PUSPATI TRIGA REACTOR (RTP) CONTROL ROD WORTH CALIBRATION DATABASE DEVELOPMENT

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Abstract

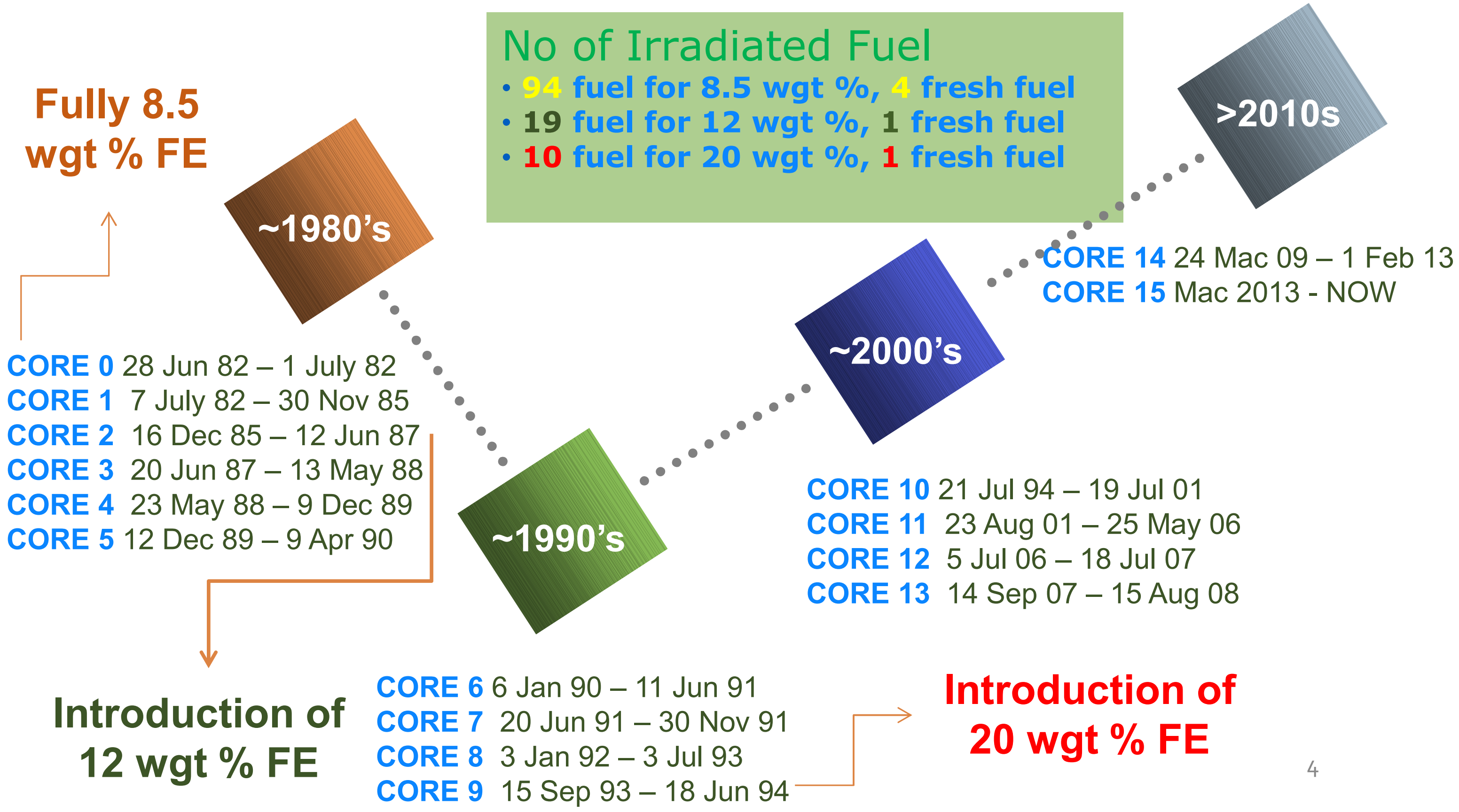
This paper is about The PUSPATI TRIGA Reactor (RTP) control rod worth calibration database development. This database is very important as part of RTP core management analysis to support the improvement of in-core management strategy for safe operation and better utilisation. Control rod worth calibration has been done annually since 1982, the year when RTP start its operation and usually done during RTP annual maintenance by using positive period method part of licensing requirement set by AELB. Few reasons of inconsistency of data were identified and elaborated in this paper such as a physical properties of control rod like control rod position inside the core. Finally, this database is crucial for security of data, data integrity of consistent and accurate data and easier data management in the future.

Keywords: RTP, TRIGA, Control Rod Worth, positive period method

Content

Objective

- RTP Control Rod Worth (CRW) calibration database development (1982-2019)
- As part of RTP core management analysis to support the improvement of in-core management strategy for safe operation



No of Irradiated Fuel

- **94 fuel for 8.5 wgt %, 4 fresh fuel**
- **19 fuel for 12 wgt %, 1 fresh fuel**
- **10 fuel for 20 wgt %, 1 fresh fuel**

Fully 8.5 wgt % FE

~1980's

CORE 0 28 Jun 82 – 1 July 82
CORE 1 7 July 82 – 30 Nov 85
CORE 2 16 Dec 85 – 12 Jun 87
CORE 3 20 Jun 87 – 13 May 88
CORE 4 23 May 88 – 9 Dec 89
CORE 5 12 Dec 89 – 9 Apr 90

Introduction of 12 wgt % FE

~1990's

CORE 6 6 Jan 90 – 11 Jun 91
CORE 7 20 Jun 91 – 30 Nov 91
CORE 8 3 Jan 92 – 3 Jul 93
CORE 9 15 Sep 93 – 18 Jun 94

Introduction of 20 wgt % FE

~2000's

CORE 10 21 Jul 94 – 19 Jul 01
CORE 11 23 Aug 01 – 25 May 06
CORE 12 5 Jul 06 – 18 Jul 07
CORE 13 14 Sep 07 – 15 Aug 08

>2010s

CORE 14 24 Mac 09 – 1 Feb 13
CORE 15 Mac 2013 - NOW

Background

- Each change in reactivity caused by control rod motion is referred to as control rod worth/control rod reactivity worth
- There are several methods for determining the reactivity worth curve of control rods and these methods depends on the reactor type, the available instrument and time:

  a) Positive period method
  b) Rod Drop Method
  c) Inverse rate method
  d) Inverse kinetics method (Reactivity meter)

Background

a) Positive period method

$$P(t) = P(0) \exp\left(\frac{t}{T}\right)$$

P(t):= reactor power at time t.
P(0):=initial power
T:= reactor period [sec]

$$\rho = \omega\left[\ell + \sum_{i=1}^{6} \frac{\beta_i}{\omega + \lambda_i}\right]$$

In-hour Eq.

ρ :=reactivity
l :=prompt neutron generation time [s]
ω:=inverse hour (if doubling time ω= ln2/t)
β(i):=i-th delayed neutron fraction
λ(i:):=i-th precursor decay constant [1/s]

Background

b) Rod drop method

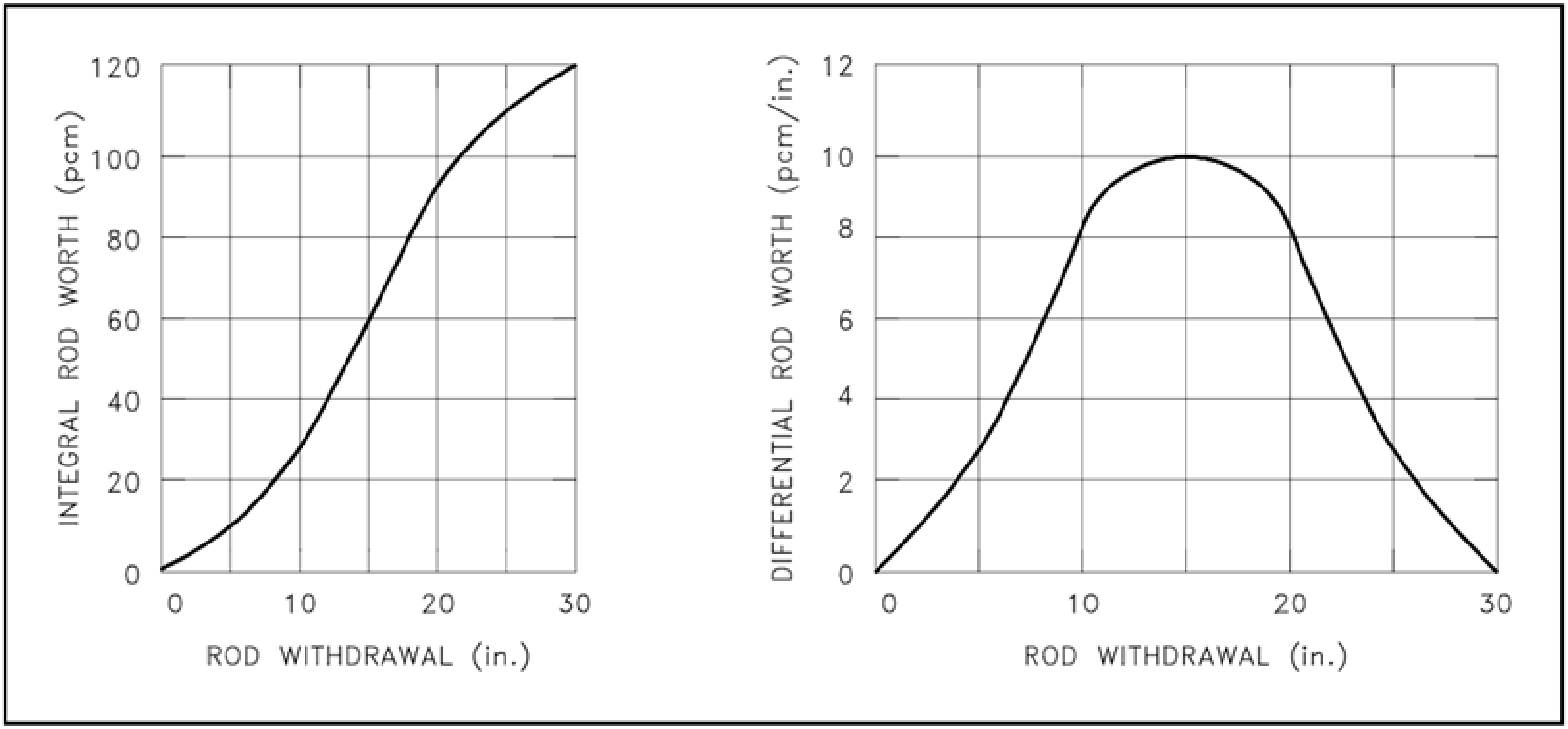
$$\frac{n_1}{n_0} = \frac{\beta}{\beta - \enclose{circle}{\rho}}$$

Derived from point kinetic Eq.

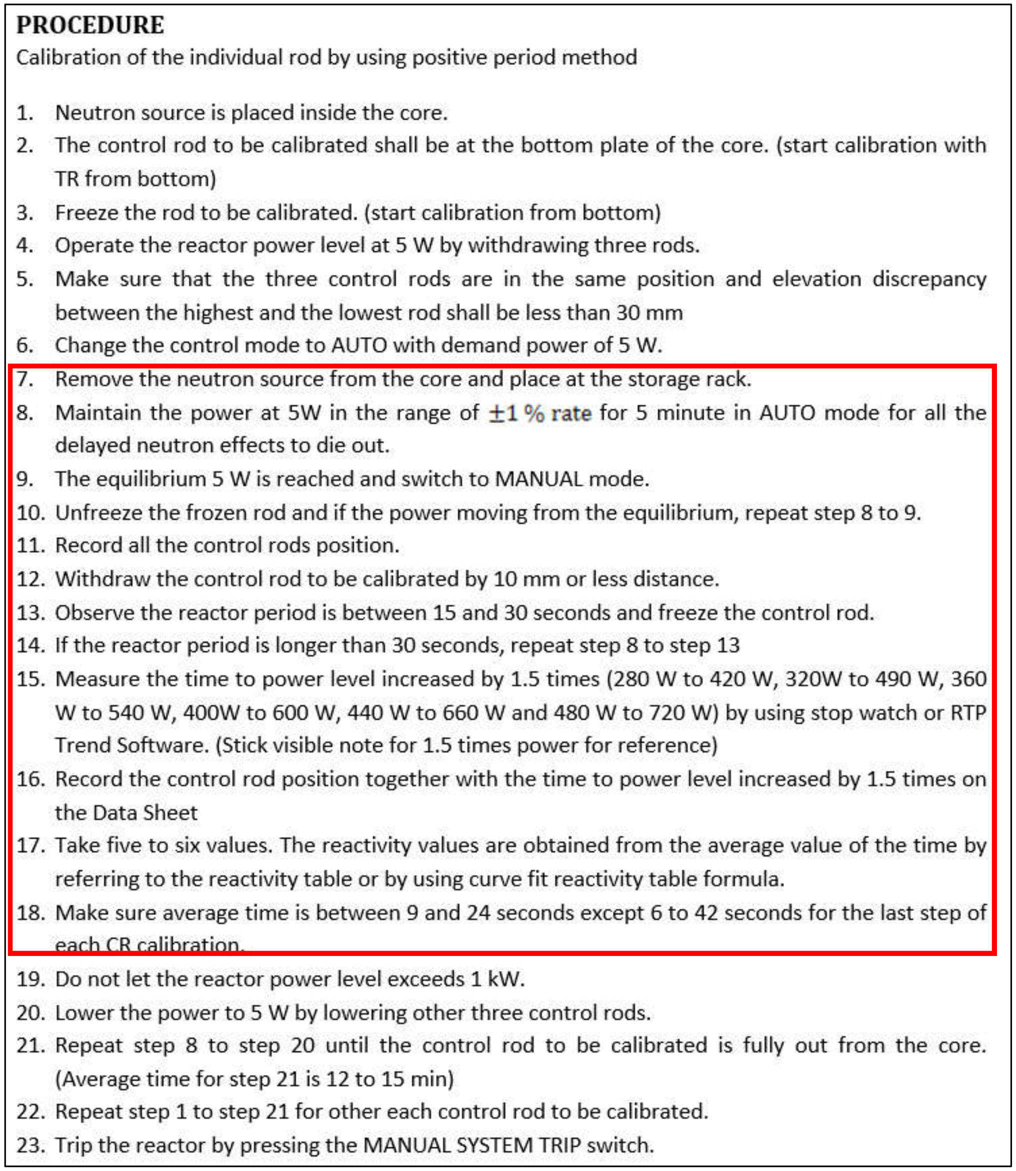
n(1):= neutron population after prompt jump.
n(0):= initial neutron population before prompt jump
β:=effective delayed neutron fraction
ρ:=reactivity

Background

Integral and Differential Rod Worth Curve



Method



PROCEDURE

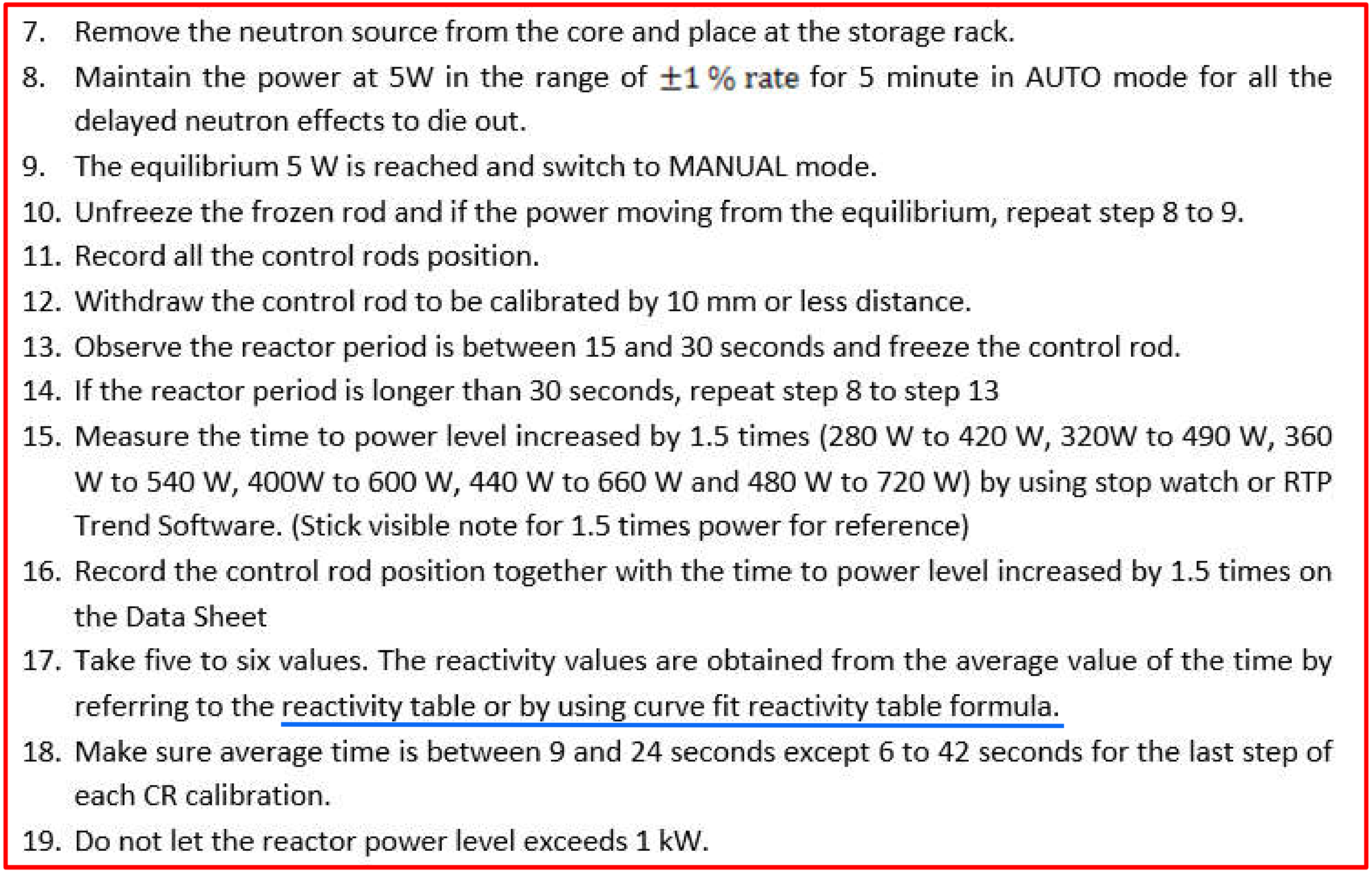
Calibration of the individual rod by using positive period method

1. Neutron source is placed inside the core.
2. The control rod to be calibrated shall be at the bottom plate of the core. (start calibration with TR from bottom)
3. Freeze the rod to be calibrated. (start calibration from bottom)
4. Operate the reactor power level at 5 W by withdrawing three rods.
5. Make sure that the three control rods are in the same position and elevation discrepancy between the highest and the lowest rod shall be less than 30 mm
6. Change the control mode to AUTO with demand power of 5 W.
7. Remove the neutron source from the core and place at the storage rack.
8. Maintain the power at 5W in the range of ±1 % rate for 5 minute in AUTO mode for all the delayed neutron effects to die out.
9. The equilibrium 5 W is reached and switch to MANUAL mode.
10. Unfreeze the frozen rod and if the power moving from the equilibrium, repeat step 8 to 9.
11. Record all the control rods position.
12. Withdraw the control rod to be calibrated by 10 mm or less distance.
13. Observe the reactor period is between 15 and 30 seconds and freeze the control rod.
14. If the reactor period is longer than 30 seconds, repeat step 8 to step 13
15. Measure the time to power level increased by 1.5 times (280 W to 420 W, 320W to 490 W, 360 W to 540 W, 400W to 600 W, 440 W to 660 W and 480 W to 720 W) by using stop watch or RTP Trend Software. (Stick visible note for 1.5 times power for reference)
16. Record the control rod position together with the time to power level increased by 1.5 times on the Data Sheet
17. Take five to six values. The reactivity values are obtained from the average value of the time by referring to the reactivity table or by using curve fit reactivity table formula.
18. Make sure average time is between 9 and 24 seconds except 6 to 42 seconds for the last step of each CR calibration.
19. Do not let the reactor power level exceeds 1 kW.
20. Lower the power to 5 W by lowering other three control rods.
21. Repeat step 8 to step 20 until the control rod to be calibrated is fully out from the core. (Average time for step 21 is 12 to 15 min)
22. Repeat step 1 to step 21 for other each control rod to be calibrated.
23. Trip the reactor by pressing the MANUAL SYSTEM TRIP switch.

Source:

1. RTP CRW Annual Maintenance Report 2019
2. RTP-JILID7, Procedure 8.0 Control rod calibration
3. IMS-T-07 Revision: 1.0 (2014) Tentukuran Rod Kawalan
4. TP-RPT-01 Rev. No.: 0 RPT Procedure of Rod Worth Measurement

Method



7. Remove the neutron source from the core and place at the storage rack.
8. Maintain the power at 5W in the range of ±1 % rate for 5 minute in AUTO mode for all the delayed neutron effects to die out.
9. The equilibrium 5 W is reached and switch to MANUAL mode.
10. Unfreeze the frozen rod and if the power moving from the equilibrium, repeat step 8 to 9.
11. Record all the control rods position.
12. Withdraw the control rod to be calibrated by 10 mm or less distance.
13. Observe the reactor period is between 15 and 30 seconds and freeze the control rod.
14. If the reactor period is longer than 30 seconds, repeat step 8 to step 13
15. Measure the time to power level increased by 1.5 times (280 W to 420 W, 320W to 490 W, 360 W to 540 W, 400W to 600 W, 440 W to 660 W and 480 W to 720 W) by using stop watch or RTP Trend Software. (Stick visible note for 1.5 times power for reference)
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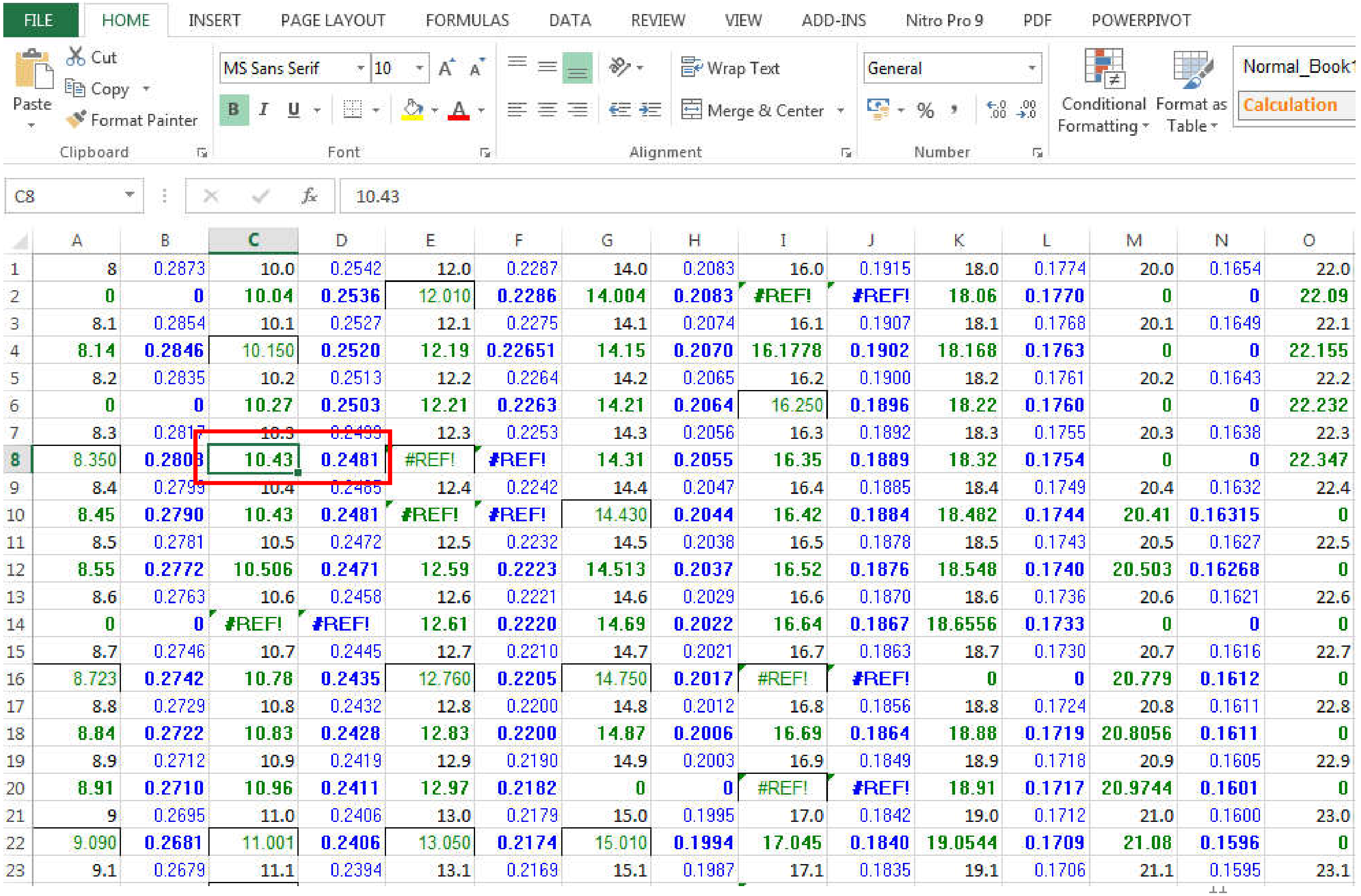
18. Make sure average time is between 9 and 24 seconds except 6 to 42 seconds for the last step of each CR calibration.
19. Do not let the reactor power level exceeds 1 kW.

Method

Reactivity Table

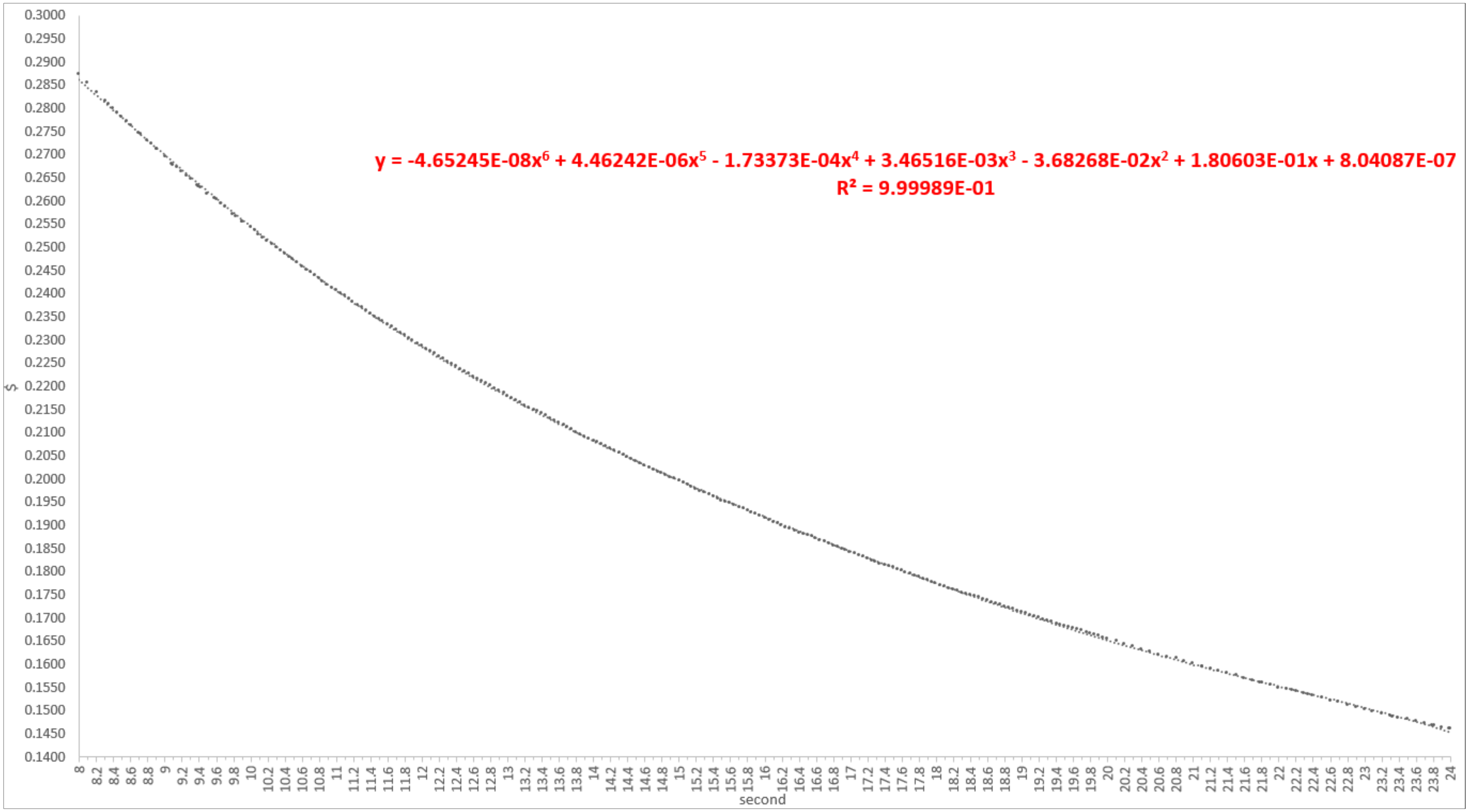


C8 10.43

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	8	0.2873	10.0	0.2542	12.0	0.2287	14.0	0.2083	16.0	0.1915	18.0	0.1774	20.0	0.1654	22.0
2	0	0	10.04	0.2536	12.010	0.2286	14.004	0.2083	#REF!	#REF!	18.06	0.1770	0	0	22.09
3	8.1	0.2854	10.1	0.2527	12.1	0.2275	14.1	0.2074	16.1	0.1907	18.1	0.1768	20.1	0.1649	22.1
4	8.14	0.2846	10.150	0.2520	12.19	0.22651	14.15	0.2070	16.1778	0.1902	18.168	0.1763	0	0	22.155
5	8.2	0.2835	10.2	0.2513	12.2	0.2264	14.2	0.2065	16.2	0.1900	18.2	0.1761	20.2	0.1643	22.2
6	0	0	10.27	0.2503	12.21	0.2263	14.21	0.2064	16.250	0.1896	18.22	0.1760	0	0	22.232
7	8.3	0.2817	10.3	0.2499	12.3	0.2253	14.3	0.2056	16.3	0.1892	18.3	0.1755	20.3	0.1638	22.3
8	8.350	0.2808	10.43	0.2481	#REF!	#REF!	14.31	0.2055	16.35	0.1889	18.32	0.1754	0	0	22.347
9	8.4	0.2799	10.4	0.2485	12.4	0.2242	14.4	0.2047	16.4	0.1885	18.4	0.1749	20.4	0.1632	22.4
10	8.45	0.2790	10.43	0.2481	#REF!	#REF!	14.430	0.2044	16.42	0.1884	18.482	0.1744	20.41	0.16315	0
11	8.5	0.2781	10.5	0.2472	12.5	0.2232	14.5	0.2038	16.5	0.1878	18.5	0.1743	20.5	0.1627	22.5
12	8.55	0.2772	10.506	0.2471	12.59	0.2223	14.513	0.2037	16.52	0.1876	18.548	0.1740	20.503	0.16268	0
13	8.6	0.2763	10.6	0.2458	12.6	0.2221	14.6	0.2029	16.6	0.1870	18.6	0.1736	20.6	0.1621	22.6
14	0	0	#REF!	#REF!	12.61	0.2220	14.69	0.2022	16.64	0.1867	18.6556	0.1733	0	0	0
15	8.7	0.2746	10.7	0.2445	12.7	0.2210	14.7	0.2021	16.7	0.1863	18.7	0.1730	20.7	0.1616	22.7
16	8.723	0.2742	10.78	0.2435	12.760	0.2205	14.750	0.2017	#REF!	#REF!	0	0	20.779	0.1612	0
17	8.8	0.2729	10.8	0.2432	12.8	0.2200	14.8	0.2012	16.8	0.1856	18.8	0.1724	20.8	0.1611	22.8
18	8.84	0.2722	10.83	0.2428	12.83	0.2200	14.87	0.2006	16.69	0.1864	18.88	0.1719	20.8056	0.1611	0
19	8.9	0.2712	10.9	0.2419	12.9	0.2190	14.9	0.2003	16.9	0.1849	18.9	0.1718	20.9	0.1605	22.9
20	8.91	0.2710	10.96	0.2411	12.97	0.2182	0	0	#REF!	#REF!	18.91	0.1717	20.9744	0.1601	0
21	9	0.2695	11.0	0.2406	13.0	0.2179	15.0	0.1995	17.0	0.1842	19.0	0.1712	21.0	0.1600	23.0
22	9.090	0.2681	11.001	0.2406	13.050	0.2174	15.010	0.1994	17.045	0.1840	19.0544	0.1709	21.08	0.1596	0
23	9.1	0.2679	11.1	0.2394	13.1	0.2169	15.1	0.1987	17.1	0.1835	19.1	0.1706	21.1	0.1595	23.1

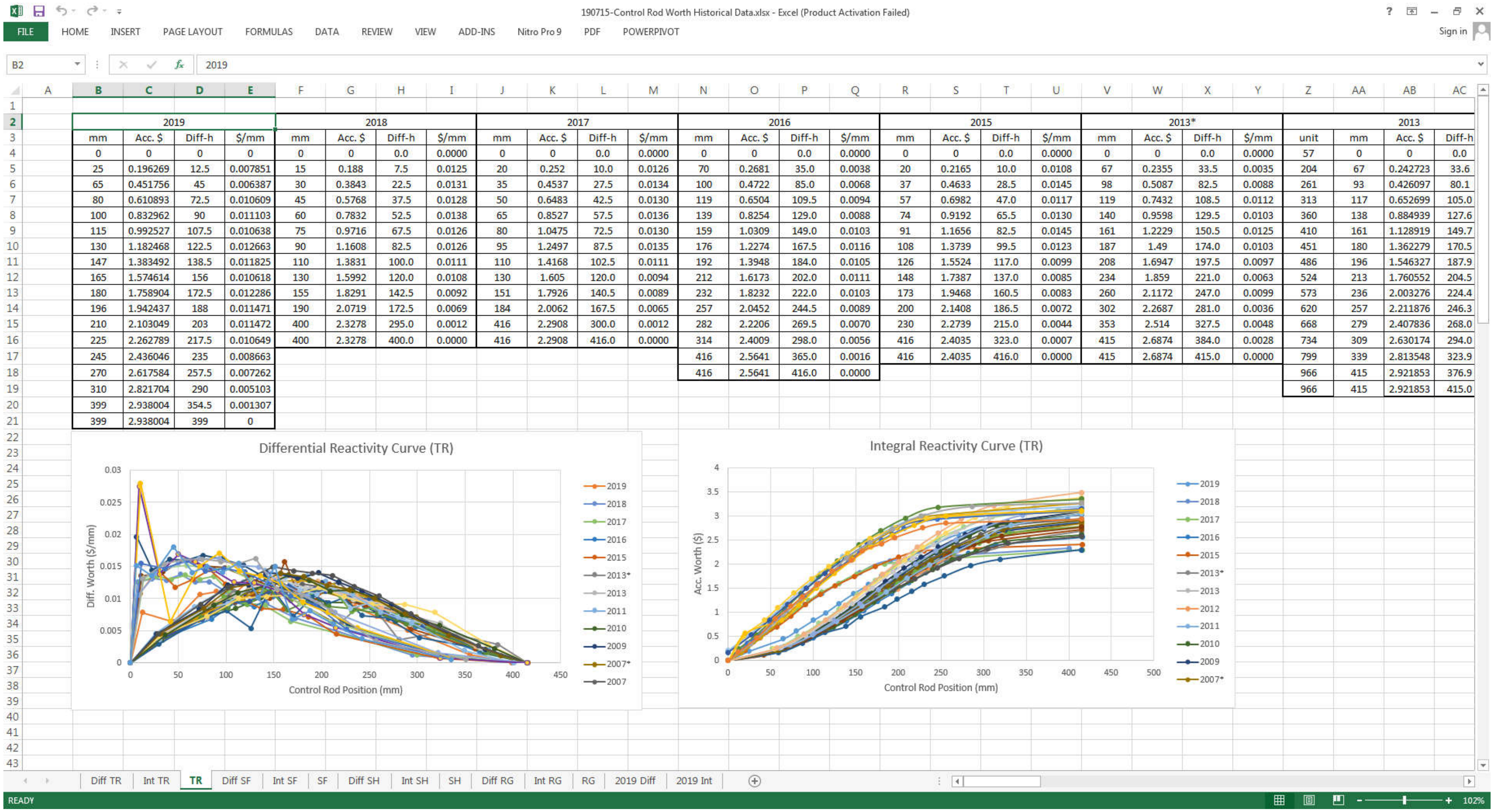
Method

Curve fit reactivity table formula



Results

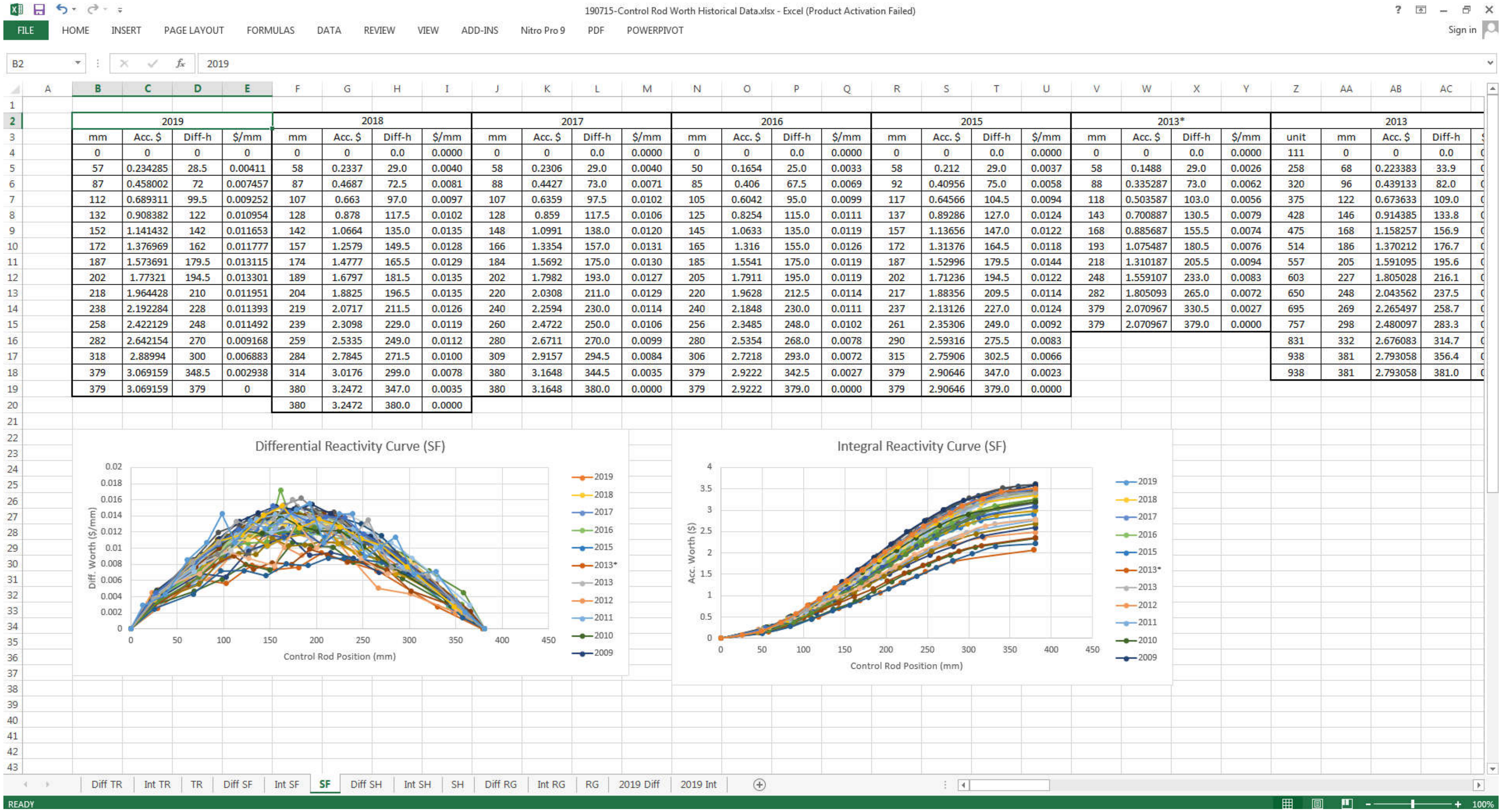
RTP CRW Database 1982-2019 (TR)



2019				2018				2017				2016				2015				2013*				2013			
mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	unit	mm	Acc. $	Diff-h
0	0	0	0	0	0	0.0	0.0000	0	0	0.0	0.0000	0	0	0.0	0.0000	0	0	0.0	0.0000	0	0	0.0	0.0000	57	0	0	0.0
25	0.196269	12.5	0.007851	15	0.188	7.5	0.0125	20	0.252	10.0	0.0126	70	0.2681	35.0	0.0038	20	0.2165	10.0	0.0108	67	0.2355	33.5	0.0035	204	67	0.242723	33.6
65	0.451756	45	0.006387	30	0.3843	22.5	0.0131	35	0.4537	27.5	0.0134	100	0.4722	85.0	0.0068	37	0.4633	28.5	0.0145	98	0.5087	82.5	0.0088	261	93	0.426097	80.1
80	0.610893	72.5	0.010609	45	0.5768	37.5	0.0128	50	0.6483	42.5	0.0130	119	0.6504	109.5	0.0094	57	0.6982	47.0	0.0117	119	0.7432	108.5	0.0112	313	117	0.652699	105.0
100	0.832962	90	0.011103	60	0.7832	52.5	0.0138	65	0.8527	57.5	0.0136	139	0.8254	129.0	0.0088	74	0.9192	65.5	0.0130	140	0.9598	129.5	0.0103	360	138	0.884939	127.6
115	0.992527	107.5	0.010638	75	0.9716	67.5	0.0126	80	1.0475	72.5	0.0130	159	1.0309	149.0	0.0103	91	1.1656	82.5	0.0145	161	1.2229	150.5	0.0125	410	161	1.128919	149.7
130	1.182468	122.5	0.012663	90	1.1608	82.5	0.0126	95	1.2497	87.5	0.0135	176	1.2274	167.5	0.0116	108	1.3739	99.5	0.0123	187	1.49	174.0	0.0103	451	180	1.362279	170.5
147	1.383492	138.5	0.011825	110	1.3831	100.0	0.0111	110	1.4168	102.5	0.0111	192	1.3948	184.0	0.0105	126	1.5524	117.0	0.0099	208	1.6947	197.5	0.0097	486	196	1.546327	187.9
165	1.574614	156	0.010618	130	1.5992	120.0	0.0108	130	1.605	120.0	0.0094	212	1.6173	202.0	0.0111	148	1.7387	137.0	0.0085	234	1.859	221.0	0.0063	524	213	1.760552	204.5
180	1.758904	172.5	0.012286	155	1.8291	142.5	0.0092	151	1.7926	140.5	0.0089	232	1.8232	222.0	0.0103	173	1.9468	160.5	0.0083	260	2.1172	247.0	0.0099	573	236	2.003276	224.4
196	1.942437	188	0.011471	190	2.0719	172.5	0.0069	184	2.0062	167.5	0.0065	257	2.0452	244.5	0.0089	200	2.1408	186.5	0.0072	302	2.2687	281.0	0.0036	620	257	2.211876	246.3
210	2.103049	203	0.011472	400	2.3278	295.0	0.0012	416	2.2908	300.0	0.0012	282	2.2206	269.5	0.0070	230	2.2739	215.0	0.0044	353	2.514	327.5	0.0048	668	279	2.407836	268.0
225	2.262789	217.5	0.010649	400	2.3278	400.0	0.0000	416	2.2908	416.0	0.0000	314	2.4009	298.0	0.0056	416	2.4035	323.0	0.0007	415	2.6874	384.0	0.0028	734	309	2.630174	294.0
245	2.436046	235	0.008663									416	2.5641	365.0	0.0016	416	2.4035	416.0	0.0000	415	2.6874	415.0	0.0000	799	339	2.813548	323.9
270	2.617584	257.5	0.007262									416	2.5641	416.0	0.0000									966	415	2.921853	376.9
310	2.821704	290	0.005103																					966	415	2.921853	415.0
399	2.938004	354.5	0.001307																								
399	2.938004	399	0																								

Results

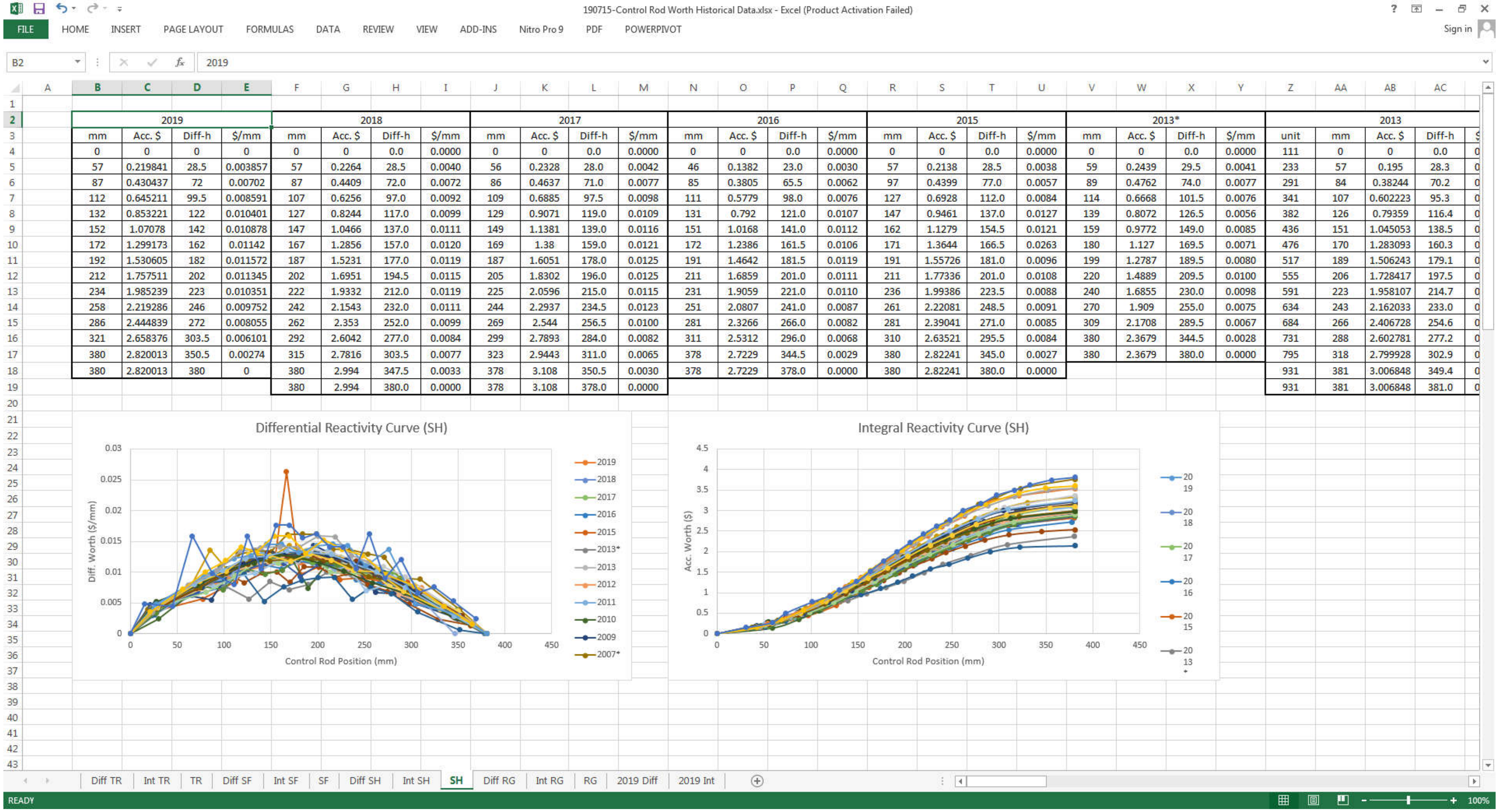
RTP CRW Database 1982-2019 (SF)



2019				2018				2017				2016				2015				2013*				2013			
mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	unit	mm	Acc. $	Diff-h
0	0	0	0	0	0	0.0	0.0000	0	0	0.0	0.0000	0	0	0.0	0.0000	0	0	0.0	0.0000	0	0	0.0	0.0000	111	0	0	0.0
57	0.234285	28.5	0.00411	58	0.2337	29.0	0.0040	58	0.2306	29.0	0.0040	50	0.1654	25.0	0.0033	58	0.212	29.0	0.0037	58	0.1488	29.0	0.0026	258	68	0.223383	33.9
87	0.458002	72	0.007457	87	0.4687	72.5	0.0081	88	0.4427	73.0	0.0071	85	0.406	67.5	0.0069	92	0.40956	75.0	0.0058	88	0.335287	73.0	0.0062	320	96	0.439133	82.0
112	0.689311	99.5	0.009252	107	0.663	97.0	0.0097	107	0.6359	97.5	0.0102	105	0.6042	95.0	0.0099	117	0.64566	104.5	0.0094	118	0.503587	103.0	0.0056	375	122	0.673633	109.0
132	0.908382	122	0.010954	128	0.878	117.5	0.0102	128	0.859	117.5	0.0106	125	0.8254	115.0	0.0111	137	0.89286	127.0	0.0124	143	0.700887	130.5	0.0079	428	146	0.914385	133.8
152	1.141432	142	0.011653	142	1.0664	135.0	0.0135	148	1.0991	138.0	0.0120	145	1.0633	135.0	0.0119	157	1.13656	147.0	0.0122	168	0.885687	155.5	0.0074	475	168	1.158257	156.9
172	1.376969	162	0.011777	157	1.2579	149.5	0.0128	166	1.3354	157.0	0.0131	165	1.316	155.0	0.0126	172	1.31376	164.5	0.0118	193	1.075487	180.5	0.0076	514	186	1.370212	176.7
187	1.573691	179.5	0.013115	174	1.4777	165.5	0.0129	184	1.5692	175.0	0.0130	185	1.5541	175.0	0.0119	187	1.52996	179.5	0.0144	218	1.310187	205.5	0.0094	557	205	1.591095	195.6
202	1.77321	194.5	0.013301	189	1.6797	181.5	0.0135	202	1.7982	193.0	0.0127	205	1.7911	195.0	0.0119	202	1.71236	194.5	0.0122	248	1.559107	233.0	0.0083	603	227	1.805028	216.1
218	1.964428	210	0.011951	204	1.8825	196.5	0.0135	220	2.0308	211.0	0.0129	220	1.9628	212.5	0.0114	217	1.88356	209.5	0.0114	282	1.805093	265.0	0.0072	650	248	2.043562	237.5
238	2.192284	228	0.011393	219	2.0717	211.5	0.0126	240	2.2594	230.0	0.0114	240	2.1848	230.0	0.0111	237	2.13126	227.0	0.0124	379	2.070967	330.5	0.0027	695	269	2.265497	258.7
258	2.422129	248	0.011492	239	2.3098	229.0	0.0119	260	2.4722	250.0	0.0106	256	2.3485	248.0	0.0102	261	2.35306	249.0	0.0092	379	2.070967	379.0	0.0000	757	298	2.480097	283.3
282	2.642154	270	0.009168	259	2.5335	249.0	0.0112	280	2.6711	270.0	0.0099	280	2.5354	268.0	0.0078	290	2.59316	275.5	0.0083					831	332	2.676083	314.7
318	2.88994	300	0.006883	284	2.7845	271.5	0.0100	309	2.9157	294.5	0.0084	306	2.7218	293.0	0.0072	315	2.75906	302.5	0.0066					938	381	2.793058	356.4
379	3.069159	348.5	0.002938	314	3.0176	299.0	0.0078	380	3.1648	344.5	0.0035	379	2.9222	342.5	0.0027	379	2.90646	347.0	0.0023					938	381	2.793058	381.0
379	3.069159	379	0	380	3.2472	347.0	0.0035	380	3.1648	380.0	0.0000	379	2.9222	379.0	0.0000	379	2.90646	379.0	0.0000								
				380	3.2472	380.0	0.0000																				

Results

RTP CRW Database 1982-2019 (SH)

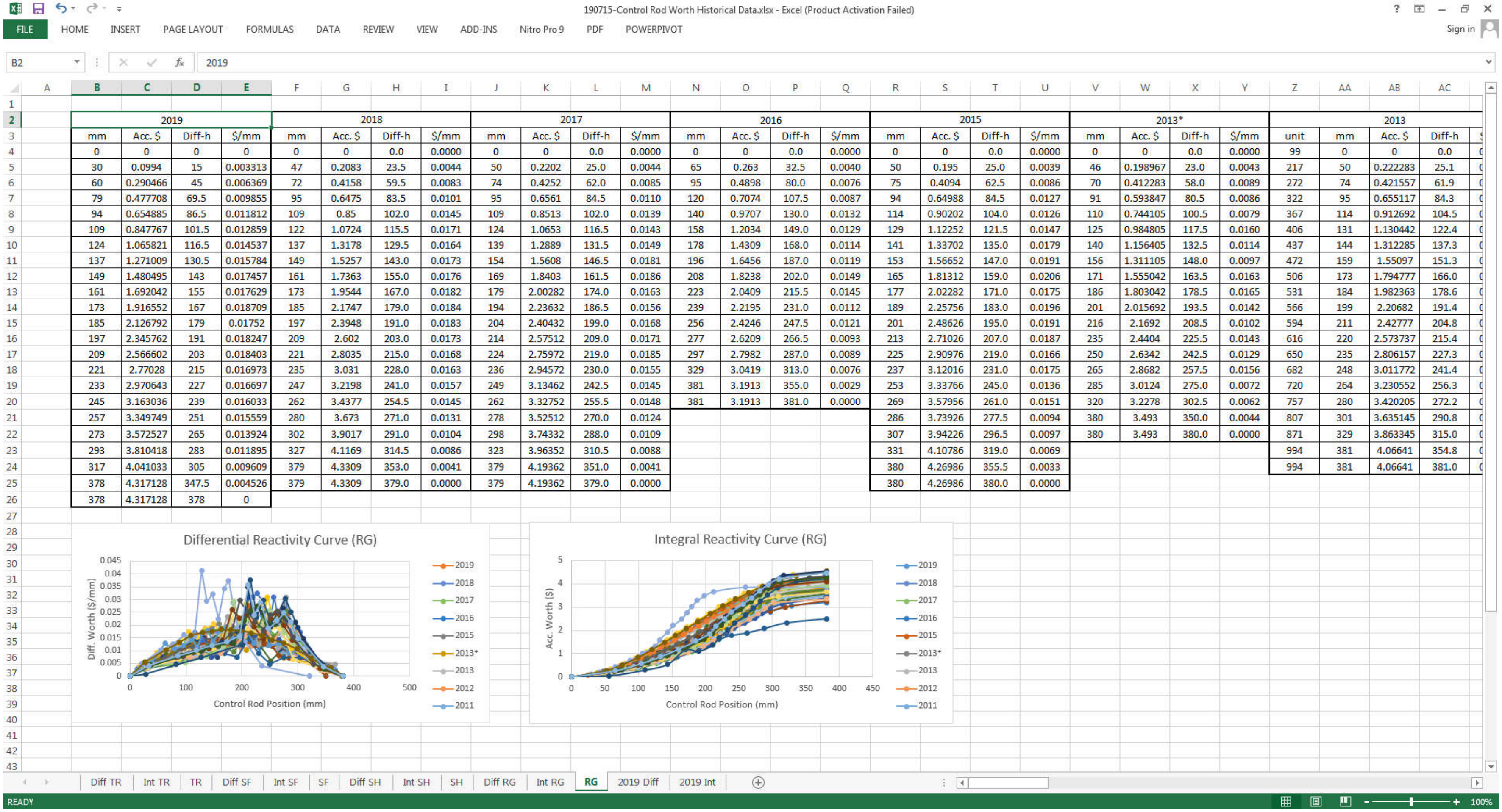


2019				2018				2017			
mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm
0	0	0	0	0	0	0.0	0.0000	0	0	0.0	0.0000
57	0.219841	28.5	0.003857	57	0.2264	28.5	0.0040	56	0.2328	28.0	0.0042
87	0.430437	72	0.00702	87	0.4409	72.0	0.0072	86	0.4637	71.0	0.0077
112	0.645211	99.5	0.008591	107	0.6256	97.0	0.0092	109	0.6885	97.5	0.0098
132	0.853221	122	0.010401	127	0.8244	117.0	0.0099	129	0.9071	119.0	0.0109
152	1.07078	142	0.010878	147	1.0466	137.0	0.0111	149	1.1381	139.0	0.0116
172	1.299173	162	0.01142	167	1.2856	157.0	0.0120	169	1.38	159.0	0.0121
192	1.530605	182	0.011572	187	1.5231	177.0	0.0119	187	1.6051	178.0	0.0125
212	1.757511	202	0.011345	202	1.6951	194.5	0.0115	205	1.8302	196.0	0.0125
234	1.985239	223	0.010351	222	1.9332	212.0	0.0119	225	2.0596	215.0	0.0115
258	2.219286	246	0.009752	242	2.1543	232.0	0.0111	244	2.2937	234.5	0.0123
286	2.444839	272	0.008055	262	2.353	252.0	0.0099	269	2.544	256.5	0.0100
321	2.658376	303.5	0.006101	292	2.6042	277.0	0.0084	299	2.7893	284.0	0.0082
380	2.820013	350.5	0.00274	315	2.7816	303.5	0.0077	323	2.9443	311.0	0.0065
380	2.820013	380	0	380	2.994	347.5	0.0033	378	3.108	350.5	0.0030
				380	2.994	380.0	0.0000	378	3.108	378.0	0.0000

2016				2015				2013*				2013			
mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm	unit	mm	Acc. $	Diff-h
0	0	0.0	0.0000	0	0	0.0	0.0000	0	0	0.0	0.0000	111	0	0	0.0
46	0.1382	23.0	0.0030	57	0.2138	28.5	0.0038	59	0.2439	29.5	0.0041	233	57	0.195	28.3
85	0.3805	65.5	0.0062	97	0.4399	77.0	0.0057	89	0.4762	74.0	0.0077	291	84	0.38244	70.2
111	0.5779	98.0	0.0076	127	0.6928	112.0	0.0084	114	0.6668	101.5	0.0076	341	107	0.602223	95.3
131	0.792	121.0	0.0107	147	0.9461	137.0	0.0127	139	0.8072	126.5	0.0056	382	126	0.79359	116.4
151	1.0168	141.0	0.0112	162	1.1279	154.5	0.0121	159	0.9772	149.0	0.0085	436	151	1.045053	138.5
172	1.2386	161.5	0.0106	171	1.3644	166.5	0.0263	180	1.127	169.5	0.0071	476	170	1.283093	160.3
191	1.4642	181.5	0.0119	191	1.55726	181.0	0.0096	199	1.2787	189.5	0.0080	517	189	1.506243	179.1
211	1.6859	201.0	0.0111	211	1.77336	201.0	0.0108	220	1.4889	209.5	0.0100	555	206	1.728417	197.5
231	1.9059	221.0	0.0110	236	1.99386	223.5	0.0088	240	1.6855	230.0	0.0098	591	223	1.958107	214.7
251	2.0807	241.0	0.0087	261	2.22081	248.5	0.0091	270	1.909	255.0	0.0075	634	243	2.162033	233.0
281	2.3266	266.0	0.0082	281	2.39041	271.0	0.0085	309	2.1708	289.5	0.0067	684	266	2.406728	254.6
311	2.5312	296.0	0.0068	310	2.63521	295.5	0.0084	380	2.3679	344.5	0.0028	731	288	2.602781	277.2
378	2.7229	344.5	0.0029	380	2.82241	345.0	0.0027	380	2.3679	380.0	0.0000	795	318	2.799928	302.9
378	2.7229	378.0	0.0000	380	2.82241	380.0	0.0000					931	381	3.006848	349.4
												931	381	3.006848	381.0

Results

RTP CRW Database 1982-2019 (RG)



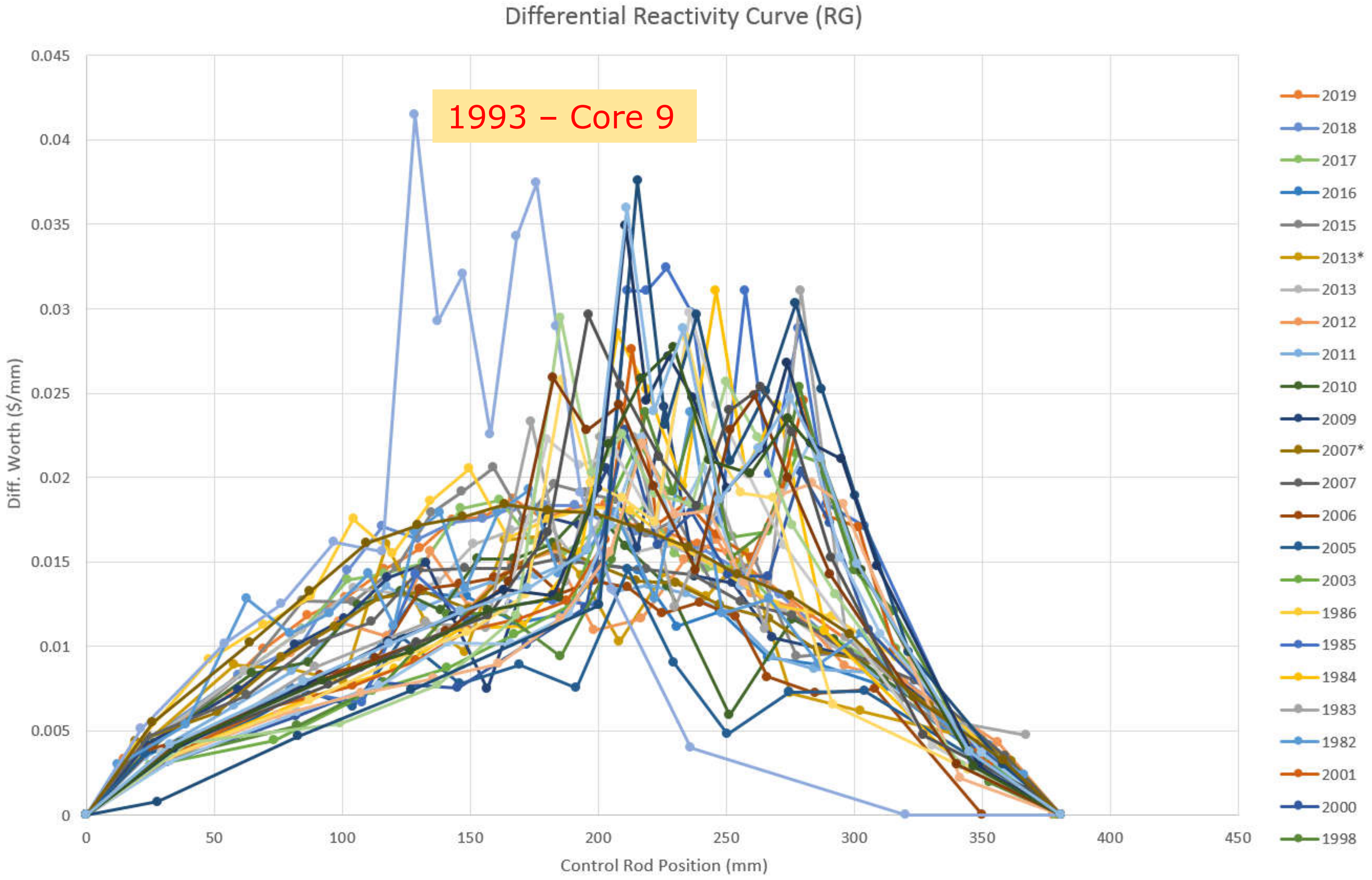
	A	B	C	D	E	F	G	H	I
1									
2		2019				2018			
3		mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm
4		0	0	0	0	0	0	0.0	0.0000
5		30	0.0994	15	0.003313	47	0.2083	23.5	0.0044
6		60	0.290466	45	0.006369	72	0.4158	59.5	0.0083
7		79	0.477708	69.5	0.009855	95	0.6475	83.5	0.0101
8		94	0.654885	86.5	0.011812	109	0.85	102.0	0.0145
9		109	0.847767	101.5	0.012859	122	1.0724	115.5	0.0171
10		124	1.065821	116.5	0.014537	137	1.3178	129.5	0.0164
11		137	1.271009	130.5	0.015784	149	1.5257	143.0	0.0173
12		149	1.480495	143	0.017457	161	1.7363	155.0	0.0176
13		161	1.692042	155	0.017629	173	1.9544	167.0	0.0182
14		173	1.916552	167	0.018709	185	2.1747	179.0	0.0184
15		185	2.126792	179	0.01752	197	2.3948	191.0	0.0183
16		197	2.345762	191	0.018247	209	2.602	203.0	0.0173
17		209	2.566602	203	0.018403	221	2.8035	215.0	0.0168
18		221	2.77028	215	0.016973	235	3.031	228.0	0.0163
19		233	2.970643	227	0.016697	247	3.2198	241.0	0.0157
20		245	3.163036	239	0.016033	262	3.4377	254.5	0.0145
21		257	3.349749	251	0.015559	280	3.673	271.0	0.0131
22		273	3.572527	265	0.013924	302	3.9017	291.0	0.0104
23		293	3.810418	283	0.011895	327	4.1169	314.5	0.0086
24		317	4.041033	305	0.009609	379	4.3309	353.0	0.0041
25		378	4.317128	347.5	0.004526	379	4.3309	379.0	0.0000
26		378	4.317128	378	0				

	J	K	L	M	N	O	P	Q
1								
2	2017				2016			
3	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm
4	0	0	0.0	0.0000	0	0	0.0	0.0000
5	50	0.2202	25.0	0.0044	65	0.263	32.5	0.0040
6	74	0.4252	62.0	0.0085	95	0.4898	80.0	0.0076
7	95	0.6561	84.5	0.0110	120	0.7074	107.5	0.0087
8	109	0.8513	102.0	0.0139	140	0.9707	130.0	0.0132
9	124	1.0653	116.5	0.0143	158	1.2034	149.0	0.0129
10	139	1.2889	131.5	0.0149	178	1.4309	168.0	0.0114
11	154	1.5608	146.5	0.0181	196	1.6456	187.0	0.0119
12	169	1.8403	161.5	0.0186	208	1.8238	202.0	0.0149
13	179	2.00282	174.0	0.0163	223	2.0409	215.5	0.0145
14	194	2.23632	186.5	0.0156	239	2.2195	231.0	0.0112
15	204	2.40432	199.0	0.0168	256	2.4246	247.5	0.0121
16	214	2.57512	209.0	0.0171	277	2.6209	266.5	0.0093
17	224	2.75972	219.0	0.0185	297	2.7982	287.0	0.0089
18	236	2.94572	230.0	0.0155	329	3.0419	313.0	0.0076
19	249	3.13462	242.5	0.0145	381	3.1913	355.0	0.0029
20	262	3.32752	255.5	0.0148	381	3.1913	381.0	0.0000
21	278	3.52512	270.0	0.0124				
22	298	3.74332	288.0	0.0109				
23	323	3.96352	310.5	0.0088				
24	379	4.19362	351.0	0.0041				
25	379	4.19362	379.0	0.0000				

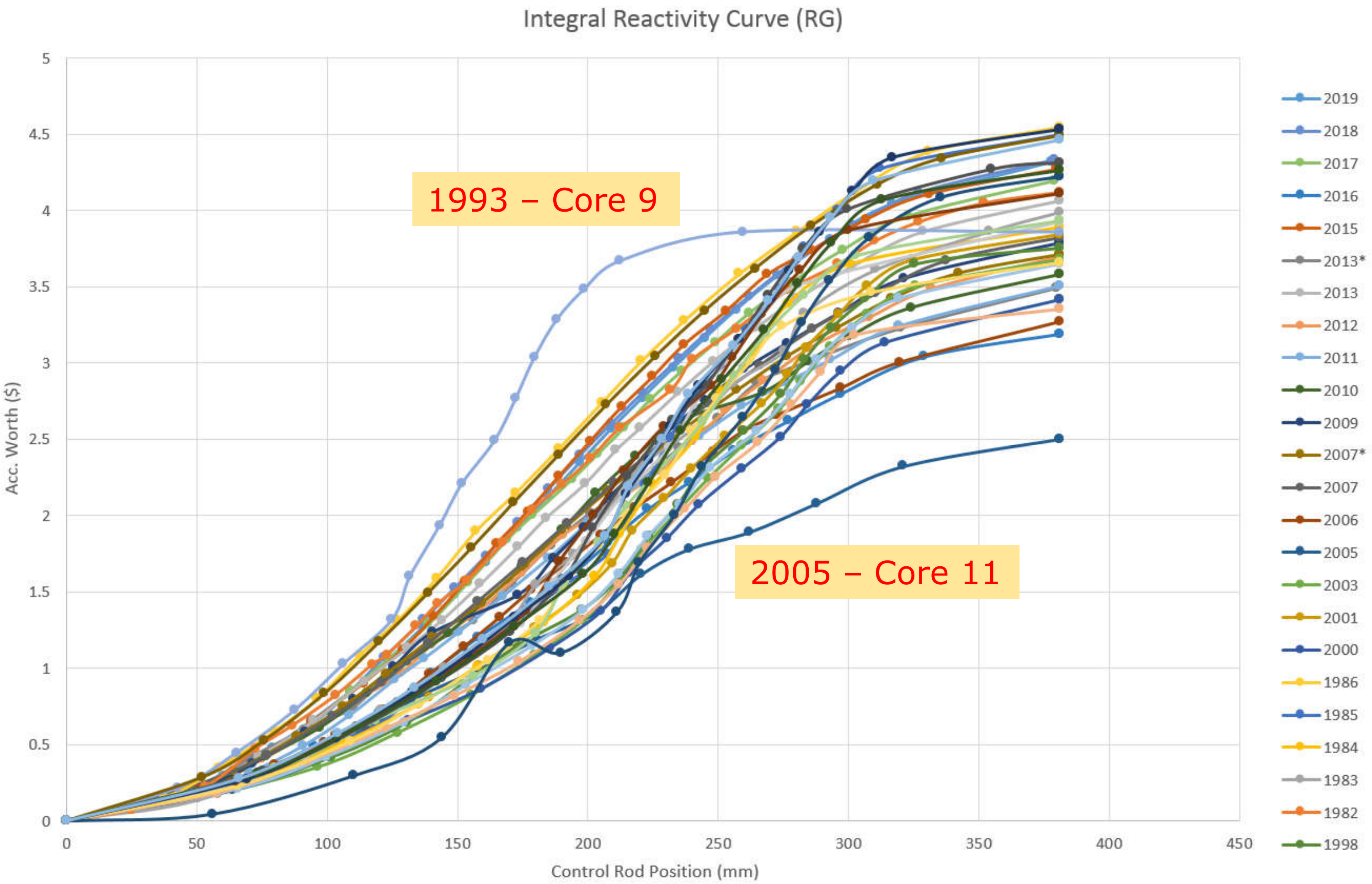
	R	S	T	U	V	W	X	Y
1								
2	2015				2013*			
3	mm	Acc. $	Diff-h	$/mm	mm	Acc. $	Diff-h	$/mm
4	0	0	0.0	0.0000	0	0	0.0	0.0000
5	50	0.195	25.0	0.0039	46	0.198967	23.0	0.0043
6	75	0.4094	62.5	0.0086	70	0.412283	58.0	0.0089
7	94	0.64988	84.5	0.0127	91	0.593847	80.5	0.0086
8	114	0.90202	104.0	0.0126	110	0.744105	100.5	0.0079
9	129	1.12252	121.5	0.0147	125	0.984805	117.5	0.0160
10	141	1.33702	135.0	0.0179	140	1.156405	132.5	0.0114
11	153	1.56652	147.0	0.0191	156	1.311105	148.0	0.0097
12	165	1.81312	159.0	0.0206	171	1.555042	163.5	0.0163
13	177	2.02282	171.0	0.0175	186	1.803042	178.5	0.0165
14	189	2.25756	183.0	0.0196	201	2.015692	193.5	0.0142
15	201	2.48626	195.0	0.0191	216	2.1692	208.5	0.0102
16	213	2.71026	207.0	0.0187	235	2.4404	225.5	0.0143
17	225	2.90976	219.0	0.0166	250	2.6342	242.5	0.0129
18	237	3.12016	231.0	0.0175	265	2.8682	257.5	0.0156
19	253	3.33766	245.0	0.0136	285	3.0124	275.0	0.0072
20	269	3.57956	261.0	0.0151	320	3.2278	302.5	0.0062
21	286	3.73926	277.5	0.0094	380	3.493	350.0	0.0044
22	307	3.94226	296.5	0.0097	380	3.493	380.0	0.0000
23	331	4.10786	319.0	0.0069				
24	380	4.26986	355.5	0.0033				
25	380	4.26986	380.0	0.0000				

	Z	AA	AB	AC
1				
2	2013			
3	unit	mm	Acc. $	Diff-h
4	99	0	0	0.0
5	217	50	0.222283	25.1
6	272	74	0.421557	61.9
7	322	95	0.655117	84.3
8	367	114	0.912692	104.5
9	406	131	1.130442	122.4
10	437	144	1.312285	137.3
11	472	159	1.55097	151.3
12	506	173	1.794777	166.0
13	531	184	1.982363	178.6
14	566	199	2.20682	191.4
15	594	211	2.42777	204.8
16	616	220	2.573737	215.4
17	650	235	2.806157	227.3
18	682	248	3.011772	241.4
19	720	264	3.230552	256.3
20	757	280	3.420205	272.2
21	807	301	3.635145	290.8
22	871	329	3.863345	315.0
23	994	381	4.06641	354.8
24	994	381	4.06641	381.0

Results


Differential Reactivity Curve (RG)
1993 – Core 9
Diff. Worth ($/mm)
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
50
100
150
200
250
300
350
400
450
Control Rod Position (mm)
2019
2018
2017
2016
2015
2013*
2013
2012
2011
2010
2009
2007*
2007
2006
2005
2003
1986
1985
1984
1983
1982
2001
2000
1998

Results

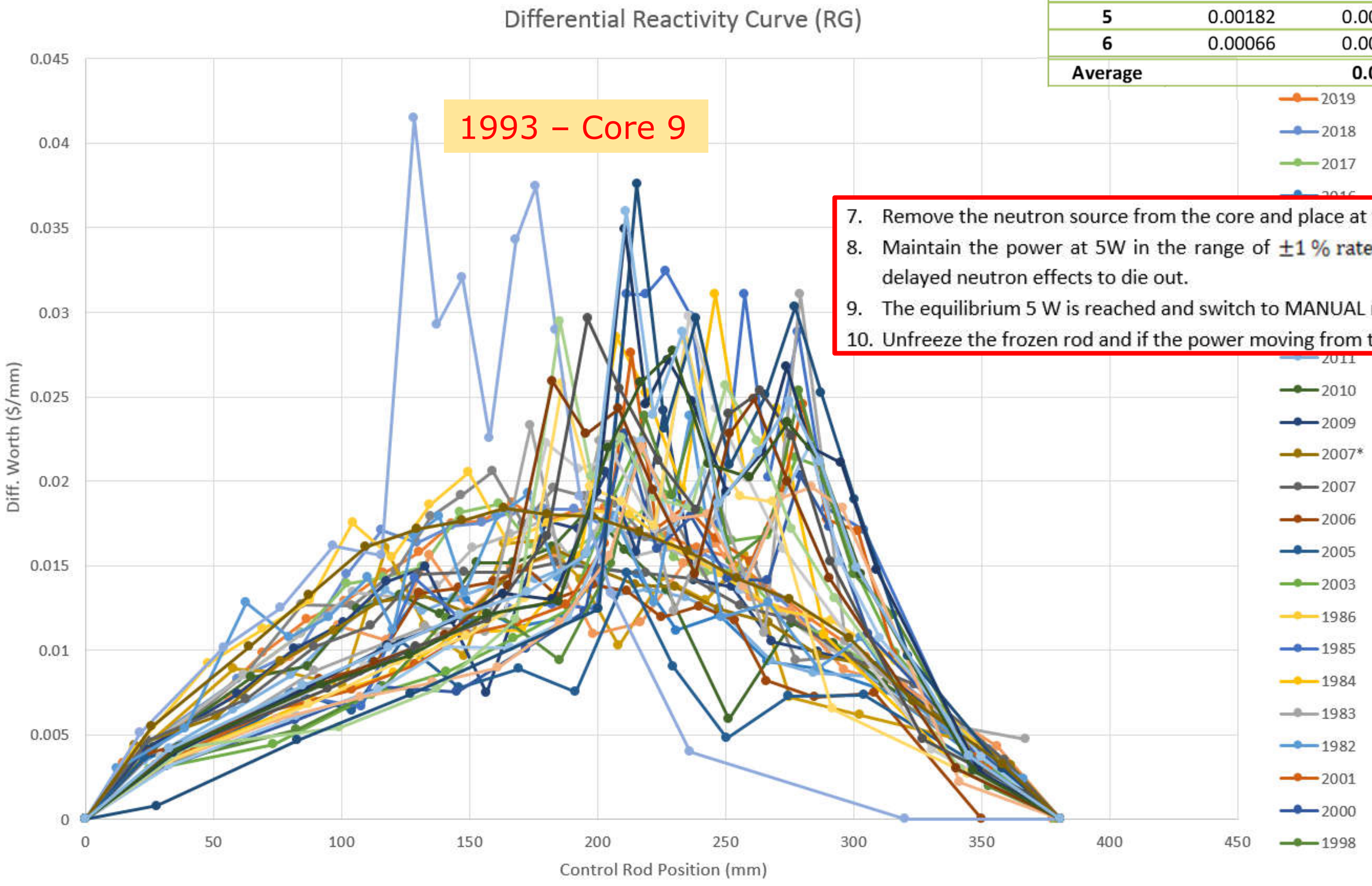


1993 – Core 9

2005 – Core 11

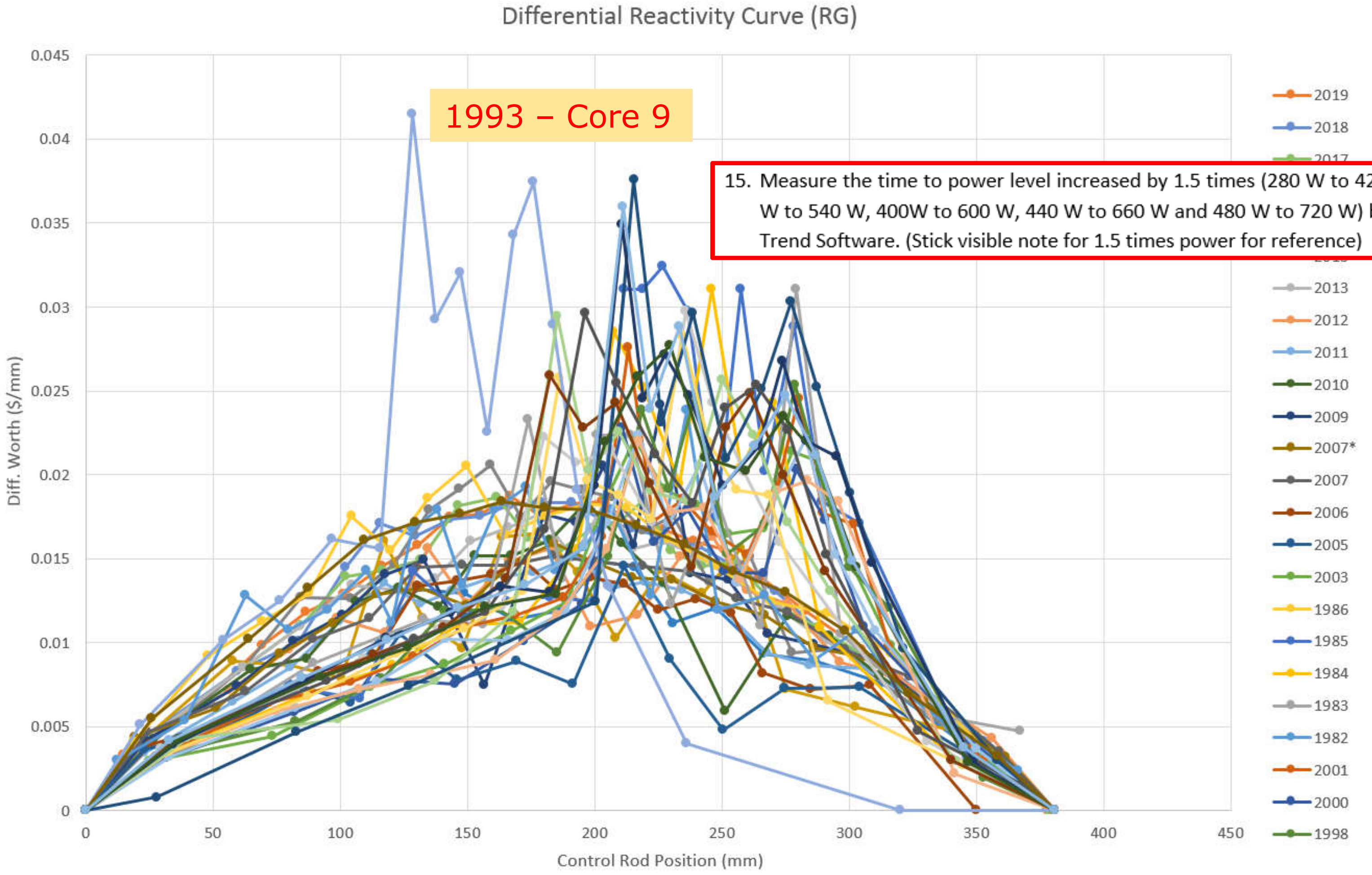
Results

Group	Yield, Neutron per Fission	Fraction, β_i	Half-life, $t_{1/2}$ (s)	Decay constant, λ_i (s^{-1})
1	0.00052	0.000215	55.72	0.0124
2	0.00346	0.001424	22.72	0.0305
3	0.0031	0.001274	6.22	0.111
4	0.00624	0.002568	2.30	0.301
5	0.00182	0.000748	0.614	1.14
6	0.00066	0.000273	0.230	3.01
Average		**0.0065**		**0.008 (near criticality)**



7. Remove the neutron source from the core and place at the storage rack.
8. Maintain the power at 5W in the range of ±1 % rate for 5 minute in AUTO mode for all the delayed neutron effects to die out.
9. The equilibrium 5 W is reached and switch to MANUAL mode.
10. Unfreeze the frozen rod and if the power moving from the equilibrium, repeat step 8 to 9.

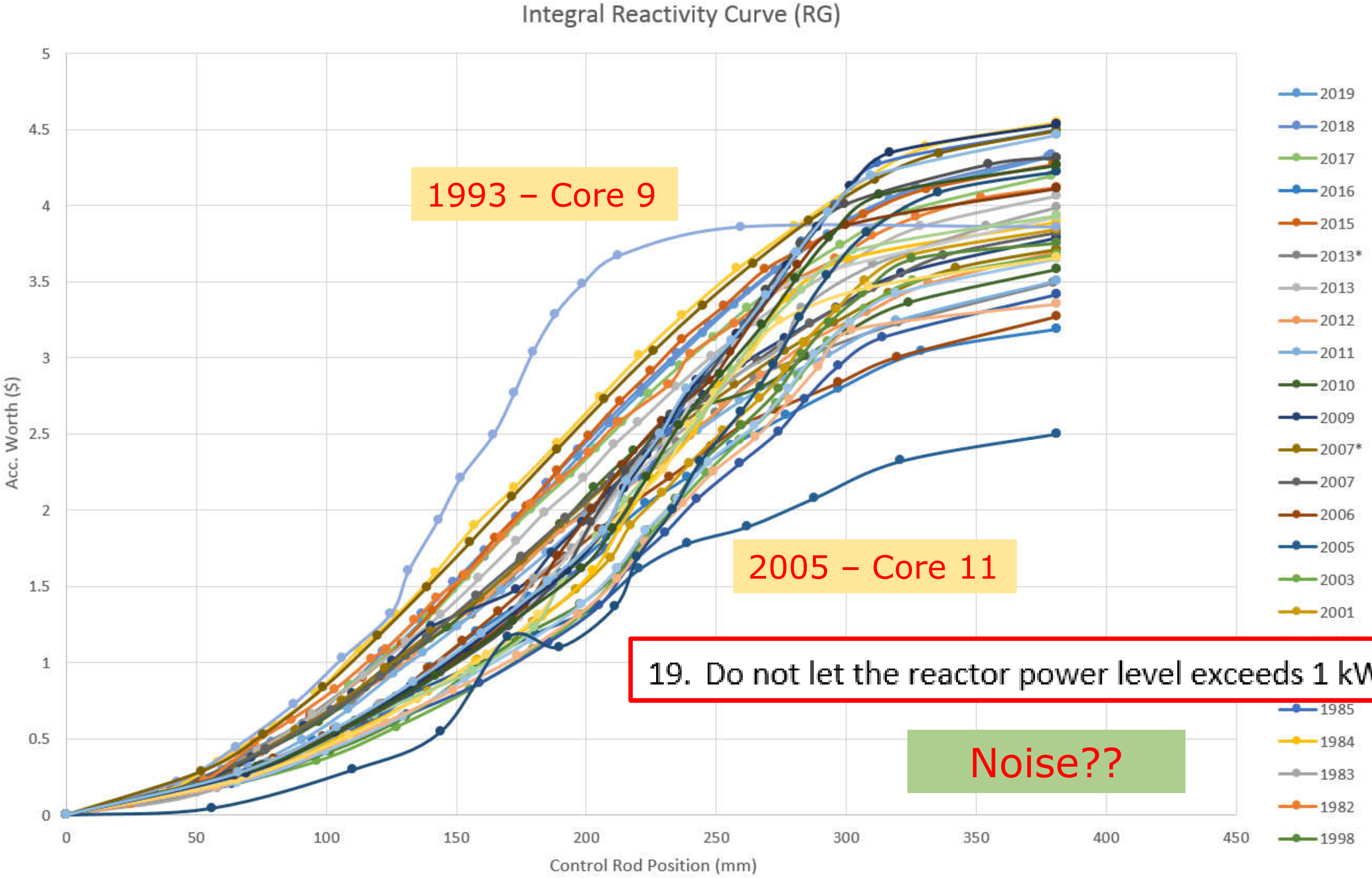
Results



1993 – Core 9

15. Measure the time to power level increased by 1.5 times (280 W to 420 W, 320W to 490 W, 360 W to 540 W, 400W to 600 W, 440 W to 660 W and 480 W to 720 W) by using stop watch or RTP Trend Software. (Stick visible note for 1.5 times power for reference)

Results



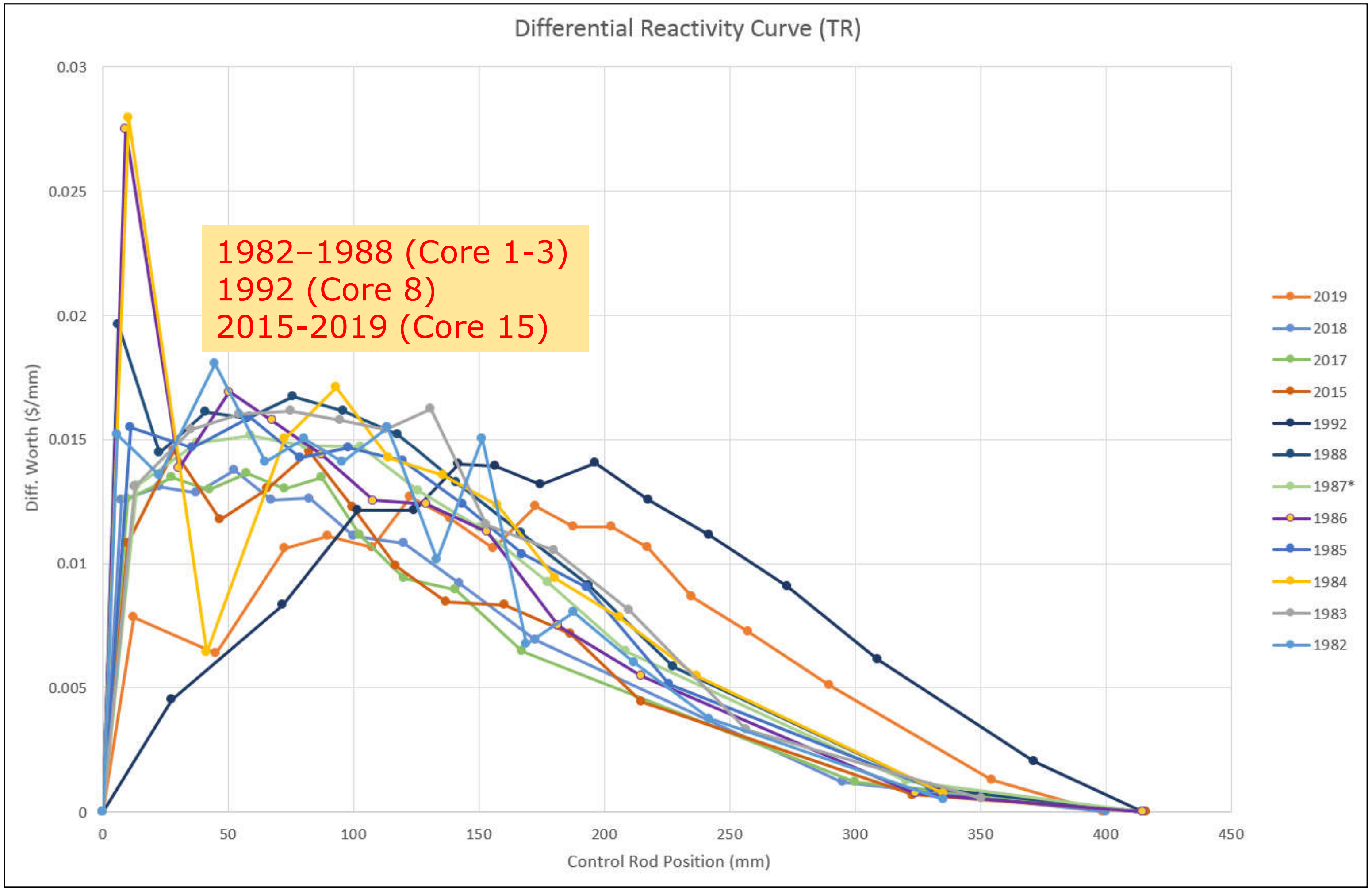
1993 – Core 9

2005 – Core 11

19. Do not let the reactor power level exceeds 1 kW.

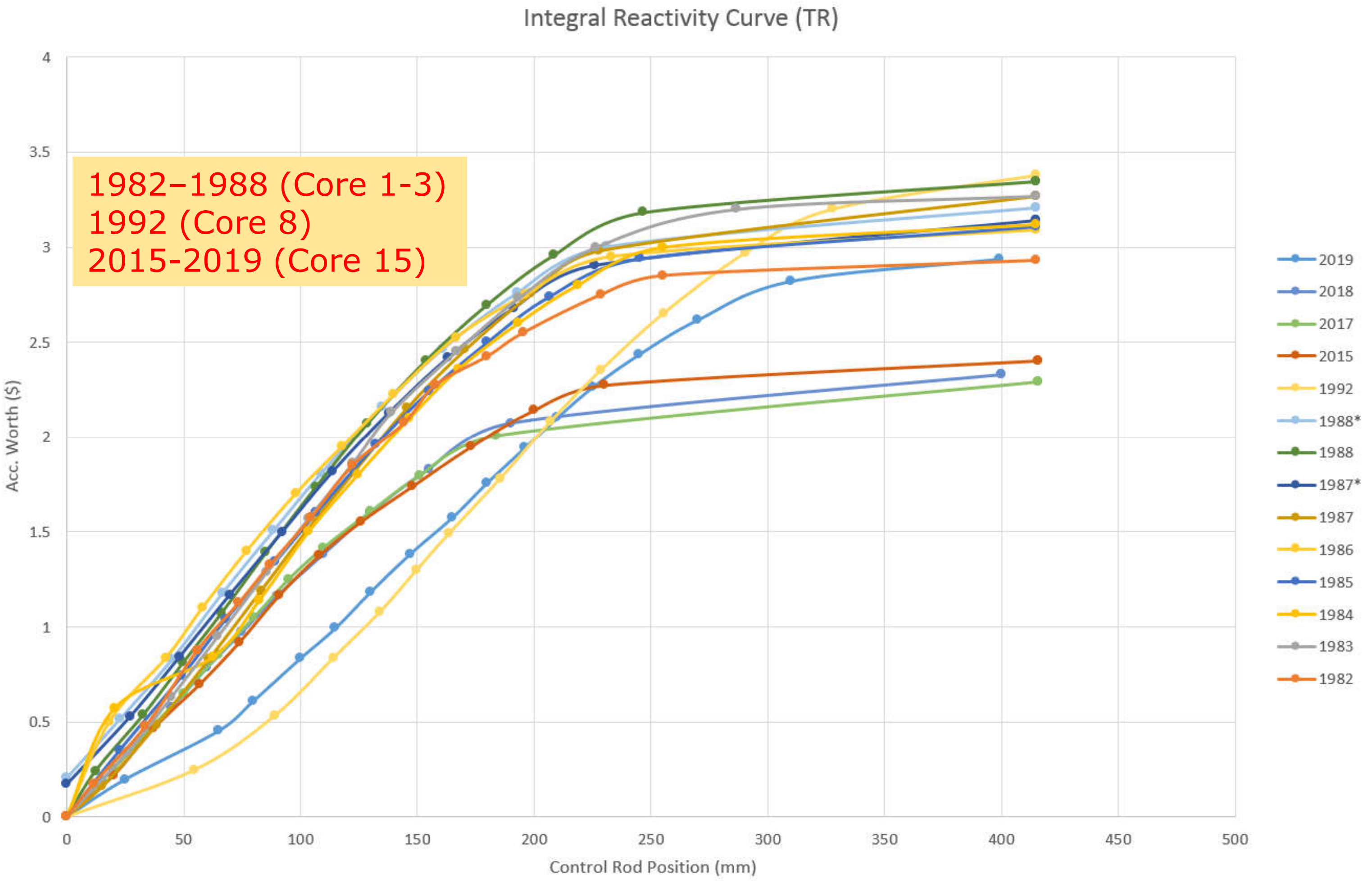
Noise??

Results



1982–1988 (Core 1-3)
1992 (Core 8)
2015-2019 (Core 15)

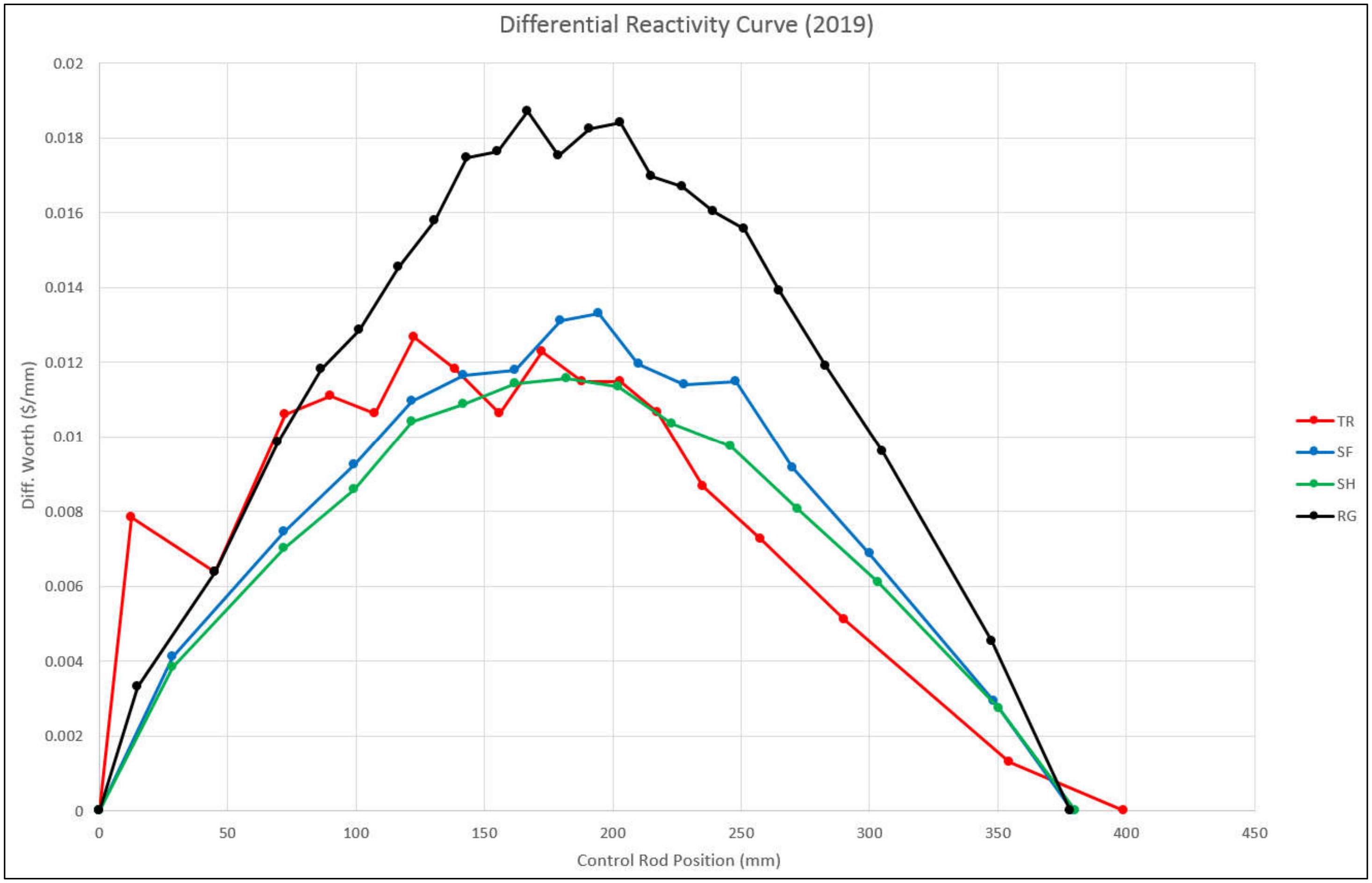
Results



Integral Reactivity Curve (TR)
Acc. Worth ($)
0
0.5
1
1.5
2
2.5
3
3.5
4
Control Rod Position (mm)
0
50
100
150
200
250
300
350
400
450
500
1982–1988 (Core 1-3)
1992 (Core 8)
2015-2019 (Core 15)
2019
2018
2017
2015
1992
1988*
1988
1987*
1987
1986
1985
1984
1983
1982

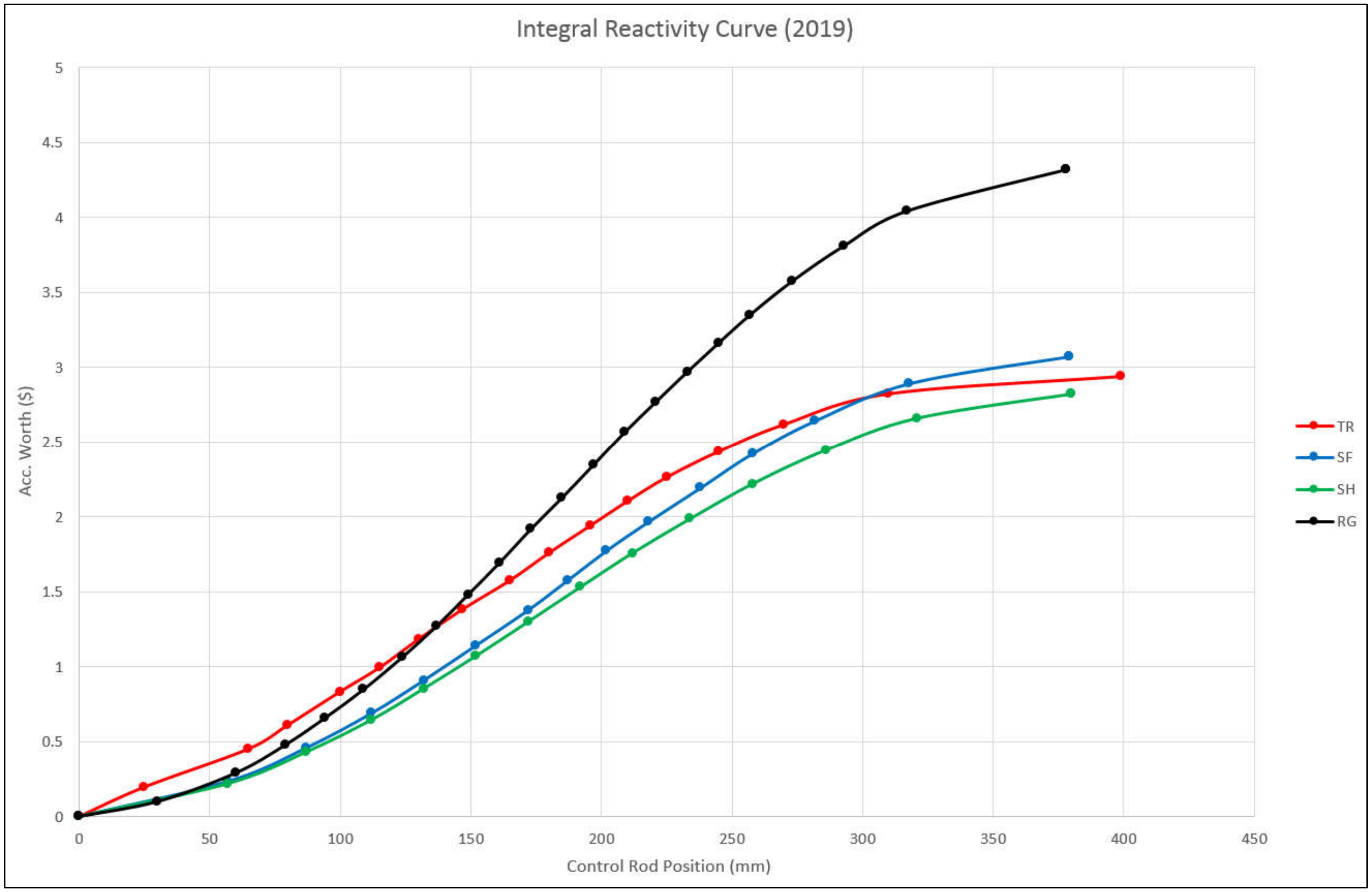
Results

RTP CRW Database 1982-2019



Results

RTP CRW Database 1982-2019



Conclusion

- This RTP CRW calibration database is important for:

  Ease of updating data;

  Security of data;

  Data integrity;

  Data analysis.

- This important as part of RTP core management analysis to support the improvement of in-core management strategy to ensure safe operation and for better utilization.

Reference

- *Safety Analysis Report* (SAR) *for* RTP, 2014
- RTP CRW Annual Maintenance Report 2019
- RTP-JILID7, Procedure 8.0 Control rod calibration
- IMS-T-07 Revision: 1.0 (2014) Tentukuran Rod Kawalan
- TP-RPT-01 Rev. No.: 0 RPT Proc+edure of Rod Worth Measurement

Thank You

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