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

Dominion®

February 6, 2017

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.: 17-017
NLOS/GDM
Docket No.: 50-280
License No.: DPR-32

VIRGINIA ELECTRIC AND POWER COMPANY (DOMINION)
SURRY POWER STATION UNIT 1
CYCLE 28 STARTUP PHYSICS TESTS REPORT

As required by Surry Power Station (Surry) Technical Specification 6.6.A.1, enclosed is the Surry Unit 1 Cycle 28 Startup Physics Tests Report. This report summarizes the results of the physics testing program performed prior to and following initial criticality of Cycle 28 on November 10, 2016. 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,

T. R. Huber, Director
Nuclear Regulatory Affairs
Dominion Resources Services, Inc. for
Virginia Electric and Power Company

Enclosure: Surry Unit 1 Cycle 28 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

Ms. B. L. Mozafari
NRC Project Manager – North Anna
U. S. Nuclear Regulatory Commission
One White Flint North
Mail Stop O8 H-12
11555 Rockville Pike
Rockville, MD 20852-2738

NRC Senior Resident Inspector
Surry Power Station

Serial No. 17-017
Docket No. 50-280

Enclosure

SURRY UNIT 1 CYCLE 28
STARTUP PHYSICS TESTS REPORT

January 2017

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

CLASSIFICATION/DISCLAIMER

The data, techniques, information, and conclusions in this report have been prepared solely for use by Dominion (the Company), and they may not be appropriate for use in situations other than those for which they have been specifically prepared. The Company therefore makes no claim or warranty whatsoever, express or implied, as to their accuracy, usefulness, or applicability. In particular, THE COMPANY MAKES NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, NOR SHALL ANY WARRANTY BE DEEMED TO ARISE FROM COURSE OF DEALING OR USAGE OF TRADE, with respect to this report or any of the data, techniques, information, or conclusions in it. By making this report available, the Company does not authorize its use by others, and any such use is expressly forbidden except with the prior written approval of the Company. Any such written approval shall itself be deemed to incorporate the disclaimers of liability and disclaimers of warranties provided herein. In no event shall the Company be liable, under any legal theory whatsoever (whether contract, tort, warranty, or strict or absolute liability), for any property damage, mental or physical injury or death, loss of use of property, or other damage resulting from or arising out of the use, authorized or unauthorized, of this report or the data, techniques, information, or conclusions in it.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

This report presents the analysis and evaluation of the physics tests that were performed to verify that the Surry Unit 1 Cycle 28 core could be operated safely, and makes an initial evaluation of the performance of the core. This report was performed in accordance with DNES-AA-NAF-NCD-5007, Rev. 3 [Ref. 17]. It is not the intent of this report to discuss the particular methods of testing or to present the detailed data taken. Standard testing techniques and methods of data analysis were used. The test data, results and evaluations, together with the detailed startup procedures, are on file at Surry Power Station. Therefore, only a cursory discussion of these items is included in this report. The analyses presented include a brief summary of each test, a comparison of the test results with design predictions, and an evaluation of the results.

The Surry Unit 1 Cycle 28 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 Engineering and Fuel Group. The acceptance criteria are based on design tolerances or applicable Technical Specifications and COLR Limits.

SECTION 1 — INTRODUCTION AND SUMMARY

On October 22, 2016, Unit No. 1 of Surry Power Station completed Cycle 27 and began refueling [Ref. 1]. During this refueling, 64 of the 157 fuel assemblies in the core were replaced with fresh Batch S1/30 assemblies [Ref. 8]. The Surry 1 Cycle 28 (S1C28) core consists of eight sub-batches of fuel: three fresh batches (S1/30A, S1/30B and S1/30C), three once-burned batches (S1/29A, S1/29B and S1/29C), and two twice-burned batches (S1/28A and S1/28C). S1C28 utilizes the 15x15 Upgrade (Upgrade) Fuel Design for all but eight of the fuel assemblies. The remaining eight assemblies are Lead Test Assemblies (LTAs) of the AREVA AGORA-5A-I (AGORA) design that are being loaded for their first cycle of irradiation [Ref. 1].

Surry 1 batches 28, 29, 30A and 30B are of the Westinghouse Upgrade fuel design, which includes ZIRLO (I-spring) structural mid grids with balanced mixing vane pattern, three ZIRLO Intermediate Flow Mixing (IFM) grids, "tube-in-tube" guide thimbles, the use of optimized ZIRLO fuel clad that improves corrosion resistance and oxidation of the bottom portion of the fuel clad to improve debris resistance, Robust Protective Grids (RPG) and modified Debris Filter Bottom Nozzles (mDFBN). In addition, Surry 1 batches 29, 30A and 30B utilize the Westinghouse Integral Nozzle (WIN) top nozzle design [Ref. 8].

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

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

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

Cycle 28 loads the secondary source assemblies (SSAs) in core locations H04 and H12 to improve Source Range Detector response. Each assembly consists of six source rods containing antimony and beryllium pellets encapsulated in a double layer of stainless steel cladding. There are no thimble plugging devices in S1C28. The cycle design report [Ref. 1] provides a more detailed description of the Cycle 28 core.

The S1C28 full core loading plan [Ref. 8 and Ref. 11] is shown in Figure 1.1, and the beginning of cycle fuel assembly burnups [Ref. 6] are shown 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 28 core [Ref. 1].

According to the Startup Physics logs, the Cycle 28 core achieved initial criticality on November 10, 2016 at 15:50 [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 S1C28 Startup Physics Testing. The tests performed are the same as in previous cycles. A summary of the test results follows.

The measured drop time of each control rod was within the 2.40 second Technical Specification [Ref. 4] limit, as well as the 1.68 second 15x15 Upgrade Fuel administrative limit [Ref. 10]. All control rods are located in Upgrade fuel assemblies.

Individual control rod bank worths were measured using the rod swap technique [Ref. 2]. For the purpose of this test, a bank was defined as 'fully inserted' when it was 2 steps off the bottom of the core [Ref. 13]. The sum of the individual measured control rod bank worths was within -1.9% of the design prediction. The reference bank (Control Bank B) worth was within -0.3% of its design prediction. Control rod banks with design predictions greater than 600 pcm were within -3.6% of the design predictions. For individual banks worth 600 pcm or less (only Control Bank A fits this category), the difference was within -6 pcm of the design prediction. These results are within the design tolerances of ±15% for individual banks worth more than 600 pcm (±10% for the reference bank worth), ±100 pcm for individual banks worth 600 pcm or less, and ±10% for the sum of the individual control rod bank worths.

Measured critical boron concentrations for two control bank configurations, all rods out (ARO) and Reference Bank (B-bank) in, were within the design tolerances and the Technical Specification criterion [Ref. 4] that the overall core reactivity balance shall be within ±1% $\Delta k/k$ of the design prediction. The boron worth coefficient measurement (the differential boron worth, DBW) was within +1.3% of the design prediction, which is within the design tolerance of ±10%.

The measured isothermal temperature coefficient (ITC) for the ARO configuration was within +0.293 pcm/^{o}F of the design prediction. This result is within the design tolerance of ±2.0 pcm/^{o}F [Ref. 14].

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

Core power distributions were within established design tolerances. The measured assembly power distributions were within ±5.3% of the design predictions, where a 5.3% maximum difference occurred in the 99.80% power map. The heat flux hot channel factors, $F_Q(Z)$, and enthalpy rise hot channel factors, $F^N_{\Delta H}$, were within the limits of the COLR [Ref. 8]. All power flux maps were within the maximum incore power tilt design tolerance of 2% (QPTR ≤ 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]. The total RCS Flow at nominal conditions was measured as 289,888 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 28
CHRONOLOGY OF TESTS

Test	Date	Time	Power	Reference Procedure
Hot Rod Drop-Hot Full Flow#	11/09/16	21:49	HSD	1-NPT-RX-014
Reactivity Computer Checkout	11/10/16	16:30	HZP	1-NPT-RX-008
Boron Endpoint – ARO	11/10/16	16:30	HZP	1-NPT-RX-008
Zero Power Testing Range	11/10/16	16:30	HZP	1-NPT-RX-008
Boron Worth Coefficient	11/10/16	21:35	HZP	1-NPT-RX-008
Temperature Coefficient – ARO	11/10/16	16:54	HZP	1-NPT-RX-008
Bank B Worth	11/10/16	18:02	HZP	1-NPT-RX-008
Boron Endpoint – B in	11/10/16	18:04	HZP	1-NPT-RX-008
Bank A Worth – Rod Swap	11/10/16	20:19	HZP	1-NPT-RX-008
Bank C Worth – Rod Swap	11/10/16	20:19	HZP	1-NPT-RX-008
Bank SA Worth – Rod Swap	11/10/16	20:19	HZP	1-NPT-RX-008
Bank D Worth – Rod Swap	11/10/16	20:19	HZP	1-NPT-RX-008
Bank SB Worth – Rod Swap	11/10/16	20:19	HZP	1-NPT-RX-008
Total Rod Worth	11/10/16	20:19	HZP	1-NPT-RX-008
Flux Map – less than 50% Power* Peaking Factor Verification & Power Range Calibration	11/11/16	21:25	46.30%	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	11/12/16	11:02	70.04%	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	11/15/16	08:44	99.80%	1-NPT-RX-002 1-NPT-RX-008 1-NPT-RX-005 1-GEP-RX-001
RCS Flow Measurement	11/14/16	15:24	HFP	1-NPT-RX-009

The time indicated is for the first rod drop, for all rods except N-07 (SA-Bank). A second drop was performed on 11/10/16 at 02:12 for only SA-Bank.

* 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).

Figure 1.1

SURRY UNIT 1 – CYCLE 28
CORE LOADING MAP

SURRY UNIT 1 - CYCLE 28
FULL CORE LOADING PLAN
REVISION NO. 0

WBP-NES-MAP

NORTH ↑

	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	
							339	247	224							15
					248	RCC 349	437	RCC 446	434	RCC 347	244					14
				249	429	443	RCC 407	359	RCC 409	442	431	252				13
			256	RCC 432	456	RCC 356	331	SS10 309	328	RCC 352	459	RCC 423	254			12
		257	422	453	RCC 304	338	AG8	301	AG4	335	RCC 306	454	426	259		11
		RCC 344	450	RCC 355	340	RCC 403	322	RCC 318	339	RCC 402	334	RCC 354	451	RCC 343		10
	221	439	RCC 405	326	AG3	314	RCC 358	461	RCC 365	321	AG2	329	RCC 412	433	222	9
270°	241	RCC 448	361	310	307	RCC 324	463	325	462	RCC 323	308	312	364	RCC 444	246	8
	218	436	RCC 410	327	AG6	313	RCC 362	464	RCC 360	317	AG5	336	RCC 408	440	220	7
		RCC 342	452	RCC 353	341	RCC 401	316	RCC 320	315	RCC 404	333	RCC 358	445	RCC 346		6
		260	425	458	RCC 302	337	AG1	305	AG7	332	RCC 303	457	430	258		5
			251	RCC 428	455	RCC 357	328	SS11 311	339	RCC 351	460	RCC 427	250			4
				253	421	449	RCC 406	363	RCC 411	441	424	255				3
					243	RCC 345	438	RCC 447	435	RCC 348	242					2
							323	245	217							1

180°

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

Prepared By: T. S. Psuik Date: 5/24/16
Reviewed By: B. B. Kinney Date: 5/25/16
Approved By: A. H. Nicholson Date: 5/26/16

Concurrence By: P. S. Williamson Date: 6/1/16
Approved By: M. N. LaPrade Date: 6/1/16

Figure 1.2

SURRY UNIT 1 – CYCLE 28
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							34.77 34.75	39.66 39.45	34.72 34.73							1
2					37.83 38.09	17.91 17.85	0.00 0.00	0.00 0.00	0.00 0.00	18.03 17.86	38.26 38.12					2
3				39.52 39.18	0.00 0.00	0.00 0.00	0.00 0.00	19.52 19.36	0.00 0.00	0.00 0.00	0.00 0.00	38.99 39.15				3
4			39.28 39.14	0.00 0.00	0.00 0.00	17.96 17.96	20.50 20.59	21.91 21.74	20.75 20.61	17.85 17.90	0.00 0.00	0.00 0.00	39.23 39.17			4
5		38.99 38.92	0.00 0.00	0.00 0.00	22.07 21.94	21.86 21.66	0.00 0.00	21.72 21.79	0.00 0.00	21.76 21.67	21.59 21.86	0.00 0.00	0.00 0.00	39.59 39.38		5
6		18.16 17.85	0.00 0.00	17.79 17.94	21.58 21.65	0.00 0.00	22.17 22.04	22.19 21.92	22.09 22.09	0.00 0.00	21.47 21.65	18.09 18.00	0.00 0.00	17.86 17.85		6
7	34.75 34.73	0.00 0.00	0.00 0.00	20.49 20.58	0.00 0.00	22.03 22.02	18.45 18.31	0.00 0.00	18.36 18.31	21.84 21.97	0.00 0.00	20.51 20.56	0.00 0.00	0.00 0.00	34.97 34.76	7
8	39.83 39.36	0.00 0.00	19.63 19.41	21.81 21.78	21.90 21.86	21.87 21.92	0.00 0.00	19.74 19.74	0.00 0.00	21.82 21.92	22.10 21.86	21.96 21.78	19.29 19.41	0.00 0.00	39.37 39.36	8
9	34.98 34.76	0.00 0.00	0.00 0.00	20.54 20.56	0.00 0.00	21.64 21.97	18.39 18.31	0.00 0.00	18.23 18.31	22.04 22.02	0.00 0.00	21.05 20.57	0.00 0.00	0.00 0.00	34.62 34.74	9
10		17.73 17.85	0.00 0.00	17.98 18.00	21.84 21.65	0.00 0.00	22.13 22.09	22.02 21.92	22.28 22.04	0.00 0.00	21.72 21.66	18.01 17.94	0.00 0.00	17.79 17.85		10
11		39.50 39.38	0.00 0.00	0.00 0.00	21.87 21.86	21.55 21.67	0.00 0.00	21.79 21.79	0.00 0.00	21.96 21.66	22.03 21.94	0.00 0.00	0.00 0.00	38.90 38.92		11
12			39.48 39.17	0.00 0.00	0.00 0.00	17.86 17.90	21.05 20.61	21.66 21.74	20.56 20.59	18.27 17.96	0.00 0.00	0.00 0.00	39.38 39.14			12
13				38.92 39.15	0.00 0.00	0.00 0.00	0.00 0.00	19.30 19.36	0.00 0.00	0.00 0.00	0.00 0.00	39.17 39.18				13
14					38.09 38.11	17.98 17.85	0.00 0.00	0.00 0.00	0.00 0.00	17.98 17.85	38.19 38.09					14
15							34.58 34.73	39.88 39.45	34.52 34.75							15

Figure 1.3

SURRY UNIT 1 – CYCLE 28
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
+ - Locations Not Used For Any Map
* - Location G7 Used as Calibration Thimble Due to Location J7 Being Unavailable Following Replacement

Figure 1.4

SURRY UNIT 1 – CYCLE 28
CONTROL ROD LOCATIONS

180°

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

0°

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

SB = Shutdown Bank SB
SA = Shutdown Bank SA

SECTION 2 — CONTROL ROD DROP TIME MEASUREMENTS

The drop time of each control rod was measured at hot shutdown (HSD) with three reactor coolant pumps in operation (full flow) and with T_{ave} greater than or equal to 530 °F per 1-NPT-RX-014. This verified 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 28 used the Rod Drop Measurement Instrument (RDMI) to gather and analyze the rod drop data [Ref. 12]. The methodology acquires data using the secondary RPI coil terminals (/3 & /4) on the Computer Enhanced Rod Position Indication (CERPI) racks for each rod. Data is immediately saved to a comma-separated value file.

It is noted that rods were dropped twice due to an issue with rod N-07 (SA-Bank); the first drop was for all rods except N-07 and the second drop was for only SA-Bank. Prior to the first drop, N-07 was noted to be on the bottom of the core due to a blown lift coil fuse. After this fuse was replaced, SA-Bank was dropped in order to obtain the drop time for N-07. For SA-Bank, the reported rod drop times for all rods, except N-07, were from the first drop as the second drop was for evaluation of N-07. For the other SA-Bank rods, it was noted that the second drop had a similar shape and time when compared to the first drop with an increased signal magnitude.

A typical rod drop trace for S1C28 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 18-28. Technical Specification 3.12.C.1 [Ref. 4] specifies a maximum rod drop time to dashpot entry of 2.4 seconds for all rods. It is noted that the AREVA fuel assemblies are not loaded in rodded core locations. These test results satisfied this Technical Specification limit, as well as the 15x15 Upgrade administrative limit [Ref. 10] of 1.68 seconds. In addition, rod bounce was observed at the end of each trace demonstrating that no control rod stuck in the dashpot region. The fastest and average rod drop times did not change from S1C27 but the slowest rod time increased by 0.01 seconds.

Table 2.1

SURRY UNIT 1 – CYCLE 28 STARTUP PHYSICS TESTS
HOT ROD DROP TIME SUMMARY

ROD DROP TIME TO DASHPOT ENTRY

SLOWEST ROD	FASTEST ROD	AVERAGE TIME
P-08 1.46 sec.	K-04 1.31 sec	1.36 sec.

Figure 2.1

SURRY UNIT 1 – CYCLE 28 STARTUP PHYSICS TESTS
TYPICAL ROD DROP TRACE

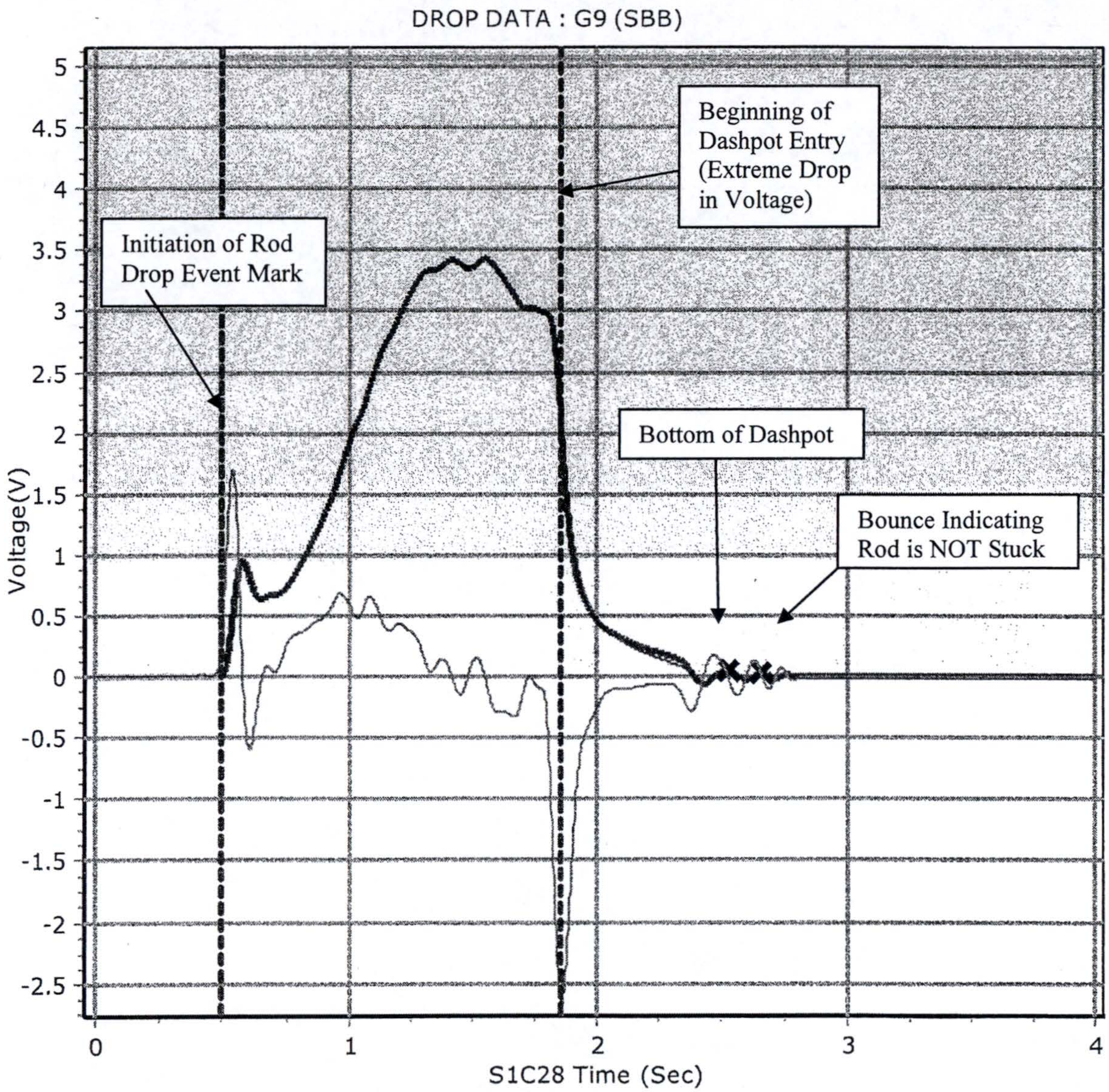


Figure 2.2

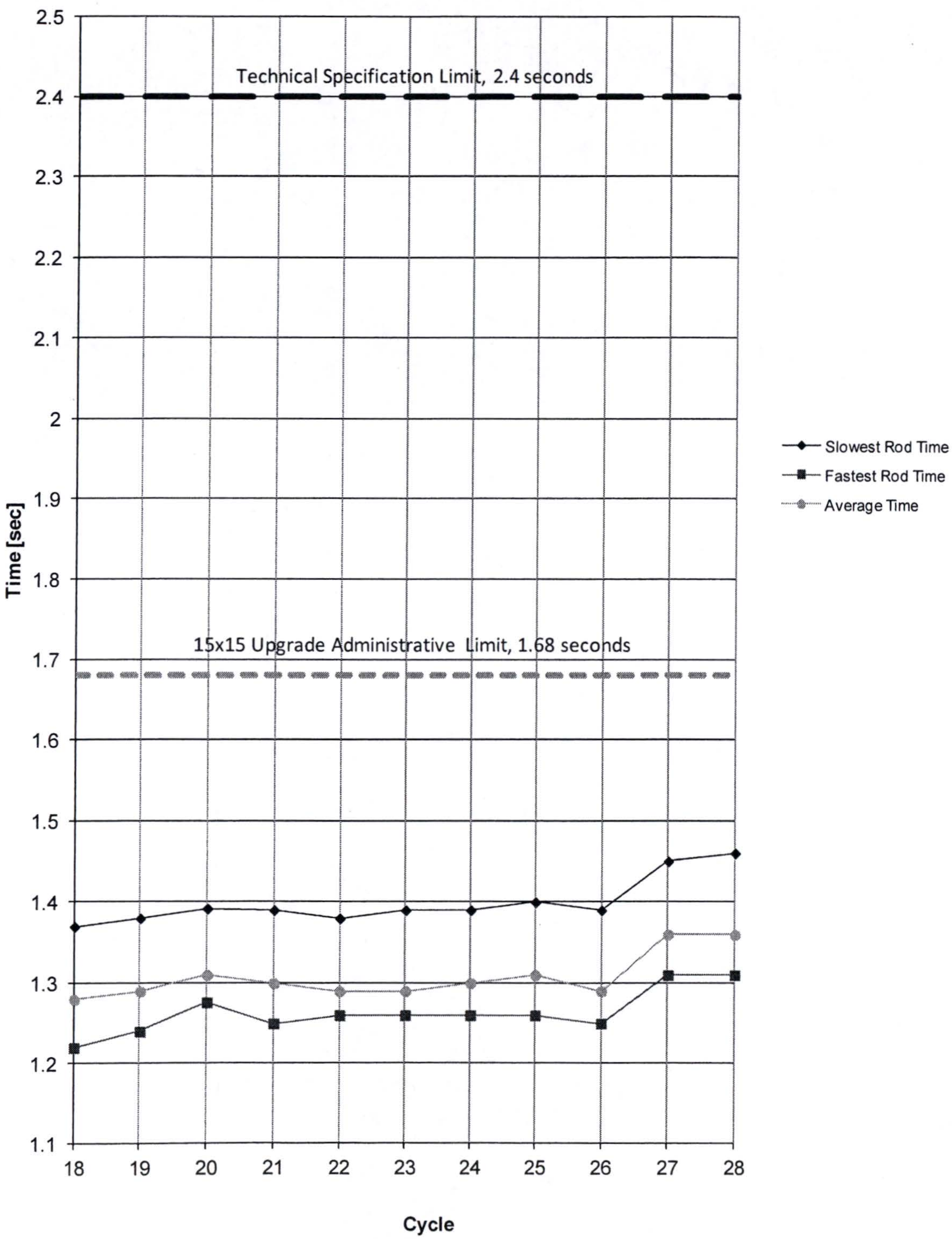
SURRY UNIT 1 – CYCLE 28 STARTUP PHYSICS TESTS
ROD DROP TIME – HOT FULL FLOW CONDITIONS

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1															
2						1.34		1.33		1.35					
3							1.34		1.36						
4				1.35		1.31				1.34		1.39			
5					1.35						1.35				
6		1.34		1.34		1.34		1.35		1.36		1.35		1.44	
7			1.33				1.36		1.34				1.34		
8		1.46				1.37				1.42				1.37	
9			1.37				1.34		1.37				1.36		
10		1.36		1.33		1.34		1.34		1.37		1.36		1.37	
11					1.35						1.36				
12				1.32		1.34				1.34		1.40			
13							1.36		1.36						
14						1.39		1.34		1.40					
15															

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

Figure 2.3

SURRY UNIT 1 – CYCLE 28 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 28, 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 S1C28 startup physics testing campaign used 2 steps withdrawn for all conditions requiring control rods to be manually fully inserted.

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

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

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

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

A summary of the test results is provided in Table 3.1. As shown in this table and the Startup Physics Test Summary Sheets 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 -1.9% 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 28 STARTUP PHYSICS TESTS
CONTROL ROD BANK WORTH SUMMARY

BANK	MEASURED WORTH (PCM)	PREDICTED WORTH (PCM)	PERCENT DIFFERENCE (%) (M-P)/P X 100
B – Reference	1543.6	1549.0	-0.3%
A	338.4	343.9	-6 pcm*
C	873.5	905.9	-3.6%
SA	918.9	919.4	-0.1%
D	989.5	1018.5	-2.8%
SB	1120.5	1158.2	-3.3%
Total Bank Worth	5784.4	5894.9	-1.9%

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

Figure 3.1

SURRY UNIT 1 – CYCLE 28 STARTUP PHYSICS TESTS
CONTROL BANK B INTEGRAL ROD WORTH - HZP
ALL OTHER RODS WITHDRAWN

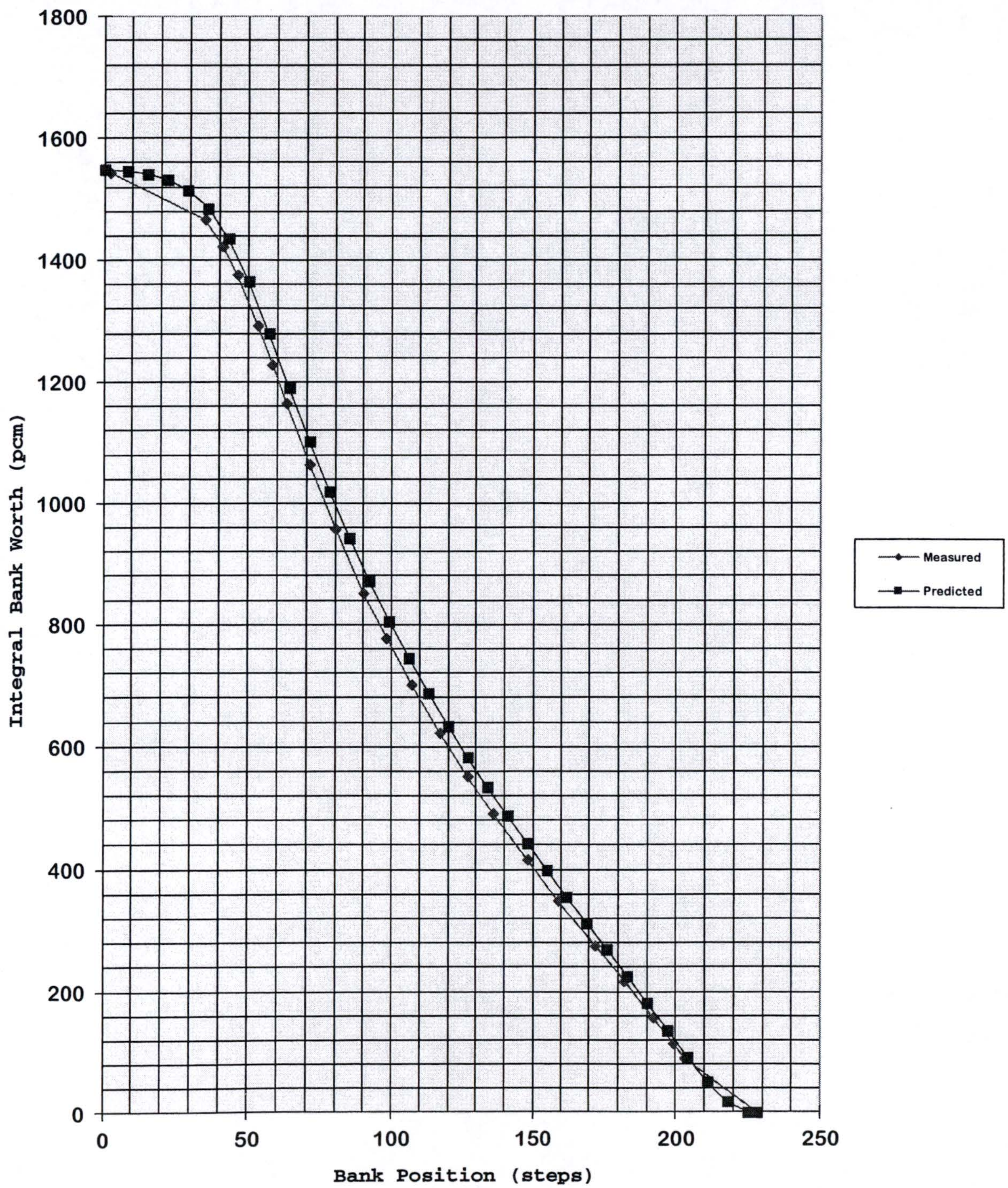
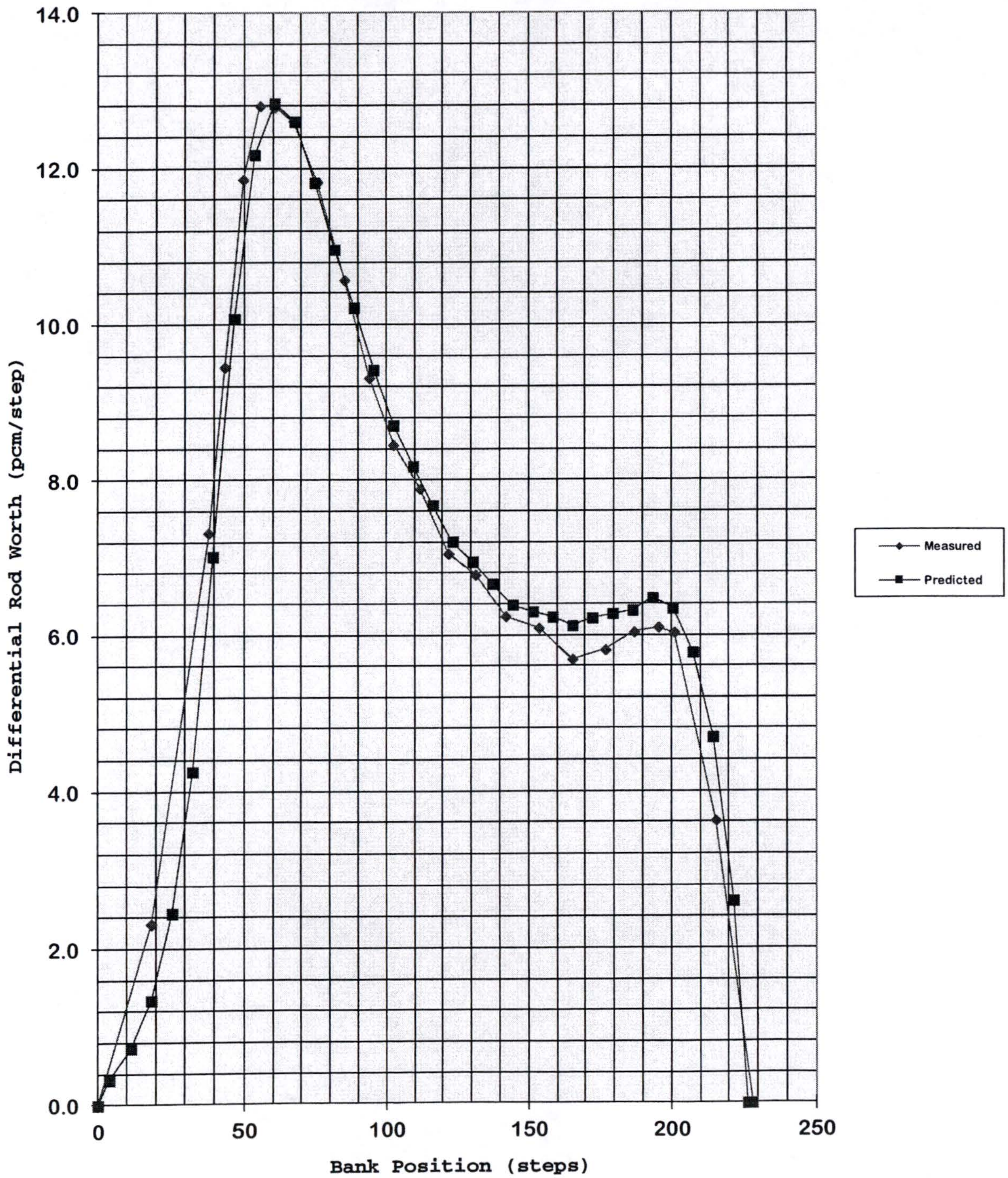


Figure 3.2

SURRY UNIT 1 – CYCLE 28 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 included 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 $\pm$10%. In summary, the measured boron worth coefficient was satisfactory.

Table 4.1

SURRY UNIT 1 – CYCLE 28 STARTUP PHYSICS TESTS
BORON ENDPOINTS SUMMARY

Control Rod Configuration	Measured Endpoint (ppm)	Predicted Endpoint (ppm)	Difference M-P (ppm)
ARO	1535.6	1546.0	-10.4
B Bank In	1336.0	1332.6*	+3.4

* 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 28 STARTUP PHYSICS TESTS
BORON WORTH COEFFICIENT

Measured Boron Worth (pcm/ppm)	Predicted Boron Worth (pcm/ppm)	Percent Difference (%) (M-P)/P x 100
-7.73	-7.63	1.3%

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 3.00 °F, followed by the RCS cool down of 3.04 °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 in the Appendix, the measured isothermal temperature coefficient value was within the design tolerance of ±2 pcm/°F. The calculated moderator temperature coefficient (MTC), which is calculated using a measured ITC of -2.325 pcm/°F, a predicted doppler temperature coefficient (DTC) of -1.83 pcm/ °F, and a measurement uncertainty of +0.5 pcm/ °F, is 0.005 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 28 STARTUP PHYSICS TESTS
ISOTHERMAL TEMPERATURE COEFFICIENT SUMMARY

BANK POSITION (STEPS)	TEMPERATURE RANGE (°F)		BORON CONCENTRATION (ppm)	ISOTHERMAL TEMPERATURE COEFFICIENT (PCM/°F)				
	LOWER LIMIT	UPPER LIMIT		HEAT-UP	COOL-DOWN	AVG. MEAS	PRED	DIFFER (M-P)
D/200	546.17	549.21	1535.6	-2.522	-2.128	-2.325	-2.619	0.293

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 that 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 28 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 provided 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 46.30% 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 70.04% and 99.80% 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 the measured relative assembly power values deviated from the design predictions by at most ±4.1% in the 46.30% power map, ±3.0% in the 70.04% power map, and ±5.3% in the 99.80% power map. The maximum average quadrant power tilts for the three maps were +0.78%, +0.54% and +0.41%, respectively. These power tilts are within the design tolerance of 2%.

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

In conclusion, the power distribution measurement results are considered acceptable with respect to the design tolerances, the accident analysis acceptance criteria, and the COLR [Ref. 8]. It is therefore anticipated that the core will continue to operate safely throughout Cycle 28.

Table 6.1

SURRY UNIT 1 – CYCLE 28 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	11/11/16	4.5	46.30	185	N-10	25	2.092	N-10	1.539	25	1.265	1.0078	NE	4.339	45
Int. Power (4)	2	11/12/16	17.5	70.04	201	N-10	31	1.936	N-10	1.505	19	1.199	1.0054	NE	3.531	45
Hot Full Power	3	11/15/16	116.9	99.80	227	N-10	32	1.866	D-6	1.480	29	1.162	1.0041	NE	0.990	45

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 28 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	2.092	5.000	25	58.2	1.539	1.898	18.9
2	1.936	3.569	31	45.8	1.505	1.782	15.5
3	1.866	2.505	32	25.5	1.480	1.636	9.5

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
46.30% POWER

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

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.262 0.261 0.37	0.299 0.300 -0.41	0.260 0.259 0.50						
2					0.349 0.348 0.17	0.720 0.718 0.35	0.928 0.925 0.36	0.907 0.907 0.02	0.927 0.923 0.45	0.725 0.718 1.04	0.352 0.348 1.24				
3				0.423 0.420 0.65	1.057 1.056 0.07	1.256 1.253 0.21	1.234 1.225 0.73	1.237 1.232 0.37	1.231 1.225 0.46	1.265 1.254 0.84	1.068 1.057 1.09	0.424 0.421 0.73			
4			0.432 0.421 2.52	1.096 1.087 0.83	1.298 1.300 -0.15	1.384 1.388 -0.25	1.231 1.237 -0.47	1.145 1.150 -0.45	1.242 1.237 0.39	1.403 1.390 0.95	1.320 1.302 1.35	1.114 1.088 2.38	0.431 0.420 2.70		
5		0.358 0.348 2.85	1.102 1.059 4.10	1.320 1.303 1.28	1.267 1.268 -0.07	1.239 1.248 -0.74	1.002 1.029 -2.62	1.081 1.093 -1.05	1.028 1.030 -0.19	1.261 1.249 0.94	1.288 1.269 1.47	1.353 1.302 3.91	1.085 1.057 2.69	0.348 0.344 1.09	
6		0.730 0.722 1.16	1.278 1.261 1.34	1.409 1.396 0.91	1.261 1.252 0.70	1.241 1.252 -0.88	1.122 1.137 -1.36	1.087 1.103 -1.45	1.133 1.136 -0.28	1.263 1.252 0.90	1.269 1.252 1.32	1.423 1.394 2.08	1.283 1.260 1.83	0.733 0.721 1.64	
7	0.262 0.262 0.03	0.932 0.932 0.00	1.233 1.238 -0.38	1.256 1.253 0.24	1.036 1.038 -0.21	1.134 1.141 -0.63	1.219 1.232 -1.07	1.116 1.131 -1.32	1.220 1.232 -0.99	1.138 1.141 -0.25	1.040 1.037 0.26	1.265 1.252 1.05	1.251 1.238 1.08	0.946 0.933 1.35	0.268 0.264 1.36
8	0.303 0.304 -0.31	0.914 0.917 -0.31	1.243 1.249 -0.51	1.190 1.190 0.04	1.100 1.105 -0.49	1.101 1.108 -0.64	1.119 1.133 -1.21	1.105 1.122 -1.53	1.110 1.133 -2.04	1.088 1.108 -1.81	1.099 1.105 -0.58	1.190 1.190 0.02	1.253 1.249 0.35	0.930 0.917 1.45	0.308 0.304 1.47
9	0.265 0.264 0.52	0.941 0.933 0.82	1.250 1.238 0.95	1.262 1.253 0.70	1.040 1.037 0.33	1.136 1.142 -0.53	1.219 1.232 -1.08	1.108 1.131 -2.05	1.191 1.232 -3.29	1.124 1.141 -1.46	1.025 1.038 -1.22	1.242 1.253 -0.86	1.233 1.238 -0.42	0.933 0.932 0.15	0.266 0.262 1.56
10		0.736 0.721 2.11	1.297 1.260 2.90	1.410 1.394 1.18	1.255 1.252 0.27	1.242 1.252 -0.78	1.127 1.136 -0.82	1.082 1.103 -1.93	1.110 1.137 -2.38	1.222 1.252 -2.37	1.237 1.252 -1.21	1.367 1.396 -2.08	1.247 1.261 -1.08	0.715 0.722 -0.90	
11		0.351 0.344 1.89	1.074 1.057 1.65	1.311 1.302 0.68	1.268 1.269 -0.06	1.240 1.249 -0.73	1.012 1.030 -1.74	1.063 1.093 -2.71	1.006 1.029 -2.26	1.213 1.248 -2.77	1.275 1.268 0.53	1.297 1.303 -0.48	1.053 1.059 -0.58	0.345 0.348 -0.76	
12			0.423 0.420 0.61	1.089 1.088 0.11	1.296 1.302 -0.47	1.378 1.390 -0.90	1.214 1.237 -1.83	1.134 1.150 -1.39	1.229 1.237 -0.66	1.385 1.388 -0.25	1.306 1.300 0.46	1.095 1.087 0.74	0.423 0.421 0.40		
13				0.420 0.421 -0.20	1.051 1.057 -0.55	1.244 1.254 -0.83	1.212 1.225 -1.03	1.227 1.232 -0.42	1.232 1.225 0.56	1.275 1.253 1.78	1.067 1.056 1.08	0.424 0.420 0.99			
14					0.346 0.348 -0.45	0.713 0.718 -0.74	0.916 0.923 -0.72	0.907 0.907 -0.03	0.944 0.925 2.02	0.732 0.718 1.90	0.353 0.348 1.37				
15							0.255 0.259 -1.47	0.301 0.300 0.23	0.266 0.261 1.78						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 1.0
STANDARD DEVIATION = 0.807

Summary:

Map No: S1-28-01
Control Rod Position:
D Bank at 185 Steps

Date: 11/11/2016

$F_Q(Z)$ = 2.092

$F_{\Delta H}^N$ = 1.539

F_Z = 1.265

Burnup = 4.5 MWD/MTU

Power: 46.30%

QPTR:

1.0004	1.0078
0.9979	0.9939

Axial Offset (%) = +4.339

Figure 6.2 — ASSEMBLYWISE POWER DISTRIBUTION 70.04% 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							0.273 0.274 -0.35	0.313 0.318 -1.66	0.270 0.272 -0.61						
2					0.354 0.353 0.23	0.724 0.724 0.00	0.936 0.937 -0.12	0.933 0.940 -0.74	0.931 0.936 -0.52	0.722 0.723 -0.20	0.354 0.354 -0.03				
3				0.424 0.423 0.20	1.047 1.045 0.18	1.238 1.238 0.00	1.222 1.219 0.24	1.222 1.231 -0.71	1.214 1.219 -0.41	1.238 1.238 -0.02	1.048 1.046 0.21	0.424 0.424 -0.04			
4			0.431 0.424 1.65	1.080 1.074 0.58	1.283 1.279 0.30	1.362 1.365 -0.18	1.221 1.227 -0.49	1.140 1.145 -0.47	1.227 1.228 -0.08	1.371 1.367 0.32	1.286 1.280 0.48	1.091 1.075 1.49	0.431 0.424 1.72		
5		0.359 0.353 1.72	1.075 1.048 2.61	1.288 1.281 0.55	1.245 1.254 -0.75	1.236 1.245 -0.73	1.012 1.035 -2.23	1.089 1.098 -0.85	1.033 1.035 -0.16	1.256 1.246 0.76	1.259 1.256 0.26	1.319 1.280 3.02	1.067 1.046 2.00	0.349 0.349 0.09	
6		0.731 0.727 0.51	1.252 1.244 0.67	1.378 1.372 0.45	1.254 1.249 0.42	1.274 1.281 -0.55	1.138 1.149 -0.93	1.102 1.112 -0.93	1.152 1.148 0.35	1.307 1.281 2.04	1.265 1.249 1.26	1.395 1.370 1.79	1.262 1.243 1.54	0.735 0.726 1.22	
7	0.273 0.274 -0.40	0.940 0.943 -0.27	1.223 1.230 -0.57	1.243 1.242 0.04	1.041 1.043 -0.20	1.149 1.152 -0.28	1.231 1.239 -0.62	1.130 1.139 -0.75	1.236 1.239 -0.25	1.158 1.153 0.43	1.047 1.042 0.48	1.256 1.241 1.19	1.245 1.230 1.23	0.954 0.944 1.10	0.279 0.276 1.13
8	0.316 0.321 -1.66	0.944 0.948 -0.39	1.238 1.247 -0.70	1.184 1.184 0.03	1.109 1.109 0.03	1.114 1.116 -0.21	1.133 1.141 -0.74	1.120 1.130 -0.91	1.127 1.141 -1.22	1.103 1.116 -1.17	1.108 1.109 -0.09	1.191 1.184 0.61	1.262 1.246 1.31	0.956 0.948 0.86	0.323 0.321 0.56
9	0.276 0.276 0.17	0.949 0.944 0.53	1.238 1.230 0.68	1.249 1.241 0.64	1.044 1.042 0.22	1.152 1.153 -0.11	1.232 1.239 -0.55	1.124 1.139 -1.29	1.215 1.239 -1.90	1.143 1.152 -0.80	1.036 1.043 -0.69	1.241 1.242 -0.10	1.233 1.230 0.22	0.945 0.943 0.22	0.273 0.274 -0.20
10		0.738 0.726 1.65	1.273 1.243 2.43	1.384 1.370 1.02	1.254 1.249 0.36	1.278 1.281 -0.27	1.145 1.148 -0.25	1.096 1.112 -1.44	1.131 1.149 -1.53	1.263 1.281 -1.39	1.241 1.249 -0.67	1.360 1.372 -0.88	1.239 1.244 -0.37	0.724 0.727 -0.35	
11		0.354 0.349 1.49	1.059 1.046 1.22	1.287 1.280 0.54	1.258 1.256 0.14	1.240 1.246 -0.46	1.019 1.035 -1.53	1.067 1.098 -2.80	1.016 1.035 -1.86	1.222 1.246 -1.96	1.255 1.254 0.06	1.279 1.281 -0.16	1.044 1.048 -0.34	0.352 0.353 -0.37	
12			0.421 0.424 -0.65	1.074 1.075 -0.11	1.274 1.280 -0.44	1.355 1.367 -0.85	1.206 1.228 -1.78	1.131 1.145 -1.26	1.223 1.227 -0.36	1.369 1.365 0.26	1.286 1.279 0.57	1.085 1.074 1.02	0.420 0.424 -0.88		
13				0.423 0.424 -0.27	1.039 1.046 -0.65	1.227 1.238 -0.87	1.206 1.219 -1.05	1.227 1.231 -0.35	1.227 1.219 0.67	1.269 1.238 2.51	1.061 1.045 1.56	0.429 0.423 1.42			
14					0.349 0.354 -1.41	0.717 0.723 -0.82	0.928 0.936 -0.82	0.939 0.939 -0.02	0.950 0.937 1.34	0.738 0.724 2.00	0.360 0.353 1.88				
15							0.267 0.272 -1.72	0.317 0.318 -0.23	0.277 0.274 1.11						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 0.8
STANDARD DEVIATION = 0.655

Summary:

Map No: S1-28-02
Control Rod Position:
D Bank at 201 Steps

Date: 11/12/2016
$F_Q(Z)$ = 1.936
$F_{\Delta H}^{N}$ = 1.505
F_Z = 1.199
Burnup = 17.5 MWD/MTU

Power: 70.04%

QPTR:		
	0.9987	1.0054
	0.9979	0.9980

Axial Offset (%) = +3.531

Figure 6.3 — ASSEMBLYWISE POWER DISTRIBUTION 99.80% 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							0.273 0.271 0.79	0.328 0.318 3.07	0.272 0.269 1.04						
2					0.345 0.347 -0.69	0.711 0.714 -0.40	0.929 0.931 -0.17	0.955 0.956 -0.10	0.931 0.930 0.10	0.720 0.714 0.90	0.349 0.347 0.62				
3				0.422 0.416 1.51	1.022 1.028 -0.58	1.215 1.222 -0.57	1.207 1.211 -0.32	1.216 1.229 -1.02	1.207 1.211 -0.34	1.225 1.222 0.26	1.034 1.029 0.48	0.426 0.417 2.15			
4			0.420 0.417 0.73	1.056 1.058 -0.22	1.250 1.266 -1.25	1.343 1.356 -0.92	1.213 1.224 -0.89	1.135 1.144 -0.81	1.221 1.225 -0.35	1.359 1.358 0.06	1.269 1.267 0.13	1.072 1.058 1.28	0.422 0.416 1.54		
5		0.350 0.346 1.16	1.050 1.031 1.88	1.267 1.268 -0.09	1.237 1.255 -1.41	1.242 1.256 -1.14	1.022 1.040 -1.78	1.095 1.105 -0.89	1.036 1.041 -0.50	1.257 1.257 0.03	1.244 1.256 -0.93	1.293 1.267 2.02	1.048 1.029 1.86	0.355 0.343 3.52	
6		0.718 0.718 0.00	1.230 1.229 0.12	1.360 1.363 -0.20	1.254 1.260 -0.51	1.319 1.329 -0.75	1.161 1.171 -0.86	1.122 1.128 -0.50	1.170 1.170 0.02	1.345 1.330 1.11	1.265 1.260 0.38	1.376 1.361 1.14	1.244 1.228 1.30	0.729 0.717 1.65	
7	0.273 0.272 0.31	0.933 0.938 -0.53	1.211 1.223 -0.99	1.233 1.239 -0.47	1.043 1.048 -0.50	1.169 1.174 -0.46	1.254 1.261 -0.57	1.151 1.159 -0.67	1.255 1.261 -0.45	1.176 1.175 0.08	1.048 1.048 0.00	1.246 1.239 0.56	1.233 1.223 0.84	0.952 0.939 1.41	0.278 0.274 1.46
8	0.331 0.322 2.69	0.960 0.966 -0.60	1.221 1.245 -1.93	1.178 1.183 -0.45	1.118 1.116 0.17	1.131 1.133 -0.18	1.154 1.160 -0.52	1.142 1.151 -0.82	1.148 1.160 -1.06	1.125 1.132 -0.65	1.112 1.116 -0.32	1.184 1.183 0.07	1.250 1.245 0.38	0.983 0.966 1.78	0.329 0.322 2.10
9	0.276 0.274 0.64	0.940 0.939 0.07	1.222 1.223 -0.09	1.243 1.239 0.30	1.058 1.048 0.98	1.177 1.175 0.18	1.257 1.261 -0.28	1.146 1.159 -1.15	1.236 1.261 -1.98	1.168 1.174 -0.51	1.040 1.048 -0.77	1.232 1.239 -0.56	1.223 1.223 0.03	0.948 0.938 1.11	0.286 0.272 5.26
10		0.723 0.717 0.86	1.245 1.228 1.41	1.371 1.361 0.77	1.265 1.260 0.44	1.331 1.330 0.06	1.171 1.170 0.10	1.115 1.128 -1.13	1.152 1.171 -1.61	1.309 1.329 -1.52	1.247 1.259 -0.95	1.341 1.363 -1.65	1.224 1.229 -0.39	0.721 0.718 0.41	
11		0.346 0.343 0.94	1.042 1.029 1.24	1.275 1.267 0.65	1.256 1.256 -0.03	1.254 1.257 -0.22	1.030 1.041 -1.04	1.083 1.105 -2.01	1.021 1.040 -1.86	1.220 1.256 -2.88	1.255 1.255 0.00	1.265 1.268 -0.23	1.033 1.031 0.16	0.347 0.346 0.31	
12			0.427 0.416 2.66	1.065 1.058 0.68	1.268 1.267 0.11	1.354 1.358 -0.28	1.210 1.225 -1.26	1.136 1.144 -0.72	1.220 1.224 -0.29	1.354 1.356 -0.12	1.272 1.266 0.45	1.069 1.058 1.00	0.429 0.417 2.83		
13				0.418 0.417 0.35	1.032 1.029 0.32	1.223 1.223 0.04	1.210 1.211 -0.12	1.234 1.229 0.41	1.224 1.211 1.09	1.248 1.222 2.13	1.041 1.028 1.28	0.420 0.416 1.05			
14					0.353 0.347 1.85	0.718 0.714 0.51	0.936 0.930 0.67	0.968 0.956 1.22	0.956 0.931 2.70	0.730 0.714 2.30	0.352 0.347 1.50				
15							0.277 0.269 3.10	0.323 0.318 1.63	0.278 0.271 2.58						

AVERAGE ABSOLUTE PERCENT DIFFERENCE = 0.9
STANDARD DEVIATION = 0.834

Summary:

Map No: S1-28-03
Control Rod Position:
D Bank at 227 Steps

Date: 11/15/2016
$F_Q(Z)$ = 1.866
$F_{\Delta H}^{N}$ = 1.480
F_Z = 1.162
Burnup = 116.9 MWD/MTU

Power: 99.80%

QPTR:		
	0.9953	1.0041
	1.0015	0.9991

Axial Offset (%) = +0.990

SECTION 7 — CONCLUSIONS

Table 7.1 summarizes the results associated with Surry Unit 1 Cycle 28 startup physics testing program. As noted herein, all test results were acceptable and within associated design tolerances, Technical Specification limits, or COLR limits. The AREVA AGORA LTAs show no signs of anomalous behavior and are performing as expected. It is anticipated, based on the results associated with the S1C28 startup physics testing program, that the Surry 1 core will continue to operate safely throughout Cycle 28.

Table 7.1

SURRY UNIT 1 – CYCLE 28 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	1535.6	1546.0	-10.4	±50
Critical Boron Concentration (HZP Ref Bank in), ppm	1336.0	1332.6	3.4	±30
Isothermal Temp Coefficient (HZP ARO), pcm/F	-2.325	-2.619	0.293	±2
Differential Boron Worth (HZP ARO), pcm/ppm	-7.73	-7.63	1.3%	±10%
Reference Bank Worth (B-bank, dilution), pcm	1543.6	1549.0	-0.3%	±10%
A-bank Worth (Rod Swap), pcm	338.4	343.9	-6	±100
C-bank Worth (Rod Swap), pcm	873.5	905.9	-3.6%	±15%
SA-bank Worth (Rod Swap), pcm	918.9	919.4	-0.1%	±15%
D-bank Worth (Rod Swap), pcm	989.5	1018.5	-2.8%	±15%
SB-bank Worth (Rod Swap), pcm	1120.5	1158.2	-3.3%	±15%
Total Bank Worth, pcm	5784.4	5894.9	-1.9%	±10%

S1C28 Testing Time:	**5.8**	**hrs**
[Criticality 11/10/2016 @ 15:50 to end of testing 11/10/2016 @ 21:37]		
Recent Startups:		
S2C27 testing time:	7.6	hrs
S1C27 testing time:	5.6	hrs
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

SECTION 8 — REFERENCES

1. J.A. Cantrell, "Surry Unit 1, Cycle 28 Design Report", Engineering Technical Evaluation ETE-NAF-20160134, Rev. 0, October 2016.

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

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

4. Surry Units 1 and 2 Technical Specifications.

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

6. J. A. Cantrell, "Surry Unit 1, Cycle 28 TOTE, Core Follow, and Accounting Calculations", Calculation PM-1847, Rev. 0, November 2016.

7. D. B. Livingston et al, "Surry Unit 1 Cycle 28 Flux Map Analysis", Calculation PM-1848, Rev. 0, and Addenda A - B, November 2016.

8. C. L. Tiernan and B. T. Miller, "Reload Safety Evaluation Surry 1 Cycle 28 Pattern APT," EVAL-ENG-RSE-S1C28, Rev. 0, October 2016.

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

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

11. T. S. Psuik, "Surry Unit 1 Cycle 28 Full Core Loading Plan", Engineering Technical Evaluation ETE-NAF-2016-0066, Rev. 0, June 2016.

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

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

14. T. S. Psuik, "Surry Unit 1 Cycle 28 Startup Physics Testing Logs and Results", Memorandum MEMO-NCD-20150033, Rev. 0, November 2016.

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. 3, "Startup Physics Tests Results Reporting".

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

APPENDIX — STARTUP PHYSICS TEST SUMMARY SHEETS

Surry Power Station Unit 1 Cycle 28 Startup Physics Test Summary Sheet - Formal Tests (Page 1 of 6)

Measured Value	Design Criteria	Acceptance Criteria	Design Criteria Met	Acceptance Criteria Met	Date/ Time of Test	Preparer/ Reviewer
Zero Power Testing Range Determination						
ZPTR= 2E-9 to 1E-7 amps	background < ZPTR < POAH background = 2.838E-11 amps POAH= 4.550E-7 amps	N/A	✓ Yes ___ No	N/A	11/10/2016 1630	SBR / MMG
Reactivity Computer Checkout						
ρ_c= +75.040/-66.312 pcm (measured reactivity) ρ_t= +75.261/-66.817 pcm (predicted reactivity) %D = {(ρc - ρt)/ρt} x 100% %D = -0.29% / -0.74%	$\lvert\{(\rho_c - \rho_t)/\rho_t\}\rvert \times 100\% \leq 4.0\%$[1] The allowable range is set to the larger of the measured results or the pre-critical bench test. Pre-critical Bench Test Results +123/-104 pcm Allowable range +120/-100 pcm	N/A	✓ Yes ___ No	N/A	11/10/2016 1630	MMG / SBR
Critical Boron Concentration - ARO						
$(C_B)^M_{ARO}$= 1535.6 ppm (Adj. To design conds.)	$(C_B)_{ARO}$=[2] 1546 ± 50 ppm $\Delta(C_B)_{ARO}=(C_B)^M_{ARO} - (C_B)_{ARO}$ = -10.4 ppm	$\lvert\alpha C_B \times \Delta(C_B)_{ARO}\rvert \leq 1000$ pcm [T.S. 4.10.A] αC_B=[2] -7.56 pcm/ppm	✓ Yes ___ No	✓ Yes ___ No	11/10/2016 1630	MMG / SBR
Isothermal Temperature Coefficient - ARO						
$(\alpha_T^{ISO})^M_{ARO}$ = -2.325 pcm/°F	$(\alpha_T^{ISO})_{ARO}$ =[2] -2.619 ± 2 pcm/°F $(\alpha_T^{ISO})^M_{ARO} - (\alpha_T^{ISO})_{ARO}$ = +0.293 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	11/10/2016 1654	MMG / SBR
Control Bank B Worth Measurement, Rod Swap Reference Bank						
$I_B^{REF,M}$= 1543.619 pcm	I_B^{REF}=[2] 1549 ± 10% 100x(Meas. - Des.)/Des. = -0.3 %	N/A	✓ Yes ___ No	N/A	11/10/2016 1802	JAC / BRK

References 1.) DNES-AA-NAF-NCD-4015, Rev. 2
2.) ETE-NAF-2016-0134, Rev. 0
3.) ETE-NAF-2016-0133, Rev. 0

Surry Power Station Unit 1 Cycle 28 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						
$(C_B)^M{}_B$= 1336.0 ppm	$(C_B)_B$=[2] 1343 +$\Delta(C_B)_{ARO}$ ± 30 ppm $\Delta(C_B)_{ARO}$= -10.4 ppm (from above) $(C_B)_B$= 1332.6 ± 30 ppm $(C_B)^M{}_B - (C_B)_B$ = 3.4 ppm	N/A	✓ Yes ___ No	N/A	11/10/16 1804	JAC/ BRM
HZP Boron Worth Coefficient Measurement						
$(\alpha C_B)^M$ = -7.73 pcm/ppm	αC_B =[2] -7.63 ± 0.76 pcm/ppm $\Delta\alpha C_B=(\alpha C_B)^M - (\alpha C_B)$ = -0.1 pcm/ppm	N/A	✓ Yes ___ No	N/A	11/10/16 2135	JAC/ BRM
Control Bank A Worth Measurement, Rod Swap						
I_A^{RS}= 338.4 pcm	$(I_A^{RS})^4$= 343.9 ± 100 pcm Meas. - Des.. = -5.5 pcm	N/A	✓ Yes ___ No	N/A	11/10/16 2013	JAC/ BRM
Control Bank C Worth Measurement, Rod Swap						
I_C^{RS}= 873.5 pcm	$(I_C^{RS})^4$= 905.9 ± 15% 100x(Meas. - Des.)/Des. = -3.6 %	N/A	✓ Yes ___ No	N/A	11/10/16 2019	JAC/ BRM
Shutdown Bank A Worth Measurement, Rod Swap						
I_{SA}^{RS}= 918.9 pcm	$(I_{SA}^{RS})^4$= 919.4 ± 15% 100x(Meas. - Des.)/Des. = -0.1 %	N/A	✓ Yes ___ No	N/A	11/10/16 2019	JAC/ BRM
Control Bank D Worth Measurement, Rod Swap						
I_D^{RS}= 989.5 pcm	$(I_D^{RS})^4$= 1018.5 ± 15% 100x(Meas. - Des.)/Des. = -2.8 %	N/A	✓ Yes ___ No	N/A	11/10/16 2019	JAC/ BRM
Shutdown Bank B Worth Measurement, Rod Swap						
I_{SB}^{RS}= 1120.5 pcm	$(I_{SB}^{RS})^4$= 1158.2 ± 15% 100x(Meas. - Des.)/Des. = -3.3 %	N/A	✓ Yes ___ No	N/A	11/10/16 2019	JAC/ BRM
Total Rod Worth, Rod Swap						
I_{Total}= 5784.4 pcm	$(I_{total})^4$= 5894.9 ± 10% 100x(Meas. - Des.)/Des. = -1.9 %	N/A	✓ Yes ___ No	N/A	11/10/16 2019	JAC/ BRM

References 1.) DNES-AA-NAF-NCD-4015, Rev. 2
2.) ETE-NAF-2016-0134, Rev. 0
4. ~~3.~~) ETE-NAF-2016-0133, Rev. 0

JAC 11/10/16
BRM 11/10/16

Surry Power Station Unit 1 Cycle 28 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) = 46.3						
Max Relative Assembly Power, %DIFF (M-P)/P					11/11/16 21:25	KLK [signature]
%DIFF= 4.1 % for Pi ≥0.9 2.9 % 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)= 1.539	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= 2.092	N/A	F_Q(Z)≤5*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.0078	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 2
2.) ETE-NAF-2016-0134, Rev. 0
3.) ETE-NAF-2016-0133, Rev. 0

Surry Power Station Unit 1 Cycle 28 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) = 70.04						
Max Relative Assembly Power, %DIFF (M-P)/P					11/12/16 1102	[initials] KLK
%DIFF= 3.0 % for Pi ≥0.9 2.0 % for P_i<0.9	±10% for P_i ≥0.9 ±15% for P_i<0.9 (P_i = assy power)[1,2]	N/A	✓ Yes ___ No	N/A		
Nuclear Enthalpy Rise Hot Channel Factor, FΔH(N)						
FΔH(N)= 1.505	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= 1.936	N/A	$F_Q(Z)≤(2.5/P)*K(Z)$ [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 0.54% (1.0054)	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 2
2.) ETE-NAF-2016-0134, Rev. 0
3.) ETE-NAF-2016-0133, Rev. 0

Surry Power Station Unit 1 Cycle 28 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) = 99.80						
Max Relative Assembly Power, %DIFF (M-P)/P					11/15/16 0844	[illegible] / [illegible]
%DIFF= -2.9 % 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)= 1.480	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= 1.866	N/A	$F_Q(Z)$≤{2.5/P}*K(Z) [COLR 3.7]	N/A	✓ Yes ___ No		
Maximum Positive Incore Quadrant Power Tilt						
Tilt= 1.0041	≤ 1.02[1]	N/A	✓ Yes ___ No	N/A		

References 1.) DNES-AA-NAF-NCD-4015, Rev. 2
2.) ETE-NAF-2016-0134, Rev. 0
3.) ETE-NAF-2016-0133, Rev. 0

Surry Power Station Unit 1 Cycle 28 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}= 289,887.7 gpm	N/A	$F_{total} \geq$ 274000 gpm [COLR 3.8]	N/A	✓ Yes ___ No	11/14/16 1524-1624	[signature]

References 1.) DNES-AA-NAF-NCD-4015, Rev. 2
2.) ETE-NAF-2016-0134, Rev. 0
3.) ETE-NAF-2016-0133, Rev. 0