NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Modernization of NBSR Operator Logging and Computational Tools

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CENTER FOR NEUTRON RESEARCH

Introduction

Two tools were identified as candidates for upgrades and modernization:

- Annual Shim arm Reactivity Calibrations
  - Includes calculations of Shutdown margin, excess reactivity, and Shim bank reactivity insertion rate.
  - Technical Specification required surveillance.

- NBSR Fuel Inventory and Tracking Sheet
  - Calculates burnup for fuel inventory at NBSR.
  - Tracks uranium content as fuel is shuffled throughout the core.
  - Aides in operating cycle determinations and fresh fuel procurement.

Shim Arm Calibrations

Shim Arm Calibrations are performed at the NBSR using the Regulating Rod as a "Measuring Stick"

- The regulating rod is experimentally calibrated using rod pulls and the inhour curve.
- The shims are then individually withdrawn with the reactor in automatic mode.
- The difference in regulating rod heights for the pull yields an equivalent worth of the shim arm.

Regulating Rod Calibration

Core Configuration	30 elements	Date	05 NOV 2019
Core Condition	26 partial / 4 new	Power Level	50 kW
Temperature		Prepared By	

Run No.	Banked 4-shim Position (deg.)	Reg. Rod Critical Position (in.)	Reg. Rod Super-Critical Position (in.)	Change In Reg. Rod Position (in.)	Power Increase by a factor of 2	Period (sec.)	Δρ From Inhour Curve	Reg. Rod Worth (cents)	Temp (°F)
1	21.92	0.0	7.4	7.4	39.2	56.6	15.0	15.0	80.4
2	21.85	7.4	12.3	4.9	26.3	37.95	19.7	34.7	80.3
3	21.63	12.3	18.7	6.4	23.5	33.91	21.24	55.94	79.7
4	21.42	18.7	25.8	7.1	29.7	42.86	18.23	74.17	80.2
5	21.30	25.8	27.9	2.1	112.0	161.6	6.9	81.07	80.0 *
Total Regulating Rod Worth								93.1	+12¢

Reactor Shutdown 19 OCT 2019
Shutdown 17 DAYS
Add 3¢ per period shutdown < 1 month

* Did not add 3¢ for last pull ⇒ Very long period.

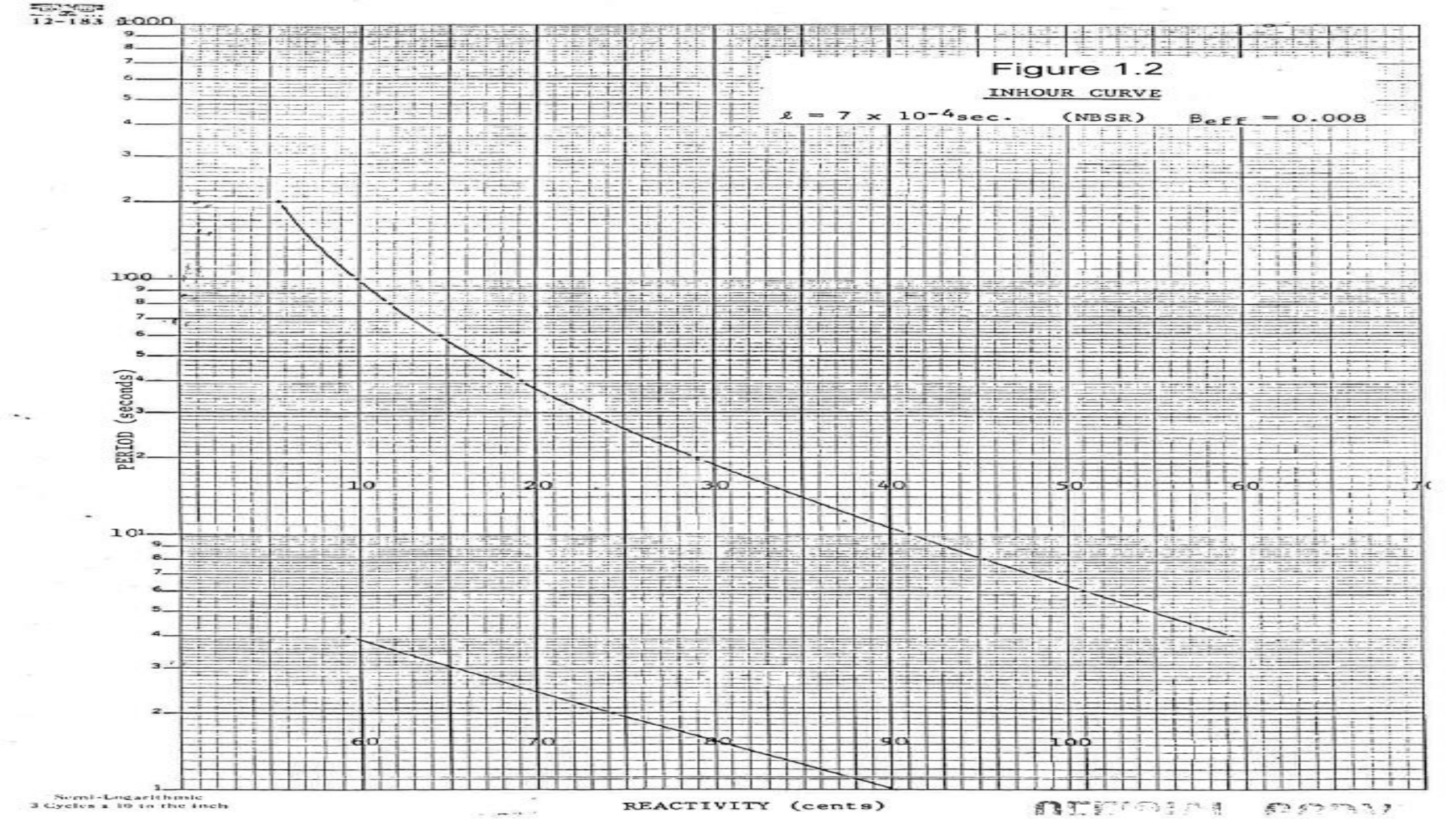
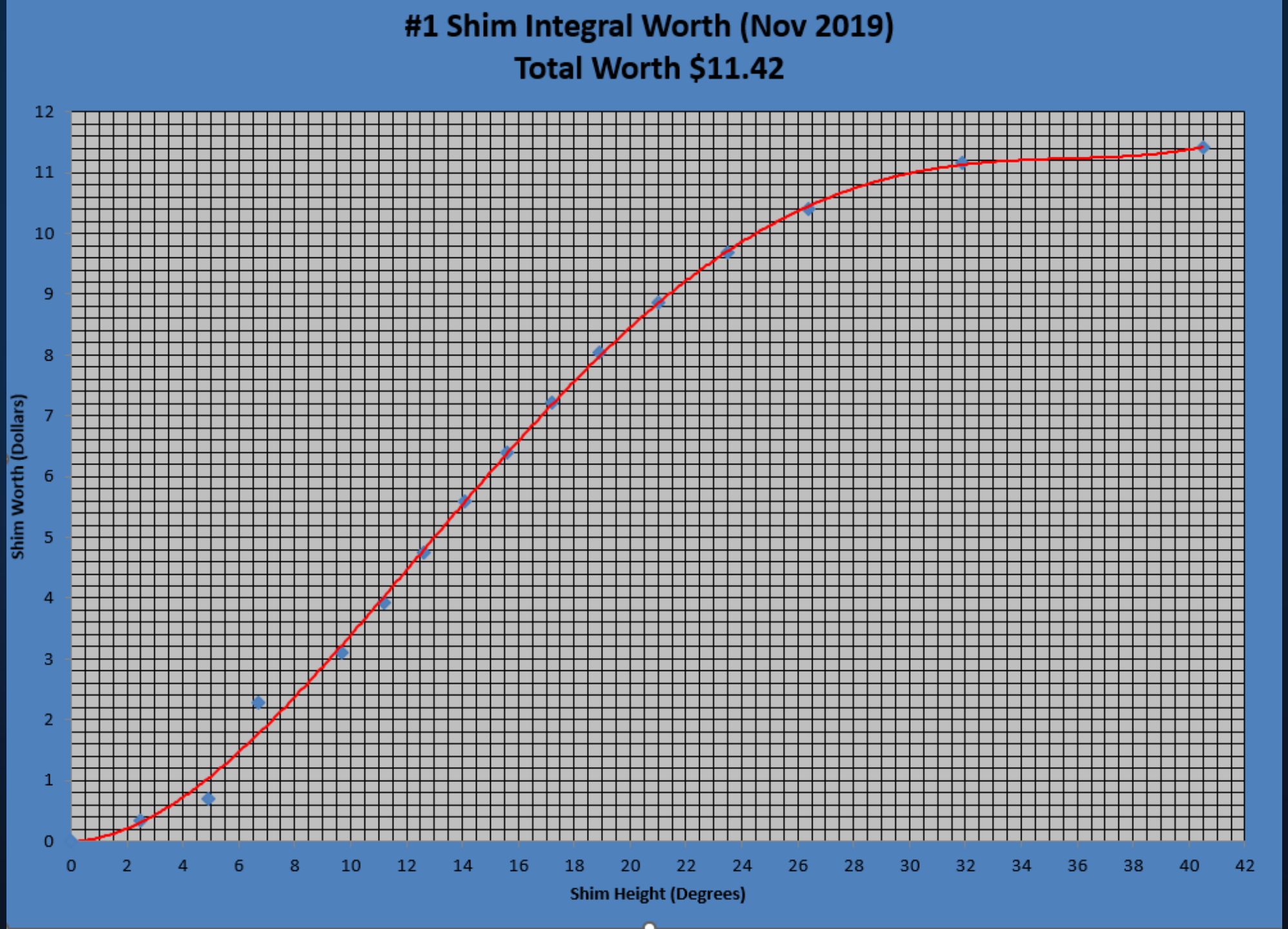


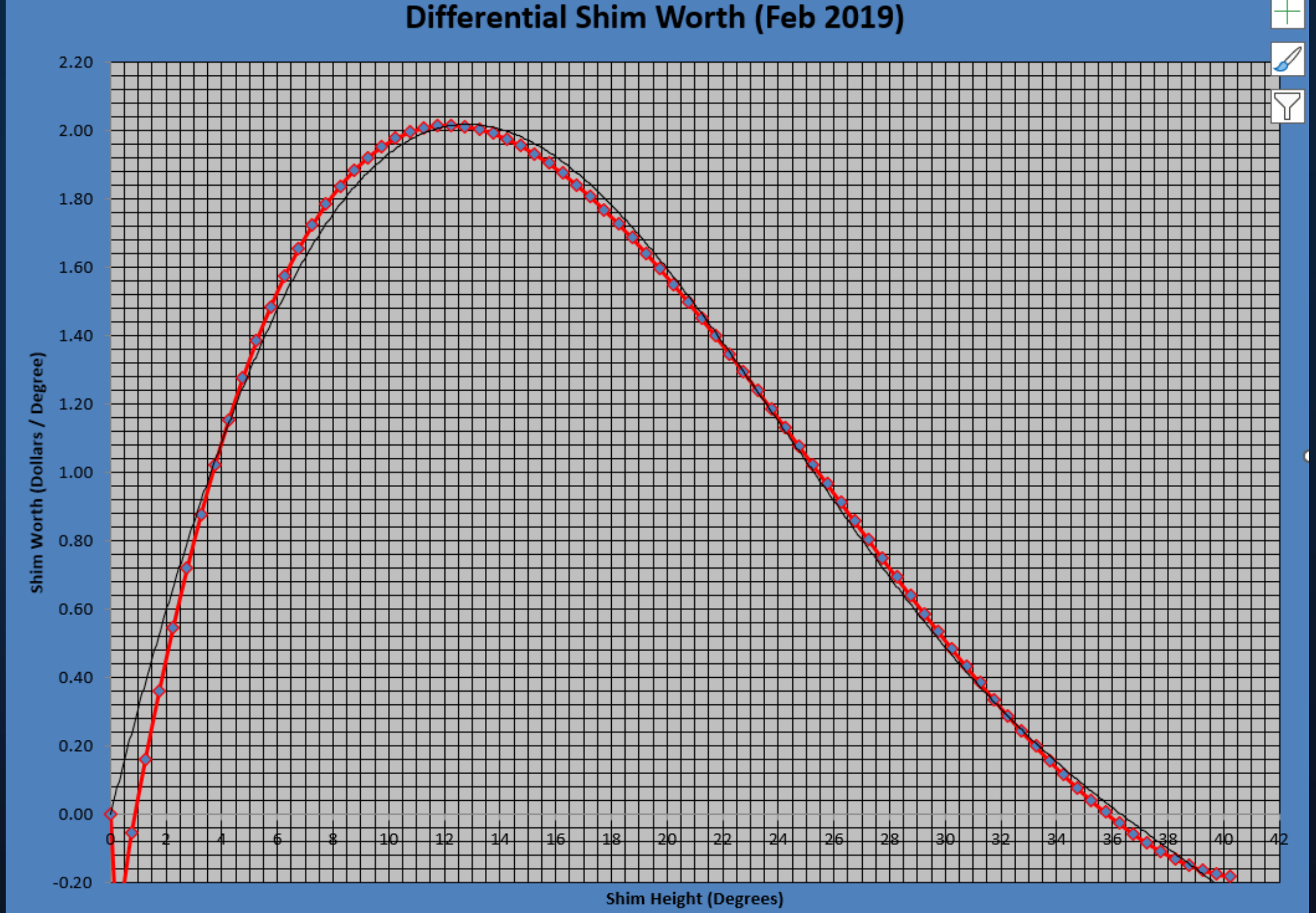
Figure 1.2
INHOUR CURVE
ℓ = 7 x 10⁻⁴sec. (NBSR) Beff = 0.008
PERIOD (seconds)
REACTIVITY (cents)
10
20
30
40
50
60
70
80
90
100
Semi-Logarithmic
3 Cycles x 10 to the inch

Shim Arm Calibration

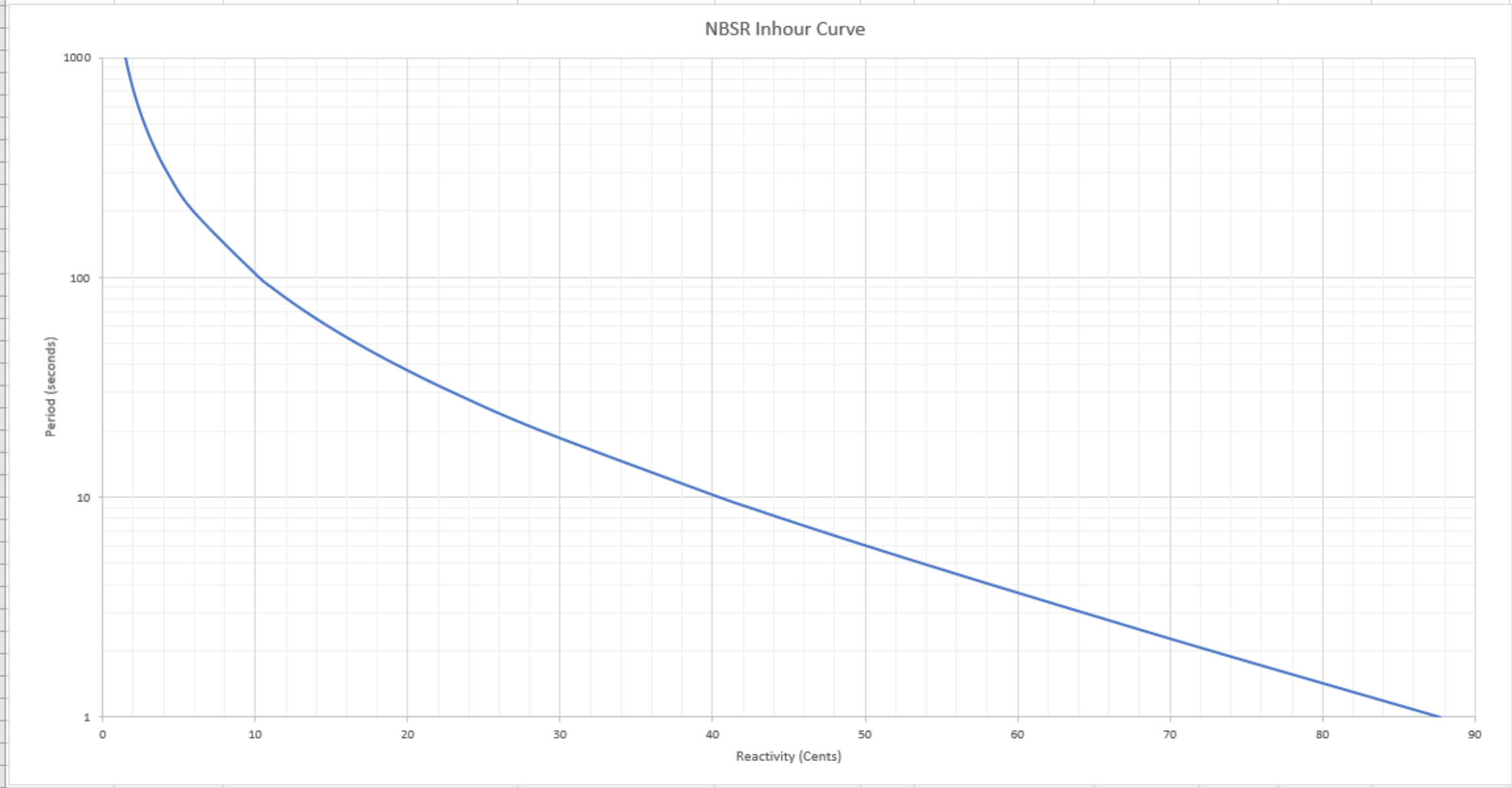
Core Configuration	30 elements	Date	05NOV 2019
Core Condition	26 partial / 4 new	Power Level	50kW
Temperature		Prepared By	

Run No.	3-Shim Bank Position (deg.)	Shim 1 Critical Position (deg.)	Reg. Rod Position (in.)	Temperature (°F)
1	32.36	2.36	23.9	80.0
	32.36	4.85	5.8	79.9
2	31.17	4.84	26.0	79.8
	31.17	6.70	4.5	79.7
3	30.02	6.70	25.9	79.7
	30.02	8.25	4.6	79.7
4	28.90	8.25 ~~26.4~~	26.4	79.7
	28.90	9.73	4.1	79.8
5	27.78	9.73	26.8	79.8
	27.78	11.18	4.4	79.9
6	26.75	11.18	26.4	79.9
	26.75	12.62	4.0	80.0
7	25.76	12.62	27.0	80.0
	25.76	14.09	4.1	80.1
8	24.82	14.09	27.0	80.1
	24.82	15.57	5.0	80.2
9	23.96	15.57	26.6	80.2
	23.96	17.18	4.4	80.2
10	23.11	17.18	26.3	80.2
	23.11	18.94	4.2	80.2
11	22.28	18.94	27.0	80.1


#1 Shim Integral Worth (Nov 2019)
Total Worth $11.42
Shim Worth (Dollars)
0
1
2
3
4
5
6
7
8
9
10
11
12
Shim Height (Degrees)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42


Differential Shim Worth (Feb 2019)
Shim Worth (Dollars / Degree)
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
Shim Height (Degrees)

New Excel Program and Datasheet



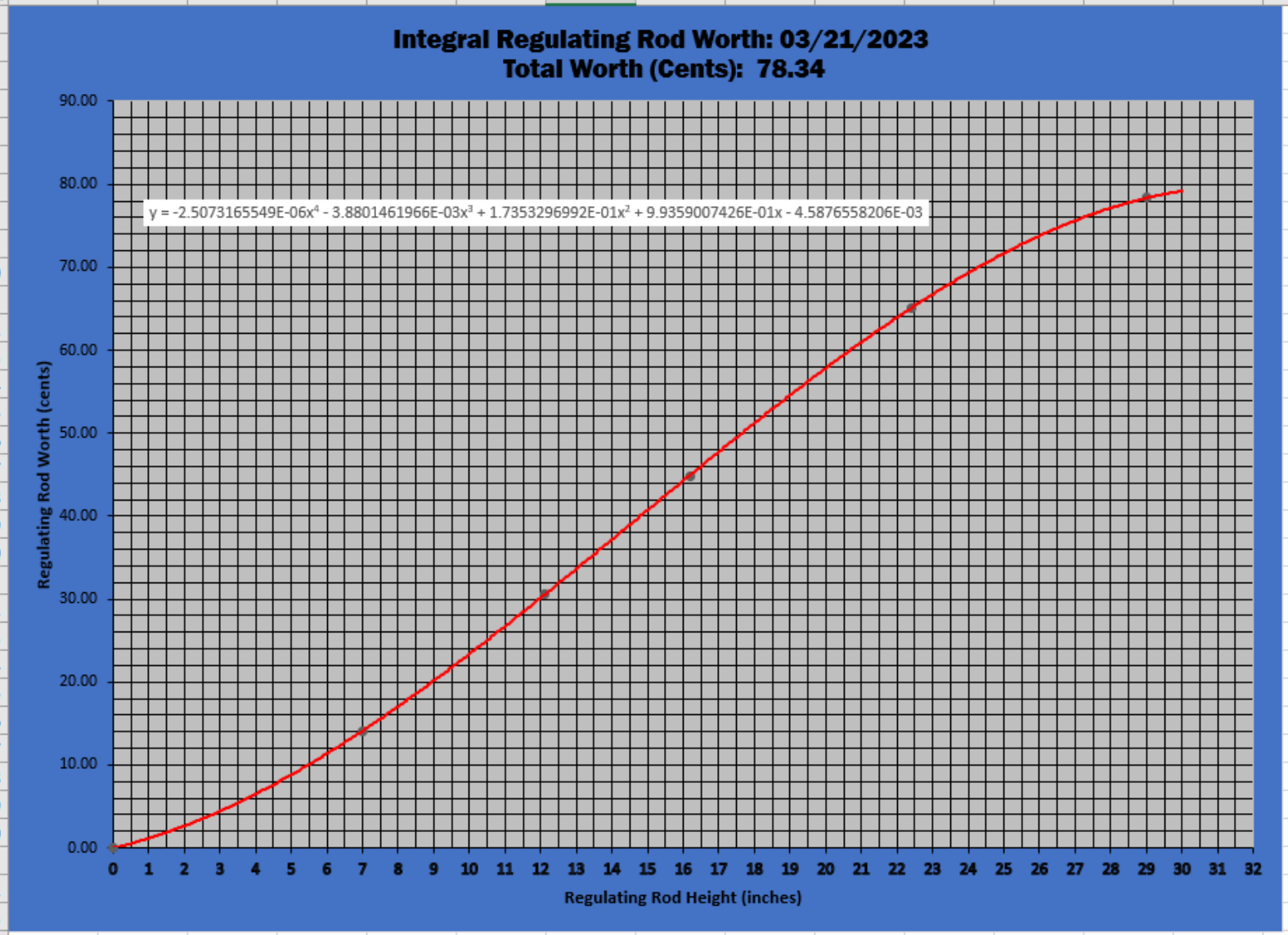
Input (Doubling Time in Seconds)	Result (Reactivity in Cents)
35	16.64
Input (Period in Seconds)	**Result (Reactivity in Cents)**
	102.69

	A	B	C	D	E	F	G	H	I	J
1	DATASHEET INFORMATION			ROD CURVE FUNCTION GENERATED		Total Regulating Rod Worth (Cents)				
2	Reg Rod Position (inches)	Rod Worth (Cents)	Rod Worth Sum (Cents)	Reg Rod Position (inches)	Rod Worth (Cents)	78.34				
3	0.0	0.00	0.00	0.0	-0.00459		Generate Function			
4	0.1		#N/A	0.1	0.09650					
5	0.2		#N/A	0.2	0.20104					
6	0.3		#N/A	0.3	0.30900					
7	0.4		#N/A	0.4	0.42037		Generated Function From Trendline			
8	0.5		#N/A	0.5	0.53511		y = -2.5073165549E-06x4 - 3.8801461966E-03x3 + 1.7353296992E-01x2 + 9.9359007426E-01x - 4.5876558206E-03			
9	0.6		#N/A	0.6	0.65320					
10	0.7		#N/A	0.7	0.77463		Constants From Trendline Function			
11	0.8		#N/A	0.8	0.89936		-2.5073165549E-06			
12	0.9		#N/A	0.9	1.02737		- 3.8801461966E-03			
13	1.0		#N/A	1.0	1.15865		+ 1.7353296992E-01			
14	1.1		#N/A	1.1	1.29317		+ 9.9359007426E-01			
15	1.2		#N/A	1.2	1.43090		- 4.5876558206E-03			
16	1.3		#N/A	1.3	1.57182					
17	1.4		#N/A	1.4	1.71591		Clear Input Data			
18	1.5		#N/A	1.5	1.86314					
19	1.6		#N/A	1.6	2.01349					
20	1.7		#N/A	1.7	2.16694					
21	1.8		#N/A	1.8	2.32347					
22	1.9		#N/A	1.9	2.48304					
23	2.0		#N/A	2.0	2.64564					
24	2.1		#N/A	2.1	2.81125					
25	2.2		#N/A	2.2	2.97984					
26	2.3		#N/A	2.3	3.15138					
27	2.4		#N/A	2.4	3.32586					
28	2.5		#N/A	2.5	3.50324					
29	2.6		#N/A	2.6	3.68352					
30	2.7		#N/A	2.7	3.86665					
31	2.8		#N/A	2.8	4.05263					
32	2.9		#N/A	2.9	4.24143					
33	3.0		#N/A	3.0	4.43301					
34	3.1		#N/A	3.1	4.62737					
35	3.2		#N/A	3.2	4.82447					
36	3.3		#N/A	3.3	5.02430					

Regulating Rod | Regulating Rod Backend | Shim #1 | Shim #1 Backend | Shim #2 | Shim #2 Backend | Shim #3 | Shim #3 Backend | Shim #4

Ready | Accessibility: Investigate | 100%

	A	B	C	D	E	F
57	15.4		#N/A	15.4	42.13944	
58	15.5		#N/A	15.5	42.49345	
59	15.6		#N/A	15.6	42.84726	
60	15.7		#N/A	15.7	43.20083	
61	15.8		#N/A	15.8	43.55414	
62	15.9		#N/A	15.9	43.90717	
63	16.0		#N/A	16.0	44.25990	
64	16.1		#N/A	16.1	44.61229	
65	16.2	14.29	44.88	16.2	44.96432	
66	16.3		#N/A	16.3	45.31598	
67	16.4		#N/A	16.4	45.66723	
68	16.5		#N/A	16.5	46.01806	
69	16.6		#N/A	16.6	46.36843	
70	16.7		#N/A	16.7	46.71832	
71	16.8		#N/A	16.8	47.06771	
72	16.9		#N/A	16.9	47.41658	
73	17.0		#N/A	17.0	47.76490	
74	17.1		#N/A	17.1	48.11264	
75	17.2		#N/A	17.2	48.45979	
76	17.3		#N/A	17.3	48.80631	
77	17.4		#N/A	17.4	49.15219	
78	17.5		#N/A	17.5	49.49739	
79	17.6		#N/A	17.6	49.84190	
80	17.7		#N/A	17.7	50.18569	
81	17.8		#N/A	17.8	50.52874	
82	17.9		#N/A	17.9	50.87101	
83	18.0		#N/A	18.0	51.21250	
84	18.1		#N/A	18.1	51.55316	
85	18.2		#N/A	18.2	51.89298	
86	18.3		#N/A	18.3	52.23194	
87	18.4		#N/A	18.4	52.57001	
88	18.5		#N/A	18.5	52.90716	
89	18.6		#N/A	18.6	53.24338	
90	18.7		#N/A	18.7	53.57862	
91	18.8		#N/A	18.8	53.91289	
92	18.9		#N/A	18.9	54.24614	

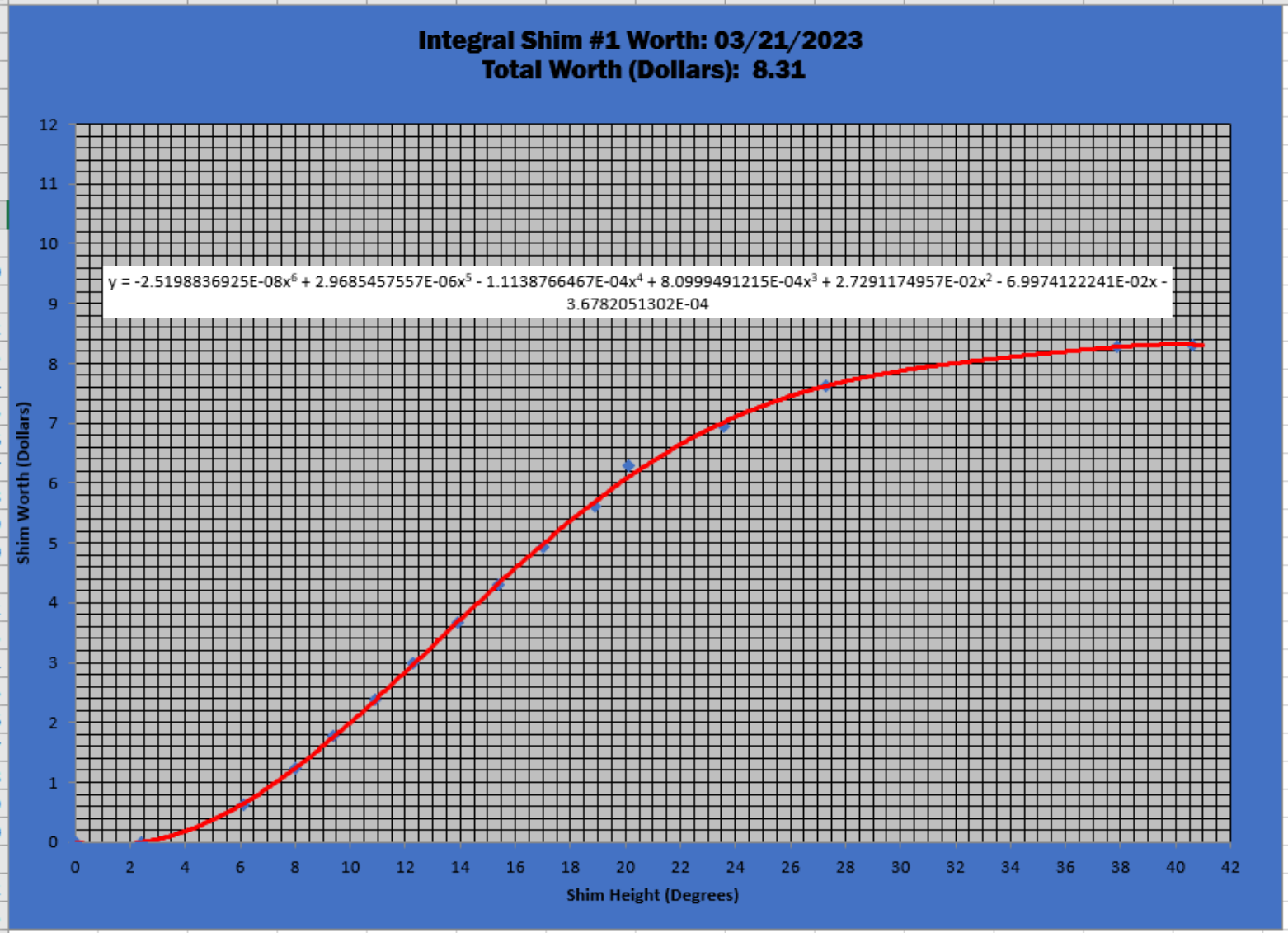


Integral Regulating Rod Worth:
Total Worth (Cents):
78.34
03/21/2023
Integral Regulating Rod Worth: 03/21/2023 Total Worth (Cents): 78.34

Regulating Rod | Regulating Rod Backend | Shim #1 | Shim #1 Backend | Shim #2 | Shim #2 Backend | Shim #3 | Shim #3 Backend | Shim #4

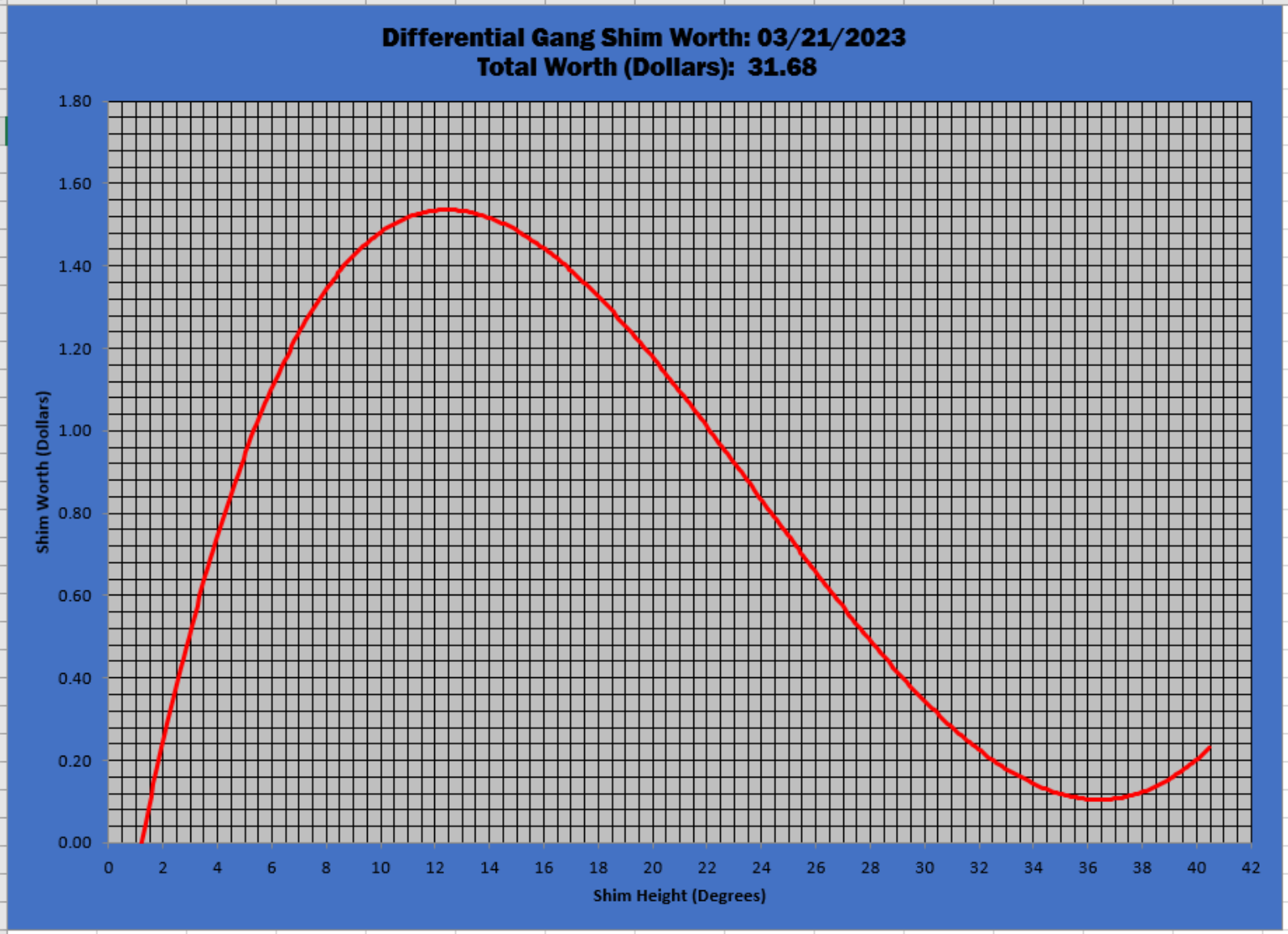
	A	B	C	D	E	F	G	H	I
1	Datasheet Information					Rod Curve Function Generated		Shim #1 Total Worth	
2	Shim Position (Degrees)	Reg Rod Start Position	Reg Rod End Position	Reactivity Reg Rod Equivalent (Cents)	Reactivity Sum (Dollars)	Shim Position (Degrees)	Reactivity (Dollars)	8.314280186	
3	0	0	0	0	0	0	-0.00037		Generate Function
4	0.1			0	#N/A	0.1	-0.00709		
5	0.2			0	#N/A	0.2	-0.01326		
6	0.3			0	#N/A	0.3	-0.01888		
7	0.4			0	#N/A	0.4	-0.02394		Generated Function From Trendline
8	0.5			0	#N/A	0.5	-0.02844		y = -2.5198836925E-08x6 + 2.9685457557E-06x5 - 1.1138766467E-04x4 + 8.0999491215E-04x3 + 2.729
9	0.6			0	#N/A	0.6	-0.03237		
10	0.7			0	#N/A	0.7	-0.03573		Constants From Trendline Function
11	0.8			0	#N/A	0.8	-0.03851		-2.5198836925E-08
12	0.9			0	#N/A	0.9	-0.04072		+ 2.9685457557E-06
13	1			0	#N/A	1	-0.04235		- 1.1138766467E-04
14	1.1			0	#N/A	1.1	-0.04340		+ 8.0999491215E-04
15	1.2			0	#N/A	1.2	-0.04386		+ 2.7291174957E-02
16	1.3			0	#N/A	1.3	-0.04374		- 6.9974122241E-02
17	1.4			0	#N/A	1.4	-0.04303		- 3.6782051302E-04
18	1.5			0	#N/A	1.5	-0.04173		
19	1.6			0	#N/A	1.6	-0.03984		Clear Input Data
20	1.7			0	#N/A	1.7	-0.03736		
21	1.8			0	#N/A	1.8	-0.03429		
22	1.9			0	#N/A	1.9	-0.03062		
23	2			0	#N/A	2	-0.02636		
24	2.1			0	#N/A	2.1	-0.02151		
25	2.2			0	#N/A	2.2	-0.01606		
26	2.3			0	#N/A	2.3	-0.01001		
27	2.4	0.00	0.00	0	0	2.4	-0.00338		
28	2.5			0	#N/A	2.5	0.00386		
29	2.6			0	#N/A	2.6	0.01168		
30	2.7			0	#N/A	2.7	0.02009		
31	2.8			0	#N/A	2.8	0.02910		
32	2.9			0	#N/A	2.9	0.03870		
33	3			0	#N/A	3	0.04888		
34	3.1			0	#N/A	3.1	0.05965		
35	3.2			0	#N/A	3.2	0.07101		
36	3.3			0	#N/A	3.3	0.08295		

	A	B	C	D	E	F	G	H
124	12.1			0	#N/A	12.1	2.88679	
125	12.2			0	#N/A	12.2	2.93041	
126	12.3	27.51	7.36	61.44493418	2.995461674	12.3	2.97409	
127	12.4			0	#N/A	12.4	3.01782	
128	12.5			0	#N/A	12.5	3.06160	
129	12.6			0	#N/A	12.6	3.10542	
130	12.7			0	#N/A	12.7	3.14927	
131	12.8			0	#N/A	12.8	3.19315	
132	12.9			0	#N/A	12.9	3.23705	
133	13			0	#N/A	13	3.28096	
134	13.1			0	#N/A	13.1	3.32488	
135	13.2			0	#N/A	13.2	3.36880	
136	13.3			0	#N/A	13.3	3.41272	
137	13.4			0	#N/A	13.4	3.45662	
138	13.5			0	#N/A	13.5	3.50051	
139	13.6			0	#N/A	13.6	3.54437	
140	13.7			0	#N/A	13.7	3.58820	
141	13.8			0	#N/A	13.8	3.63199	
142	13.9	28.70	5.70	67.33103026	3.668771977	13.9	3.67574	
143	14			0	#N/A	14	3.71944	
144	14.1			0	#N/A	14.1	3.76309	
145	14.2			0	#N/A	14.2	3.80667	
146	14.3			0	#N/A	14.3	3.85019	
147	14.4			0	#N/A	14.4	3.89364	
148	14.5			0	#N/A	14.5	3.93701	
149	14.6			0	#N/A	14.6	3.98029	
150	14.7			0	#N/A	14.7	4.02349	
151	14.8			0	#N/A	14.8	4.06658	
152	14.9			0	#N/A	14.9	4.10958	
153	15			0	#N/A	15	4.15248	
154	15.1			0	#N/A	15.1	4.19526	
155	15.2			0	#N/A	15.2	4.23792	
156	15.3			0	#N/A	15.3	4.28046	
157	15.4	26.06	5.83	62.9578255	4.298350232	15.4	4.32288	
158	15.5			0	#N/A	15.5	4.36516	
159	15.6			0	#N/A	15.6	4.40730	



Integral Shim #1 Worth:
Total Worth (Dollars):
8.31
03/21/2023
Integral Shim #1 Worth: 03/21/2023 Total Worth (Dollars): 8.31

Regulating Rod | Regulating Rod Backend | Shim #1 | Shim #1 Backend | Shim #2 | Shim #2 Backend | Shim #3 | Shim #3 Backend | Shim #4



Q
Differential Gang Shim Worth:
Total Worth (Dollars):
31.68
03/21/2023
Differential Gang Shim Worth: 03/21/2023 Total Worth (Dollars): 31.68

C18

	A	B	C	D	E	F	G
1		Initial Bank Position (Degrees)	Final Bank Position (Degrees)	Change In Bank Position (Degrees)	Doubling Time (Seconds)	Period (Seconds)	Reactivity From Inhour Curve (Cents)
2	Reg Rod Full Out	21.9	22.05	0.15	38	54.82	15.81
3	Reg Rod Full In	22.72	22.92	0.2	36.8	53.09	16.15
4							
5	Bank Speed (Degrees/Second)	0.0429					
6	Bank Worth (Cents/Second)	4.52		Clear Data			
7	Reactivity Insertation Rate (Delta Rho/Second)	3.42E-04					
8	Excess Reactivity (%Delta Rho)	5.540530692					
9	Shutdown Margin (Dollars)	15.08465541					
10	Regulating Rod Worth (Cents)	78.34					
11	Shim #1 Worth (Dollars)	8.314280186					
12	Shim #2 Worth (Dollars)	9.27180397					
13	Shim #3 Worth (Dollars)	6.541506631					
14	Shim #4 Worth (Dollars)	7.547931594					
15	Gang Shim Worth (Dollars)	31.67552238					
16							
17	Date Performed (Month/Day/Year)	3/21/2023					
18							
19							
20	Signature:_____	Date:_____					
21							
22							
23							
24	Print Charts	Print Signature Sheet					
25							
26							
27							
28							
29							
30							

Current Fuel Inventory Tracking

NH	NI	NJ	NK	NL	NM	NN	NO	NP	NQ
1082 Power	1082 Equivalent	1083 Power	1083 Equivalent	1084 Power	1084 Equivalent	1085 Power	1085 Equivalent	Core Position	Power Factor
18511.30	17955.96							A4	0.97
18547.80	19104.23							F1	1.03
17969.90	17969.90							B3	1.00
18201.20	17655.16							C6	0.97
17904.40	19515.80							E2	1.09
18540.80	18169.98							E6	0.98
17952.60	18670.70							E4	1.04
		18511.30	17955.96					M4	0.97
		18547.80	20217.10					H1	1.09
		17969.90	18329.30					L3	1.02
		18201.20	17837.18					K6	0.98
		17904.40	19515.80					I2	1.09
		18540.80	18355.39					I6	0.99
		17952.60	18670.70					I4	1.04
				18511.30	17030.40			D1	0.92
				18547.80	18362.32			D7	0.99
				17969.90	18329.30			C2	1.02
				18201.20	17655.16			B5	0.97
				17904.40	17188.22			F7	0.96
				18540.80	18169.98			C4	0.98
				17952.60	19388.81			F3	1.08
				17428.70	16034.40			F5	0.92
						18511.30	18511.30	J1	1.00
						18547.80	18733.28	J7	1.01
						17969.90	18509.00	K2	1.03
						18201.20	17291.14	L5	0.95
						17904.40	17367.27	H7	0.97
						18540.80	17799.17	K4	0.96
						17952.60	19388.81	H3	1.08
						17428.70	16034.40	H5	0.92

Total/30			**4301.39**		**4362.71**		**4738.62**	
TO CORE		Cycle 631	08/16/16		08/16/16		08/16/16	
FIRST STARTUP			08/18/16		08/18/16		08/18/16	
LAST SHUTDOWN			09/11/17		09/11/17		02/16/18	
TO POOL			09/25/17		09/25/17		02/22/18	
COOL DATE								
COOLING DAYS								
REACTOR DAYS								
U			375		375		375	
PERCENTAGE			93.19		93.19		93.19	
U 235			350		350		350	
DELIVERED			05/25/16		05/25/16		08/04/16	
STORAGE			SE-D4		SE-D6		SE-E1	
CUT								
		Cycle 637		Cycle 637		Cycle 638		Cycle 638

Fuel Element Archive Logger (FEAL)

Fuel Element Archive Logger (FEAL)

GUI-driven tool for managing the fuel inventory at the NCNR

- Better accessibility and easier editing
- Enable version control
- Enable improved protection of sensitive information

Improves cross-cutting with engineering efforts including the following

- Cycle planning and reuse of fuel elements in alternative fuel management schemes
  - *Improved compliance with 10 CFR 50.59 requirements*
- Spent fuel shipment analyses
  - *Improved reporting for compliance with 49 CFR 173.435 (subpart 1)*
- Self-protection tracking
  - *Easier inventory management for 10 CFR 73.6 compliance*

Fuel Element Archive Logger (FEAL)

Legend
Ready
In-development

Nerdy details

- MATLAB-developed (R2022a+)
  - ❑ The code development is currently chronicled on a secure git repository
- Controlled subversion (SVN) tracking of data with database version tracking
- Will be deployed as a standalone executable
- Planned to contain capabilities for streamlining engineering fuel shipment analyses
  - ❑ ORIGEN input deck generators
  - ❑ Automated simulation execution
  - ❑ Automated post-processing for quick isotopic analysis of spent fuel
- Planned to contain capabilities for streamlining self-protection analyses
  - MCNP input deck generators
  - Automated simulation execution
  - Automated post-processing for quick analyses of spent fuel dose rates

NBSR Fuel Element Archive Logger

Main Tab

Element #	1038
Date Recieved	15-Aug-2014
Date To Core	06-Nov-2014
Date 1st SU	12-Nov-2014
Date Last SD	19-Dec-2015
Date To Pool	04-Jan-2016
Stored Location	NW-C2
U Mass	375
U-235 Enrichment	0.9317
U-235 Mass	349.3875

☐ Editing?

Cycle	Position	Power	MWh	Equivalent MWh
619	A4	0.97	19014.2	18443.774
620	F1	1.03	18981.9	19551.357
621	B3	1	19181.9	19181.9
622	C6	0.97	19164.9	18589.953
623	E2	1.09	19084.8	20802.432
624	E6	0.98	18888.1	18510.338
625	E4	1.04	18859.4	19613.776
0		0	0	0
0		0	0	0

Notes/Comments

N/A

NBSR Fuel Element Archive Logger

Main Tab

Element #	1175
Date Recieved	05-Aug-2020
Date To Core	22-Oct-2020
Date 1st SU	10-Nov-2020
Date Last SD	20-Dec-2020
Date To Pool	
Stored Location	
U Mass	378
U-235 Enrichment	0.92499
U-235 Mass	349.6474

☐ Editing?

Cycle	Position	Power	MWh	Equivalent MWh
653	D1	0.92	17486.7	16087.764
654	D7	0	0	0
655	C2	0	0	0
656	B5	0	0	0
657	F7	0	0	0
658	C4	0	0	0
659	F3	0	0	0
660	F5	0	0	0
0		0	0	0

Notes/Comments

Partially melted on February 3rd, 2021 (Cycle 654) during startup.

NBSR Fuel Element Archive Logger

Main Tab

Element #	1175
Date Recieved	05-Aug-2020
Date To Core	22-Oct-2020
Date 1st SU	10-Nov-2020
Date Last SD	20-Dec-2020
Date To Pool	
Stored Location	
U Mass	378
U-235 Enrichment	0.92499
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Cycle	Position	Power	MWh	Equivalent MWh
653	D1	0.92	17486.7	16087.764
654	D7	0	0	0
655	C2	0	0	0
656	B5	0	0	0
657	F7	0	0	0
658	C4	0	0	0
659	F3	0	0	0
660	F5	0	0	0
0		0	0	0

Notes/Comments

Partially melted on February 3rd, 2021 (Cycle 654) during startup.

☑ Editing Mode

Key Points / Lessons Learned

- “If it ain’t broke, don’t fix it!”
  - As software and technology improve, internal processes can improve.

- Development tools such as ADDIE can foster regular innovation.
  - Analysis
  - Design
  - Development
  - Implementation
  - Evaluation

NIST CENTER FOR NEUTRON RESEARCH

Questions?

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