	0.982 0.970 1.28	1.235 1.219 1.31	1.229 1.214 1.20	1.231 1.218 1.05	1.335 1.320 1.15	1.224 1.211 1.08	1.224 1.212 0.96	1.227 1.218 0.78	0.963 0.970 -0.75	0.359 0.367 -2.23		
13				0.370 0.365 1.47	1.010 0.998 1.21	1.117 1.104 1.20	1.229 1.214 1.22	1.293 1.273 1.56	1.246 1.221 2.08	1.141 1.105 3.29	1.016 0.998 1.85	0.368 0.365 0.76			
14					0.304 0.301 1.12	0.571 0.563 1.35	0.948 0.937 1.17	0.985 0.970 1.58	0.971 0.942 3.07	0.583 0.565 3.16	0.309 0.302 2.33				
15							0.238 0.240 -0.89	0.293 0.289 1.49	0.247 0.240 2.89						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 1.1
STANDARD DEVIATION = 0.735

Summary:

Map No: S1-27-01
Control Rod Position:
D Bank at 171 Steps

Date: 05/28/2015
$F_Q(Z) = 2.183$
$F^N_{\Delta H} = 1.513$
$F_Z = 1.358$
Burnup = 1.3 MWD/MTU

Power: 29.01%

QPTR:

0.9982	0.9953
1.0091	0.9974

Axial Offset (%) = +5.640

Figure 6.2 — ASSEMBLYWISE POWER DISTRIBUTION 70.45% 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							0.263 0.263 0.04	0.315 0.319 -1.41	0.261 0.262 -0.29						
2					0.316 0.317 -0.18	0.589 0.587 0.26	0.975 0.971 0.43	1.025 1.028 -0.24	0.965 0.966 -0.13	0.587 0.585 0.35	0.316 0.317 -0.36				
3				0.369 0.378 -2.29	0.993 1.000 -0.68	1.106 1.105 0.11	1.233 1.219 1.18	1.268 1.272 -0.33	1.211 1.213 -0.17	1.101 1.104 -0.31	0.992 1.000 -0.80	0.368 0.378 -2.52			
4			0.377 0.379 -0.50	0.957 0.969 -1.19	1.190 1.203 -1.04	1.194 1.198 -0.30	1.202 1.197 0.44	1.310 1.294 1.24	1.208 1.203 0.39	1.197 1.200 -0.21	1.194 1.203 -0.79	0.962 0.969 -0.70	0.377 0.379 -0.52		
5		0.316 0.317 -0.36	1.004 1.005 -0.11	1.194 1.208 -1.17	1.180 1.211 -2.53	1.285 1.297 -0.90	1.243 1.252 -0.72	1.317 1.311 0.48	1.258 1.256 0.15	1.296 1.298 -0.17	1.194 1.210 -1.35	1.207 1.206 0.08	1.000 1.005 -0.52	0.308 0.317 -2.98	
6		0.584 0.591 -1.14	1.103 1.114 -0.97	1.206 1.210 -0.36	1.315 1.305 0.74	1.206 1.206 -0.03	1.213 1.210 0.24	1.304 1.289 1.13	1.213 1.212 0.12	1.215 1.206 0.74	1.301 1.303 -0.19	1.207 1.208 -0.07	1.111 1.115 -0.39	0.587 0.593 -0.96	
7	0.259 0.266 -2.65	0.961 0.979 -1.87	1.205 1.231 -2.14	1.219 1.223 -0.34	1.276 1.270 0.50	1.222 1.217 0.44	1.310 1.307 0.19	1.178 1.179 -0.08	1.283 1.306 -1.79	1.214 1.214 0.03	1.264 1.265 -0.07	1.216 1.216 0.03	1.234 1.237 -0.26	0.974 0.984 -1.03	0.264 0.267 -1.16
8	0.308 0.323 -4.69	1.026 1.043 -1.66	1.280 1.296 -1.22	1.349 1.346 0.22	1.350 1.330 1.53	1.305 1.296 0.72	1.185 1.181 0.32	1.161 1.165 -0.37	1.172 1.181 -0.75	1.307 1.296 0.87	1.334 1.330 0.28	1.348 1.346 0.11	1.301 1.296 0.41	1.040 1.043 -0.27	0.320 0.323 -0.92
9	0.262 0.267 -1.77	0.978 0.984 -0.61	1.237 1.237 -0.01	1.225 1.216 0.75	1.283 1.265 1.41	1.225 1.215 0.81	1.310 1.306 0.30	1.175 1.180 -0.46	1.281 1.307 -2.00	1.226 1.217 0.74	1.270 1.270 -0.02	1.218 1.223 -0.39	1.224 1.231 -0.57	0.968 0.979 -1.10	0.254 0.266 -4.54
10		0.596 0.593 0.51	1.130 1.116 1.30	1.221 1.209 0.99	1.318 1.303 1.12	1.214 1.206 0.64	1.218 1.212 0.46	1.290 1.289 0.05	1.205 1.210 -0.41	1.204 1.206 -0.21	1.302 1.305 -0.24	1.192 1.210 -1.49	1.100 1.115 -1.31	0.579 0.591 -1.96	
11		0.320 0.318 0.52	1.011 1.005 0.63	1.216 1.207 0.77	1.226 1.212 1.17	1.309 1.298 0.87	1.265 1.257 0.63	1.323 1.311 0.89	1.255 1.252 0.22	1.292 1.297 -0.38	1.219 1.212 0.57	1.201 1.208 -0.61	0.993 1.005 -1.17	0.313 0.317 -1.35	
12			0.371 0.379 -2.13	0.972 0.969 0.30	1.211 1.204 0.59	1.209 1.200 0.74	1.213 1.204 0.78	1.307 1.294 1.01	1.210 1.197 1.11	1.213 1.198 1.24	1.213 1.203 0.87	0.968 0.969 -0.11	0.369 0.379 -2.63		
13				0.380 0.379 0.17	1.003 1.000 0.27	1.109 1.104 0.49	1.221 1.213 0.66	1.286 1.272 1.09	1.240 1.219 1.69	1.142 1.105 3.38	1.020 1.000 1.98	0.382 0.379 0.82			
14					0.311 0.317 -2.00	0.587 0.585 0.29	0.970 0.966 0.40	1.037 1.028 0.88	0.986 0.971 1.56	0.602 0.587 2.57	0.324 0.317 2.31				
15							0.256 0.262 -2.15	0.321 0.319 0.47	0.267 0.263 1.35						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 0.9
STANDARD DEVIATION = 0.814

Summary:

Map No: S1-27-02
Control Rod Position:
D Bank at 197 Steps

Date: 05/29/2015
$F_Q(Z)$ = 1.907
$F_{\Delta H}^N$ = 1.467
F_Z = 1.214
Burnup = 24.8 MWD/MTU

Power: 70.45%

QPTR:		
	0.9966	0.9973
	1.0048	1.0013

Axial Offset (%) = +3.532

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							0.271	0.328	0.270						
							0.271	0.331	0.270						
							0.10	-0.84	-0.18						
2					0.318	0.590	0.976	1.055	0.967	0.586	0.317				
					0.319	0.589	0.972	1.055	0.968	0.587	0.318				
					-0.45	0.13	0.40	0.04	-0.08	-0.16	-0.19				
3				0.367	0.977	1.093	1.221	1.264	1.205	1.091	0.980	0.371			
				0.379	0.985	1.095	1.210	1.262	1.205	1.093	0.985	0.379			
				-3.15	-0.85	-0.18	0.88	0.12	0.02	-0.15	-0.51	-2.00			
4			0.376	0.944	1.176	1.181	1.191	1.295	1.201	1.189	1.183	0.954	0.379		
			0.380	0.957	1.188	1.187	1.190	1.279	1.195	1.188	1.188	0.956	0.379		
			-1.07	-1.39	-1.00	-0.47	0.06	1.26	0.50	0.09	-0.39	-0.25	-0.11		
5		0.316	0.983	1.177	1.180	1.285	1.240	1.311	1.266	1.301	1.196	1.194	0.987	0.311	
		0.319	0.989	1.192	1.204	1.299	1.259	1.306	1.263	1.300	1.203	1.191	0.989	0.319	
		-1.00	-0.61	-1.30	-2.01	-1.10	-1.51	0.41	0.21	0.08	-0.56	0.29	-0.22	-2.57	
6		0.583	1.086	1.188	1.306	1.255	1.225	1.316	1.230	1.267	1.305	1.198	1.102	0.590	
		0.593	1.103	1.198	1.306	1.260	1.226	1.298	1.228	1.259	1.304	1.196	1.104	0.594	
		-1.62	-1.54	-0.85	-0.03	-0.38	-0.05	1.39	0.15	0.60	0.09	0.13	-0.23	-0.62	
7	0.266	0.958	1.188	1.204	1.276	1.234	1.314	1.188	1.292	1.229	1.271	1.209	1.226	0.976	0.272
	0.274	0.980	1.222	1.214	1.276	1.232	1.313	1.188	1.313	1.230	1.271	1.207	1.227	0.984	0.274
	-2.87	-2.20	-2.75	-0.84	-0.01	0.13	0.09	0.01	-1.61	-0.04	0.03	0.16	-0.09	-0.81	-0.78
8	0.321	1.052	1.268	1.328	1.338	1.311	1.193	1.176	1.183	1.314	1.328	1.332	1.291	1.063	0.331
	0.335	1.069	1.284	1.329	1.324	1.305	1.190	1.179	1.190	1.305	1.324	1.329	1.284	1.069	0.335
	-4.25	-1.60	-1.22	-0.05	1.07	0.49	0.23	-0.24	-0.59	0.71	0.29	0.20	0.53	-0.60	-1.13
9	0.270	0.978	1.227	1.216	1.291	1.240	1.317	1.186	1.295	1.235	1.276	1.211	1.217	0.970	0.261
	0.274	0.984	1.227	1.207	1.271	1.230	1.313	1.188	1.313	1.232	1.276	1.214	1.222	0.980	0.273
	-1.42	-0.59	-0.02	0.71	1.57	0.82	0.28	-0.21	-1.37	0.27	-0.02	-0.27	-0.43	-1.06	-4.30
10		0.598	1.118	1.209	1.319	1.268	1.233	1.300	1.223	1.258	1.307	1.185	1.093	0.585	
		0.594	1.104	1.197	1.305	1.260	1.228	1.298	1.226	1.260	1.306	1.198	1.103	0.593	
		0.59	1.27	0.97	1.10	0.67	0.40	0.13	-0.25	-0.13	0.09	-1.10	-0.88	-1.38	
11		0.321	0.996	1.200	1.218	1.310	1.270	1.316	1.262	1.297	1.220	1.190	0.982	0.316	
		0.319	0.990	1.192	1.204	1.300	1.264	1.307	1.259	1.299	1.204	1.192	0.990	0.319	
		0.71	0.62	0.69	1.15	0.80	0.51	0.67	0.24	-0.17	1.37	-0.20	-0.79	-1.00	
12			0.374	0.960	1.195	1.197	1.204	1.290	1.202	1.201	1.199	0.955	0.372		
			0.380	0.957	1.189	1.189	1.196	1.279	1.190	1.187	1.188	0.957	0.380		
			-1.50	0.34	0.53	0.64	0.64	0.88	0.98	1.14	0.94	-0.23	-2.04		
13				0.380	0.988	1.098	1.212	1.275	1.229	1.125	1.002	0.382			
				0.379	0.985	1.094	1.205	1.262	1.211	1.095	0.985	0.379			
				0.28	0.26	0.40	0.59	1.04	1.53	2.70	1.73	0.73			
14					0.313	0.589	0.972	1.066	0.991	0.603	0.325				
					0.318	0.588	0.968	1.055	0.973	0.589	0.319				
					-1.51	0.17	0.40	1.05	1.82	2.41	1.96				
15							0.264	0.333	0.275						
							0.270	0.331	0.271						
							-2.35	0.67	1.63						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 0.8
STANDARD DEVIATION = 0.783

Summary:

Map No: S1-27-03
Control Rod Position:
D Bank at 225 Steps

Date: 06/04/2015
$F_Q(Z)$ = 1.826
$F^N_{\Delta H}$ = 1.447
F_Z = 1.172
Burnup = 196.0 MWD/MTU

Power: 99.87%

QPTR:		
	0.9942	0.9989
	1.0045	1.0023

Axial Offset (%) = +1.661

SECTION 7 — CONCLUSIONS

Table 7.1 summarizes the results associated with Surry Unit 1 Cycle 27 startup physics testing program. As noted herein, all test results were acceptable and within associated design tolerances, technical specification limits, or COLR limits. It is anticipated, based on the results associated with the S1C27 startup physics testing program, that the Surry 1 core will continue to operate safely throughout Cycle 27.

Table 7.1

SURRY UNIT 1 – CYCLE 27 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	1472.4	1477.0	-4.6	±50
Critical Boron Concentration (HZP Ref Bank in), ppm	1312.8	1308.4	4.4	±26
Isothermal Temp Coefficient (HZP ARO), pcm/F	-2.866	-3.055	0.189	±2
Differential Boron Worth (HZP ARO), pcm/ppm	-7.64	-7.60	0.5%	±10%
Reference Bank Worth (B-bank, dilution), pcm	1219.4	1247.0	-2.2%	±10%
A-bank Worth (Rod Swap), pcm	250.8	257.6	-6.8	±100
SA-bank Worth (Rod Swap), pcm	886.3	875.0	1.3%	±15%
C-bank Worth (Rod Swap), pcm	908.6	908.2	0.0%	±15%
D-bank Worth (Rod Swap), pcm	1044.5	1045.1	-0.1%	±15%
SB-bank Worth (Rod Swap), pcm	1162.7	1204.8	-3.5%	±15%
Total Bank Worth, pcm	5472.3	5537.7	-1.2%	±10%
S1C27 Testing Time:		**5.6 hrs**		
[criticality 5/27/2015 @ 00:21 to end of testing 5/27/2015 @ 05:59]				
Recent Startups:				
S2C26 testing time:		7.2 hrs		
S1C26 testing time:		7.8 hrs		
S2C25 testing time:		6.1 hrs		
S1C25 testing time:		5.7 hrs		
S2C24 testing time:		7.1 hrs		
S1C24 testing time:		7.0 hrs		
S2C23 testing time:		9.4 hrs		
S1C23 testing time:		6.2 hrs		
S2C22 testing time:		6.2 hrs		
S1C22 testing time:		8.0 hrs		

SECTION 8 — REFERENCES

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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.

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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.

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14. T. S. Psuik, "Surry Unit 1 Cycle 27 Startup Physics Testing Logs and Results", Memorandum MEMO-NCD-20150016, Rev. 0, May 2015.

15. A. M. Scharf, "The CECOR Flux Map Analysis Code Version 3.3 Additional Software Requirements and Design", Engineering Technical Evaluation ETE-NAF-2013-0088, Rev. 0, November 2013.

16. A. M. Scharf, "Qualification and Verification of the CECOR-GUI", Engineering Technical Evaluation ETE-NAF-2013-0081, Rev. 0, November 2013.

17. Nuclear Engineering Standard DNES-AA-NAF-NCD-5007, Rev. 1, "Startup Physics Tests Results Reporting".

18. J. E. Kloecker, et al., "Results from Test Plan of DC SU-14-01164 – RCS Loop Flows", Engineering Technical Evaluation ETE-NAF-2015-0071, Rev. 0, June 2015.

19. A. T. Folkening, "Surry Rod Drop Measurement Instrument (RDMI) Data Comparison & Analysis Report", AREVA Document No. 51-9228549-000, Feb 2015.

20. D. Ingell et al., "Unit 1 RCP Replacement" Design Change SU-14-01164, April 2015.

APPENDIX — STARTUP PHYSICS TEST SUMMARY SHEETS

Surry Power Station Unit 1 Cycle 27 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= 2.0×10^{-9} to 1.0×10^{-7} amps	background < ZPTR < POAH background = 1.2×10^{-11} amps POAH= 2.275×10^{-7} amps	N/A	✓ Yes ___ No	N/A	5/27/15 1:10	BRK/ KLK
Reactivity Computer Checkout						
ρ_c= 61.521/-41.001 pcm (measured reactivity) ρ_t= 61.908/-41.627 pcm (predicted reactivity) %D = {(ρc - ρt)/ρt} x 100% %D = -0.62%/-1.49%	$\vert\{(\rho_c - \rho_t)/\rho_t\}\vert \times 100\% \leq 4.0\ \%$[1] The allowable range is set to the larger of the measured results or the pre-critical bench test. Pre-critical Bench Test Results +120/-100 pcm Allowable range +120/-100 pcm	N/A	✓ Yes ___ No	N/A	5/27/15 1:10	BRK/ KLK
Critical Boron Concentration - ARO						
$(C_B)^M_{ARO}$= 1472.4 ppm (Adj. To design conds.)	$(C_B)_{ARO}$=[2] 1477 ± 50 ppm $\Delta(C_B)_{ARO}=(C_B)^M_{ARO} - (C_B)_{ARO}$ = -4.6 ppm	$\vert\alpha C_B \times \Delta(C_B)_{ARO}\vert \leq 1000$ pcm [T.S. 4.10.A] αC_B=[2] -7.530 pcm/ppm	✓ Yes ___ No	✓ Yes ___ No	5/27/15 1:10	BRK/ KLK
Isothermal Temperature Coefficient - ARO						
$(\alpha_T^{ISO})^M_{ARO}$ = -2.866 pcm/°F	$(\alpha_T^{ISO})_{ARO}$ =[2] -3.055 ± 2 pcm/°F $(\alpha_T^{ISO})^M_{ARO} - (\alpha_T^{ISO})_{ARO}$ = 0.189 pcm/°F	$\alpha_T^{ISO} \leq \alpha_M^{lim} - \alpha_T^{mod} + \alpha_T^{DOP}$ $\alpha_T^{ISO} \leq$ 3.670 pcm/°F where: (α_M^{lim}); 6.0 pcm/°F [COLR 3.4] (α_T^{mod})[1]; 0.5 pcm/°F (α_T^{DOP})[2]; -1.83 pcm/°F	✓ Yes ___ No	✓ Yes ___ No	5/27/15 1:50	BRK/ KLK
Control Bank B Worth Measurement, Rod Swap Reference Bank						
$I_B^{REF,M}$= 1219.382 pcm	I_B^{REF}=[2] 1247 ± 10% 100x(Meas. - Des.)/Des. = -2.2 %	N/A	✓ Yes ___ No	N/A	5/27/15 2:48	BRK/ KLK

References
1.) DNES-AA-NAF-NCD-4015, Rev. 1
2.) ETE-NAF-2015-0044, Rev. 0
3.) ETE-NAF-2015-0043, Rev. 0

Surry Power Station Unit 1 Cycle 27 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						
$(C_B)^M_B$= 1312.8 ppm	$(C_B)_B$=[2] 1313 +$\Delta(C_B)_{ARO}$ ± 26 ppm $\Delta(C_B)_{ARO}$= -4.6 ppm (from above) $(C_B)_B$= 1308.4 ± 26 ppm $(C_B)^M_B - (C_B)_B$ = 4.4 ppm	N/A	✓ Yes ___ No	N/A	5/27/15 4:40	BRM/ KLK
HZP Boron Worth Coefficient Measurement						
$(\alpha C_B)^M$ = -7.64 pcm/ppm	αC_B =[2] -7.60 ± 0.76 pcm/ppm $\Delta\alpha C_B = (\alpha C_B)^M - (\alpha C_B)$ = -0.04 pcm/ppm	N/A	✓ Yes ___ No	N/A	5/27/15 4:40	BRM/ KLK
Control Bank A Worth Measurement, Rod Swap						
I_A^{RS}= 250.8 pcm	$(I_A^{RS})^3$= 257.6 ± 100 pcm Meas. - Des.. = -6.8 pcm	N/A	✓ Yes ___ No	N/A	5/27/15 4:45	BRM / KLK
Shutdown Bank A Worth Measurement, Rod Swap						
I_{SA}^{RS}= 886.3 pcm	$(I_{SA}^{RS})^3$= 875.0 ± 15% 100x(Meas. - Des.)/Des. = 1.3 %	N/A	✓ Yes ___ No	N/A	5/27/15 4:45	BRM / KLK
Control Bank C Worth Measurement, Rod Swap						
I_C^{RS}= 908.6 pcm	$(I_C^{RS})^3$= 908.2 ± 15% 100x(Meas. - Des.)/Des. = 0 %	N/A	✓ Yes ___ No	N/A	5/27/15 4:45	BRM / KLK
Control Bank D Worth Measurement, Rod Swap						
I_D^{RS}= 1044.5 pcm	$(I_D^{RS})^3$= 1045.1 ± 15% 100x(Meas. - Des.)/Des. = -0.1 %	N/A	✓ Yes ___ No	N/A	5/27/15 4:45	BRM / KLK
Shutdown Bank B Worth Measurement, Rod Swap						
I_{SB}^{RS}= 1162.7 pcm	$(I_{SB}^{RS})^3$= 1204.8 ± 15% 100x(Meas. - Des.)/Des. = -3.5 %	N/A	✓ Yes ___ No	N/A	5/27/15 4:45	BRM / KLK
Total Rod Worth, Rod Swap						
I_{Total}= 5472.3 pcm	$(I_{total})^3$= 5537.7 ± 10% 100x(Meas. - Des.)/Des. = -1.2 %	N/A	✓ Yes ___ No	N/A	5/27/15 4:45	BRM / KLK

References 1.) DNES-AA-NAF-NCD-4015, Rev. 1
2.) ETE-NAF-2015-0044, Rev. 0
3.) ETE-NAF-2015-0043, Rev. 0

Surry Power Station Unit 1 Cycle 27 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) = 29.01						
Max Relative Assembly Power, %DIFF (M-P)/P					5/28/15 02:57	KLK / RAH
%DIFF= -3.3 % 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)= 1.513	N/A	FΔH(N)≤1.56(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= 2.183	N/A	$F_Q(Z) \leq 5^*K(Z)$ [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.0091	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 1
2.) ETE-NAF-2015-0044, Rev. 0
3.) ETE-NAF-2015-0043, Rev. 0

Surry Power Station Unit 1 Cycle 27 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) = 70.45%						
Max Relative Assembly Power, %DIFF (M-P)/P					5/29/15 12:10	BRK/ [illegible]
%DIFF= 3.4 % for PI ≥0.9 -4.7 % 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)= 1.467	N/A	FΔH(N)≤1.56(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= 1.907	N/A	F_Q(Z)≤(2.5/P)*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.0048	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 1
2.) ETE-NAF-2015-0044, Rev. 0
3.) ETE-NAF-2015-0043, Rev. 0

Surry Power Station Unit 1 Cycle 27 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					6/14/15 0900	AKK/DTH
%DIFF= -2.8 ✓ % for Pi ≥0.9 -4.3 ✓ % 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)= 1.447 ✓	N/A	$F\Delta H(N) \le 1.56(1+0.3(1-P))$ [COLR 3.7]	N/A	✓ Yes __ No		
Total Heat Flux Hot Channel Factor, FQ(Z)						
Peak $F_Q(Z)$ Hot Channel Factor= 1.826 ✓	N/A	$F_Q(Z) \le (2.5/P)*K(Z)$ [COLR 3.7]	N/A	✓ Yes __ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 0.49% 1.0049	≤ 1.02[1]	N/A	✓ Yes __ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 1
2.) ETE-NAF-2015-0044, Rev. 0
3.) ETE-NAF-2015-0043, Rev. 0

Surry Power Station Unit 1 Cycle 27 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}= 289,422.1 gpm	N/A	$F_{total} \geq$ 274000 gpm [COLR 3.8]	N/A	✓ Yes ___ No	6/1/15 1200	AMC/DJA

References 1.) DNES-AA-NAF-NCD-4015, Rev. 1
2.) ETE-NAF-2015-0044, Rev. 0
3.) ETE-NAF-2015-0043, Rev. 0