Docket No. 50-336 B15414

Attachment 1

Millstone Nuclear Power Station, Unit No. 2 Startup Test Report for Cycle 13

October 1995

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1. SUMMARY

The refueling outage preceding the Cycle 13 startup was approximately 304 days, starting on October 1, 1994 and ending on July 31, 1995.

The results of the Millstone 2, Cycle 13 low power physics testing and power ascension testing programs were in good agreement with the core design predictions and all measured parameters were within the acceptance criteria of the tests. One item is noteworthy of mention:

The measured rod worth for the "reference" CEA group was 8.52% less than the predicted value. While this measurement is within the \pm 10% acceptance criteria, the low measurement is believed to have been caused by a signal bias from the excore detectors into the reactivity calculation. This theory was further confirmed upon reviewing the difference between the measured critical boron concentrations for the unrodded and rodded conditions. The measured difference was within 1 ppm boron of the predicted difference. The fact that the reference group rod worth value is used to calculate the rod worth parameters for the remaining CEA groups causes the measured rod worths to be less than the predicted values.

Two plant shutdowns and several downpowers during the power ascension testing program caused delays in the completion of these tests:

- On August 3, 1995, the reactor was shutdown from a power level of about 10% power due to a problem with a control rod power supply.
- On August 8, 1995, plant power was decreased from 80% to about 60% due to a problem with a pump seal in the secondary plant. At about 60% power, the reactor was manually tripped due to a secondary plant pipe rupture.
- On August 21, 1995, plant power was decreased from 100% to about 90% due to a problem with a valve leaking in the secondary plant.
- On August 22, 1995, plant power was decreased from 100% to about 90% due to a problem with pump vibration in the secondary plant.

2. INTRODUCTION

The Millstone 2 Cycle 13 fuel loading was completed on April 27, 1995. The attached core map (Figure 6.1) shows the final core loading. The subsequent operation/testing milestones were completed as follows:

Initial Criticality	July 31, 1995
Low Power Physics Testing Complete	August 2, 1995
Turbine On-Line	August 4, 1995
65% Power Testing Complete	August 6, 1995
96% Power Testing Complete	August 20, 1995
100% Power Testing Complete	August 29, 1995

The Millstone 2 Cycle 13 core is comprised of 217 Siemens Power Corporation manufactured fuel assemblies. The design of the 84 new fuel assemblies is slightly changed from the fuel design previously supplied by Siemens and was evaluated in accordance with 10CFR50.59. The new fuel assembly design changes were:

- Decreasing the thickness of the fuel rod cladding
- Increasing the diameter of the fuel pellet
- Decreasing the pellet-to-clad gap
- The high thermal performance spacer grid (used for debris protection) is replaced by a standard spacer grid and a longer fuel rod lower end plug
- Increasing the fuel rod fill gas pressure
- Increasing the uranium loading in each fuel assembly
- Increasing the exposure capability of the fuel assembly

3. LOW POWER PHYSICS TESTING RESULTS

Low Power Physics Testing was conducted at a power level of approximately 2×10^{-2} % power.

3.1 Unrodded Critical Boron Concentration

The Critical Boron Concentration measured with CEA Group 7 at 143 steps withdrawn and an RCS temperature of 533.2°F was 1466 ppm.

Adjusted to the prediction conditions of Group 7 at 140 steps withdrawn and an RCS temperature of 532°F yields an adjusted, measured CBC of 1464 ppm.

Adjusted, measured unrodded CBC	=	1464 ppm
Predicted unrodded CBC	=	1452 ppm
Difference	=	12 ppm

Acceptance Criteria is \pm 50 ppm of the predicted CBC.

Acceptance Criteria met? Yes

3.2 Moderator Temperature Coefficient

The Moderator Temperature Coefficient (MTC) measurements were performed at a boron concentration of 1466 ppm, an average RCS temperature of 529.6°F, and CEA Group 7 at 143 steps.

The measured MTC at these conditions was $+0.213 \times 10^{-4} \Delta \rho / {}^{\circ}\mathrm{F}$.

Adjusted to the prediction conditions for an RCS boron concentration of 1452 ppm and an RCS temperature of 532° F yields an adjusted, measured MTC of +0.188 × 10⁻⁴ $\Delta \rho/^{\circ}$ F.

Adjusted, measured MTC	=	$+0.188\times 10^{\text{-4}}\text{\Delta}\rho/^{\circ}F$
Predicted MTC	=	$+0.213 \times 10^{.4} \text{dp/}^{\circ}\text{F}$
Difference	=	-0.025 \times 10 $^{\rm 4}$ Dp/°F

Acceptance Criteria is $\pm 0.2 \times 10^{-4} \Delta \rho / {}^{\circ}F$ of the predicted MTC.

Acceptance Criteria met? Yes

Additionally, per the Millstone 2 Technical Specifications, the MTC must be less positive than $+0.7 \times 10^{-4} \Delta \rho/^{\circ}$ F for power levels less than 70% power.

Technical Specification limit met? Yes

3.3 Control Element Assembly Rod Worth Parameters

Control Element Assembly (CEA) Rod Worth Parameters were measured using the "rod swap" method. Figure 6.2 shows the CEA group configuration.

CEA Group "A" was used as the "reference" group and its reactivity worth was measured using the "boron exchange" method (dilution results are shown below). The reactivity worth of the remaining CEA groups was measured by establishing a critical condition with the "test" group fully inserted and the "reference" group partially withdrawn.

Group	Measured	Prediction	Difference	% Difference
Α	1.020 %Δρ	1.115 %Δρ	-0.095 %Δρ	-8.52%
В	0.421 %Δρ	0.432 %Δρ	-0.011 %Δp	-2.55%
1	0.679 %Δρ	0.746 %Δρ	-0.067 %Δp	-8.98%
2	0.690 %Δρ	0.739 %Δρ	-0.049 %Δp	-6.63%
3	0.447 %Δρ	0.536 %Δρ	-0.089 %Δp	-16.60%
4	0.664 %Δρ	0.731 %Δρ	-0.067 %Δp	-9.17%
5	0.312 %Δρ	0.323 %Δρ	-0.011 %Δρ	-3.41%
6	0.375 %Δρ	0.400 %Δρ	-0.025 %Δρ	-6.25%
7	0.692 %Δρ	0.784 %Δρ	-0.092 %Δp	-11.73%
Total	5.300 %Δρ	5.806 %Δρ	-0.506 %Δp	-8.72%

The results of the CEA worth measurements were:

The Acceptance Criteria are:

- 1. The measured "reference" group worth is within \pm 10% of the predicted worth.
- 2. The measured worth of the individual CEA groups is within $\pm 0.1\% \Delta \rho \text{ or } \pm 15\%$ of the predicted worth, whichever is larger.
- 3. The sum of the measured CEA worths is within \pm 10% of the sum of the predicted CEA worths.

Acceptance Criteria met for "reference" CEA group? Yes

Acceptance Criteria met for individual CEA groups? Yes, $\pm 15\%$ of the predicted worth for CEA Group 3 is $\pm 0.080\%\Delta\rho$ (which is less than $\pm 0.1\%\Delta\rho$)

Acceptance Criteria met for sum of CEA group worths? Yes

The measured rod worth (dilution) for the "reference" CEA group was 8.52% less than the predicted value. The "reference" CEA group worth was also measured as it was withdrawn (boration), resulting in a measured value of $1.003 \ Map$ (which is -10.07% less than the predicted value). While the average of these two measurements is within the $\pm 10\%$ acceptance criteria, the low measurements are believed to have been caused by performing the rod worth tests with a signal bias from the excore detectors into the reactivity calculation. This theory was further confirmed upon reviewing the difference between the measured critical boron concentrations for the unrodded and rodded conditions. The measured difference was within 1 ppm boron of the predicted difference. The fact that the reference group rod worth value is used to calculate the rod worth parameters for the remaining CEA groups causes all of the measured rod worths to be less than the predicted values.

3.4 Rodded Critical Boron Concentration

The Critical Boron Concentration measured with CEA Group A at 6 steps withdrawn and an RCS temperature of 532°F was 1354 ppm.

Adjusted to the prediction conditions of Group A at 0 steps withdrawn and an RCS temperature of 532°F yields an adjusted, measured CBC of 1353 ppm.

Adjusted, measured rodded CBC	Ξ	1353 ppm
Predicted rodded CBC	=	1340 ppm
Difference	=	13 ppm

Acceptance Criteria is \pm 50 ppm of the predicted CBC.

Acceptance Criteria met? Yes

3.5 Control Rod Drop Time Measurements

Control rod drop times were determined by measuring the time between the opening of the first reactor trip circuit breaker and the time when the 100% insertion position was reached ("dropped rod" limit switch). The Millstone 2 Technical Specifications require that all CEAs drop in ≤ 2.75 seconds to the 90% inserted position, with RCS conditions at ≥ 515 °F and full flow (all reactor coolant pumps operating).

Control rod drop time testing was done at an RCS temperature of 534°F with all 4 reactor coolant pumps operating. The average control rod drop time was 2.48 seconds to 100% insertion, with the fastest and slowest drop times being 2.37 seconds and 2.64 seconds, respectively.

Technical Specification limits met? Yes

4. POWER ASCENSION TESTING RESULTS

4.1 Power Peaking, Linear Heat Rate and Incore Tilt Measurements

The following core power distribution parameters were measured during the power ascension to ensure compliance with the Technical Specifications:

- Total Unrodded Integrated Radial Peaking Factor (Fr^T) is the ratio of the peak fuel rod power to the average fuel rod power in an unrodded core. This value includes the effect of Azimuthal Power Tilt.
- Linear Heat Rate is the amount of power being produced per linear length of fuel rod.
- Azimuthal Power Tilt is the maximum difference between the power generated in any core quadrant (upper or lower) and the average power of all quadrants in that half (upper or lower) of the core divided by the the average power of all quadrants in that half (upper or lower) of the core.

The measurements of these parameters were:

Power Level	$\mathbf{F}_{r}^{\mathrm{T}}$	Peak Linear Heat Rate	Incore Tilt
65%	1.688	9.05 KW/ft	0.014
96%	1.638	12.92 KW/ft	0.012
100%	1.619	13.16 KW/ft	0.013

These measurements were obtained with all control rods fully withdrawn.

The corresponding Technical Specification limits for all power levels for these parameters are:

- $F_r{}^{\rm T} \leq 1.69$ (Note larger values of $F_r{}^{\rm T}$ are permissible at less than 100% power)
- Peak Linear Heat Rate ≤ 15.1 KW/ft
- Azimuthal Power Tilt ≤ 0.02

Technical Specification limits met? Yes

4.2 Critical Boron Measurements

Critical Boron Concentration (CBC) measurements were performed at 96% power and 100% power at equilibrium xenon conditions.

The CBC measured at 96% power with CEA Group 7 at 155 steps withdrawn and an RCS temperature of 570.2°F was 1017 ppm. The cycle average exposure at the time of this measurement was 195 MWD/MTU.

Adjusted to the prediction conditions of 96% power with CEA Group 7 at 155 steps withdrawn and an RCS temperature of 573.7°F yields an adjusted, measured CBC of 1020 ppm.

Adjusted, measured 96% power CBC	11	1020 ppm
Predicted 96% power CBC	=	1022 ppm
Difference	=	-2 ppm

Acceptance Criteria is \pm 50 ppm of the predicted CBC

Acceptance Criteria met? Yes

The CBC measured at 100% power with CEA Group 7 completely withdrawn and an RCS temperature of 571.5°F was 990 ppm. The cycle average exposure at the time of this measurement was 473 MWD/MTU.

Adjusted to the prediction conditions of 100% power at an All Rods Out (ARO) condition and an RCS temperature of 572°F yields an adjusted, measured CBC of 991 ppm.

Adjusted, measured 100% power CBC = 991 ppm

Predicted 100% power CBC = 999 ppm

Difference = -3 ppm

Acceptance Criteria is \pm 50 ppm of the predicted C.3C

Acceptance Criteria met? Yes

4.3 Flux Symmetry Measurements

The core neutron flux symmetry was measured at approximately 30% power using the fixed incore detector monitoring system. The measured deviation between the highest and lowest values in operable symmetric incore detector locations ranged from 0.52% to 7.06%.

Acceptance Criteria is \pm 10% (deviation between the highest and lowest values in symmetric incore locations).

Acceptance Criveria met? Yes

4.4 Moderator Temperature Coefficient

The Moderator Temperature Coefficient (MTC) measurements were performed at a power level of 96%, an RCS boron concentration of 1017 ppm, an average RCS temperature of 566.7°F, and CEA Group 7 at 155 steps.

The measured MTC at these conditions was -0.592 \times 10 4 $\Delta\rho/^{o}F.$

Adjusted to the prediction conditions for an RCS boron concentration of 1022 ppm and an RCS temperature of 573.7°F yields an adjusted, measured MTC of -0.663 × 10⁻⁴ $\Delta \rho$ /°F.

Adjusted, measured MTC	H	$\text{-}0.663\times10^{\text{-}4}\text{d}\rho/\text{°F}$
Predicted MTC		$-0.600\times 10^{.4}~\text{dp/°F}$
Difference	=	$-0.063 \times 10^{-4} \text{ Ap/}^{\circ}\text{F}$

Acceptance Criteria is $\pm 0.3 \times 10^{-4} \Delta \rho / {}^{\circ}F$ of the predicted MTC.

Acceptance Criteria met? Yes

4.5 Reactor Coolant System Flow

The RCS flow rate was measured using the secondary calorimetric method, in which the RCS flow rate is inferred by performing a heat balance around the steam generators and RCS to determine reactor power, and measuring the differential temperature across the reactor core to determine the enthalpy rise.

The measured RCS flow rate at 100% power was 386,043 GPM.

When 13,000 GPM is subtracted from the measured flow rate to account for measurement uncertainties, the Minimum Guaranteed Safety Analysis RCS Flow Rate is 373,043 GPM. This value is used to satisfy the Technical Specification surveillance requirement.

The measurement uncertainty value of 13,000 GPM is 4% of the Design Flow Rate value of 324,800 GPM.

The Millstone 2 Technical Specifications require the RCS flow rate to be greater than 360,000 GPM.

Technical Specification limit met? Yes

4.6 Core Power Distributions

The core power distribution measurements were inferred from the signals obtained by the fixed incore detector monitoring system. These measurements were performed at 65% power and 100% power at an All Rods Out (ARO) condition to determine if the measured and predicted core power distributions are consistent.

The core power distribution map for 65% power, cycle average exposure of 24 MWD/MTU, *non*-equilibrium xenon conditions is shown in Figure 6.3.

This map shows that there is good agreement between the measured and predicted values.

The core power distribution map for 100%, cycle average exposure of 446 MWD/MTU, equilibrium xenon conditions is shown in Figure 6.4. This map also shows that there is good agreement between the measured and predicted values.

The Acceptance Criteria for these measurements are:

- 1. The difference between the measured and predicted Relative Power Densities (RPDs) for core locations with *e* 1 operable incore detector is less than 0.1.
- 2. The Root Mean Square (RMS) of all of the differences between the measured and predicted RPDs is less than 5%.

Acceptance Criteria met? Yes, for both 65% and 100% power

4.7 Reactor Coolant System Radiochemistry

RCS radiochemistry analysis during the power ascension testing program and during subsequent power operation indicate low activity levels with Iodine-131 values of about $8 \times 10^{-4} \,\mu$ Ci/ml. These low RCS activity levels are indicative of defect free fuel cladding.

5. <u>REFERENCES</u>

1.14

- 5.1 In-Service Test T95-14, "Low Power Physics Tests Cycle 13"
- 5.2 In-Service Test T95-16, "Power Ascension Tests Cycle 13"
- 5.3 EMF-94-201(P), "Millstone Unit 2, Cycle 13, Startup and Operations Report"

6. FIGURES

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- 6.1 Cycle 13 Core Loading Map
- 6.2 CEA Group Configuration
- 6.3 65% Core Power Distribution Map
- 6.4 100% Core Power Distribution Map

T	S			-	0
	″O	CP	0		- MG -
ж	a	26.1	0	- 4	0
-		0		-	-

W4 N55 8 P9 93 74 P18 5 3 R75 107 7 N62 4 9 R56 106 2 N48	x5 N20 W5 R20 167 V5 P21 T5 R70 5 86 P65 R63 103 N5 P37	x6 R1 W6 P5 V6 R65 110 T6 P63 82 P63 82 P58 N6 R47	x7 P64 W7 R39 115 V7 N65 157 S7 P57 R7 P57 R7 P42 116	x9 R1(79 P33 P33 V9 R49 114 T9 P52 S9 R43 R43 R43	x11 N11 N11 R81 98 V11 N52 T11 R31 R31 S11 N43	x13 R15 89 W13 P36 V13 R55 160 T13 P44 \$13 R46	x15 P45 W15 R80 135 V15 N61 T15 R62 120 S15 P61	x16 R6 P4 V16 R74 161 T16 P40 S16	x17 N27 W17 R23 124 V17 P26 T17 R69	W18 N57 V18 P14 95 T18 P17	V19 N54 T19 R19	T20 N25	
W4 W4 N55 i8 P9 93 24 P18 5 3 R73 107 7 N62 9 R56 106 2 N48	W5 R20 167 V5 P21 T5 R70 5 P65 P65 P65 R63 103 N5 P37	W6 P5 V6 R65 110 T6 P63 S6 P19 82 F6 P58 N6 R47	W7 R39 115 V7 N65 ⁷⁷ R59 157 ⁸⁷ P57 ⁸⁷ P57	 W9 P33 V9 R49 P52 S9 R43 R9 N3 	W11 R81 98 V11 N52 T11 R31 S11 N43	w13 P36 V13 R55 160 T13 P44 S13 R46	W15 R80 135 V15 N61 T15 R62 120 S15 P61	w16 P4 w16 R74 161 T16 P40 s16	W17 R23 124 V17 P26 T17 R69	W18 N57 V18 P14 95 T18 P17	V19 N54 T19 R19	T20 N25	
V4 P9 93 74 24 P18 5 84 3 R7: 107 R4 7 N62 4 9 9 R56 106 L4	V5 P21 T5 R70 5 P65 P65 R63 103 N5 P37	V6 R65 110 T6 P63 S6 P19 82 R6 P58 N6 R47	V7 N65 17 R59 157 \$7 P57 R7 P42 116	V9 R49 114 T9 P52 S9 R43 R9 N3	V11 N52 T11 R31 S11 N43	v13 R55 160 T13 P44 \$13 R46	V15 N61 T15 R62 120 \$15 P61	v16 R74 161 T16 P40	V17 P26 T17 R69	V18 P14 95 T18 P17	V19 N54 T19 R19	T20 N25	
24 P18 5 S4 3 R7: 107 7 N62 4 9 R56 106	 T5 R70 S6 P65 R63 103 N5 P37 L5 	76 P63 P19 82 P58 P58 N6 R47	¹⁷ R59 157 ⁸⁷ P57 ⁸⁷ P57 ⁸⁷ P42 116	^{T9} P52 S9 R43 R9 N3	⁵¹¹ R31 S ¹¹ N43	^{T13} P44 ^{S13} R46	T15 R62 120 S15 P61	T16 P40	R69	^{т18} Р17	R19	T20 N25	1
3 R7: 107 7 N62 4 9 R56 106	5 P65 P65 P65 P63 103 N5 P37	86 P19 82 P58 N6 R47	⁸⁷ P57 P57 P42 116	R43	N43	813 R46	^{\$15} P61	S16	- 1 m	and the second second second	122	1420	
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9 R56 106	P37	R47	The second se		R11 R27 77	R13 N6	R15 P38 109	P71	R17 R58 118	R18 N68	R19 R38 123	P20 P54	P2
2 N48	L5		N7 N7	R35 113	P10	R34 134	N15 N2	R42	P68	R52 165	P32	R9 84	Ma
3	R32	L6 N44	R28 87	P12	N46	P13	L15 R26 90	L16 N42	R30	N51	R84 99	N16	KA
1 R50 127	^{л5} Р48	^{J6} R44	J7 N4	ля R36 158	P11	лз R33 159	J15 N5	R45	P51	R54 164	P30	, _{J20} R14 91	H
0 N66	65 R60 130	66 P72	G7 P39 137	G9 N8	G11 R25 78	G13 N1	G15 P43 111	G16 P56	G17 R61 163	G18 N64	G19 R79 121	G20 P67	-
8 R66 105	P50	F6 P22 76	F7 P60	F9 R48	F11 N41	F13 R41	F15 P59	F16 P20 83	F17 P53	F18 R73 126	F19 P6	F20 R5	
17 P24	R71	^{Е6} Р70	ε7 R64 156	E9 P49	8 R29	E13 P41	E15 R57 117	E16 P55	R72	E18 P23	E19 R22 166	E20 N12	
6 P16 92	P25	R76 108	N63	R53	D11 N50	D13 R51 133	D15 N67	D16 R67 119	D17 P28	D18 P15 94	D19 N60		
N59	R21 129	P1	C7 R78 132	P35	C11 R83 97	C13 P34	C15 R37 136	C16 P7	C17 R18 162	C18 N53			
	^{вб} N17	R8	⁸⁷ P46	Be R1: 81	B11 N21	813 R12 86	P69	R3	^{в17} N10				
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	N59	N59 R21 129 85 N17	N59 R21 P1 129 86 N17 R8	N59 R21 P1 R78 129 132 B6 B6 B7 N17 R8 P46	N59 R21 P1 R78 P35 129 132 133 133 133	N59 R21 P1 R78 P35 R83 129 132 97 B5 B6 B7 B9 B11 N17 R8 P46 R13 N21 81 Image: state stat	N59 R21 P1 R78 P35 R83 P34 129 132 97 97 97 97 97 97 97 97 132 97 132 97 132 97 132 97 132 132 97 132 97 132 133 133 133 133 133 133 133 133 133 133	N59 R21 P1 R78 P35 R83 P34 R37 129 132 97 136 B5 B6 B7 B9 B11 B13 B15 P69 N17 R8 P46 R13 N21 R12 P69 81 9 86 86 86 86 86 86	N59 R21 P1 R78 P35 R83 P34 R37 P7 129 132 97 136 167 167 167	N59 R21 P1 R78 P35 R83 P34 R37 P7 R18 129 132 97 136 162 B6 B7 B6 B11 B13 B15 B16 B17 N10 N17 R8 P46 R13 N21 R12 P69 R3 N10 81 Image: State	N59 R21 P1 R78 P35 R83 P34 R37 P7 R18 N53 129 132 97 136 162 163 162 163 162 163 163 163 163 163 163 163 163 163 163 163 163 163 163	N59 R21 P1 R78 P35 R83 P34 R37 P7 R18 N53 129 132 97 136 162 162 B6 B7 B9 B11 B13 B15 B16 B17 N17 R8 P46 R13 N21 R12 P69 R3 N10 A8 A10 A12 N18 N35 Key N20 R9 N18 N35 Key	N59 R21 P1 R78 P35 R83 P34 R37 P7 R18 N53 129 132 97 136 136 162 162 162 86 87 88 97 813 815 816 817 N10 81 81 81 86 86 87 N10 N10 A8 N30 N9 N18 N35 Key Core Locatio Fuel Assem/ CEA ID Core Locatio

Cycle 13 Core Loading Map



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CEA Group Configuration

NORTH

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65% Power Distribution Map All Rods Out, Non-Equilibrium Xenon, 24 MWD/MTU

NORTH

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100% Power Distribution Map All Rods Out, Equilibrium Xenon, 446 MWD/MTU