



ANTONY SU
PROJECT MENTOR
TOM QUIRK

TLD Data Mining

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Thermoluminescent Dosimeters (TLDs)



CaF₂ chips doped with manganese.

Electrons jump to higher energy states due to radiation and remain trapped.

Electrons drop down when heated, releasing the photons and glow.

A reader heats the chips and records the light emitted, translates to dose.

Data

- 20 years worth of TLD readings (221,045 individual readings)
 - Microsoft Access Database
 - Text Files
 - Excel Files
- 4 Machines
- 19 Batches

15464 203.61328125 700.1953125
15414 205.56640625 700.1953125
14953 208.0078125 700.1953125
14829 209.47265625 700.1953125
14782 211.9140625 700.1953125
14612 213.8671875 700.1953125
14619 215.8203125 700.1953125
14426 217.7734375 700.1953125
14430 219.7265625 700.1953125
14313 221.6796875 700.1953125
14924 223.14453125 700.1953125
14928 225.5859375 700.1953125
15308 227.5390625 700.1953125
15842 229.4921875 700.1953125
16656 231.4453125 700.1953125
17239 233.3984375 700.1953125
18417 235.3515625 700.1953125
19820 237.3046875 700.1953125
20921 239.2578125 700.1953125
23142 241.2109375 700.1953125
24843 243.65234375 700.1953125
27462 245.1171875 700.1953125
30471 247.0703125 700.1953125
33389 249.51171875 700.1953125
37120 251.46484375 700.1953125
41466 253.41796875 700.1953125
46924 255.37109375 700.1953125
51948 257.32421875 700.1953125
57823 259.27734375 700.1953125

17792 202.1484375 700.1953125
17766 204.1015625 700.1953125
17586 206.0546875 700.1953125
17833 208.0078125 700.1953125
17853 209.9609375 700.1953125
17433 211.9140625 700.1953125
17139 213.8671875 700.1953125
17370 215.8203125 700.1953125
17566 217.7734375 700.1953125
16962 219.7265625 700.1953125
17509 221.6796875 700.1953125
17629 223.6328125 700.1953125
17673 225.5859375 700.1953125
17591 228.02734375 700.1953125
18089 229.98046875 700.1953125
18880 231.4453125 700.1953125
19296 233.3984375 700.1953125
20245 235.83984375 700.1953125
21491 237.79296875 700.1953125
23532 239.74609375 700.1953125
24407 241.69921875 700.1953125
26336 243.65234375 700.1953125
28881 245.60546875 700.1953125
31760 247.55859375 700.1953125
34708 249.51171875 700.1953125
37664 251.46484375 700.1953125
41906 253.41796875 700.1953125
46557 255.37109375 700.1953125
51967 257.32421875 700.1953125
57998 259.27734375 700.1953125

Record											
RunNo	StartDate	StartTime	StopDate	StopTime	Reader	Batch	NumTLDs	StartNum	Comments	Session	
11076	5/17/2019	13:53	5/17/2019	13:53	06	40	6	1	4029331-40293		
11076	5/17/2019	13:53	5/17/2019	13:53	07	40	32	1	4029182-40292		
11075	5/17/2019	13:12	5/17/2019	13:12	06	40	4	3	4029325-40293		
11075	5/17/2019	13:12	5/17/2019	13:12	06	40	6	1	4029325-40293		
11075	5/17/2019	13:12	5/17/2019	13:12	07	40	32	1	4029151-40291		
11074	5/17/2019	12:15	5/17/2019	12:15	07	40	32	1	4029119-40291		
11074	5/17/2019	12:15	5/17/2019	12:15	06	40	6	1	4029319-40293		
11073	5/17/2019	11:06	5/17/2019	11:06	06	40	6	1	4029313-40293		
11073	5/17/2019	11:06	5/17/2019	11:06	07	40	32	1	4029087-40291		
2184	3/21/2019	14:24	3/21/2019	15:35	06	40	4	1	9.884E+1 Gy(Ca		
2184	3/21/2019	14:24	3/21/2019	15:35	07	40	4	1	9.884E+1 Gy(Ca		
11072	5/16/2019	15:49	5/16/2019	15:49	06	40	6	1	4029307-40293		
11072	5/16/2019	15:49	5/16/2019	15:49	07	40	32	1	4029055-40290		
11071	5/16/2019	13:07	5/16/2019	13:07	07	40	18	14	4029023-40290		
11071	5/16/2019	13:07	5/16/2019	13:07	06	40	6	1	4029301-40293		
11071	5/16/2019	13:07	5/16/2019	13:07	07	40	32	1	4029023-40290		
Controls	5/4/2019	8:39	5/4/2019	12:39	07	40	8	1	4018830-40188		
7B	5/4/2019	8:39	5/4/2019	12:39	07	40	20	26201	4026201-40262		
8	5/4/2019	13:00	5/5/2019	4:00	06	40	64	26221	4026221-40262		

Questions

1. Fading Effect
2. Statistics on Readings (Control Chart)
3. Distribution of Readings



Fading

Methodology

Queried for “check” in comments

Record						
e	StopTime	Reader	Batch	NumTLDs	StartNum	Comments
/2014	13:42 03	33	33	18	1	TLDs # 1-6: 0914-1128
/2014	13:42 03	33	33	18	1	
/2014	12:37 03	33	33	2	39	High Dose 204
/2014	12:37 03	33	33	2	39	High Dose 204
/2014	10:00 03	33	33	2	37	Low Dose 142
/2013	13:45 03	33	33	3	1	Reader Checks, 10.00 krad
/2014	12:19 03	33	33	4	13	Case B
/2014	10:49 03	33	33	4	9	Case B
/2014	10:14 03	33	33	4	5	Case B
/2014	9:43 03	33	33	4	1	Case B
/2014	14:23 03	33	33	4	1	Stack, #13 (4 ea.)
/2014	14:23 03	33	33	4	1	Stack, #13 (4 ea.)
/2014	14:23 03	33	33	48	1	Stack, #1-12 (4 ea.)
/2014	14:23 03	33	33	3	13	TLDs # 13,14,15
/2014	9:50 03	33	33	8	1	
/2014	11:30 03	33	33	8	1	
/2014	10:15 03	33	33	2	35	Low Dose 142
/2013	13:45 03	33	33	3	1	Reader Checks, 10.00 krad
.....		..	..	-	..	

Methodology

Removed dose not ~10kRad

Removed non-reader checks

Batch	NumTLDs	StartNum	Comments
39	1	1	functional check
39	1	1	functional check
39	1	1	functional check
39	1	1	functional check
39	1	1	functional check
39	2	1	functional check
39	1	1	functional check
39	2	1	functional check
39	1	1	functional check
39	1	1	functional check
39	1	1	functional check

Methodology

Unusual TLD numbers (>8)

DailyChecks

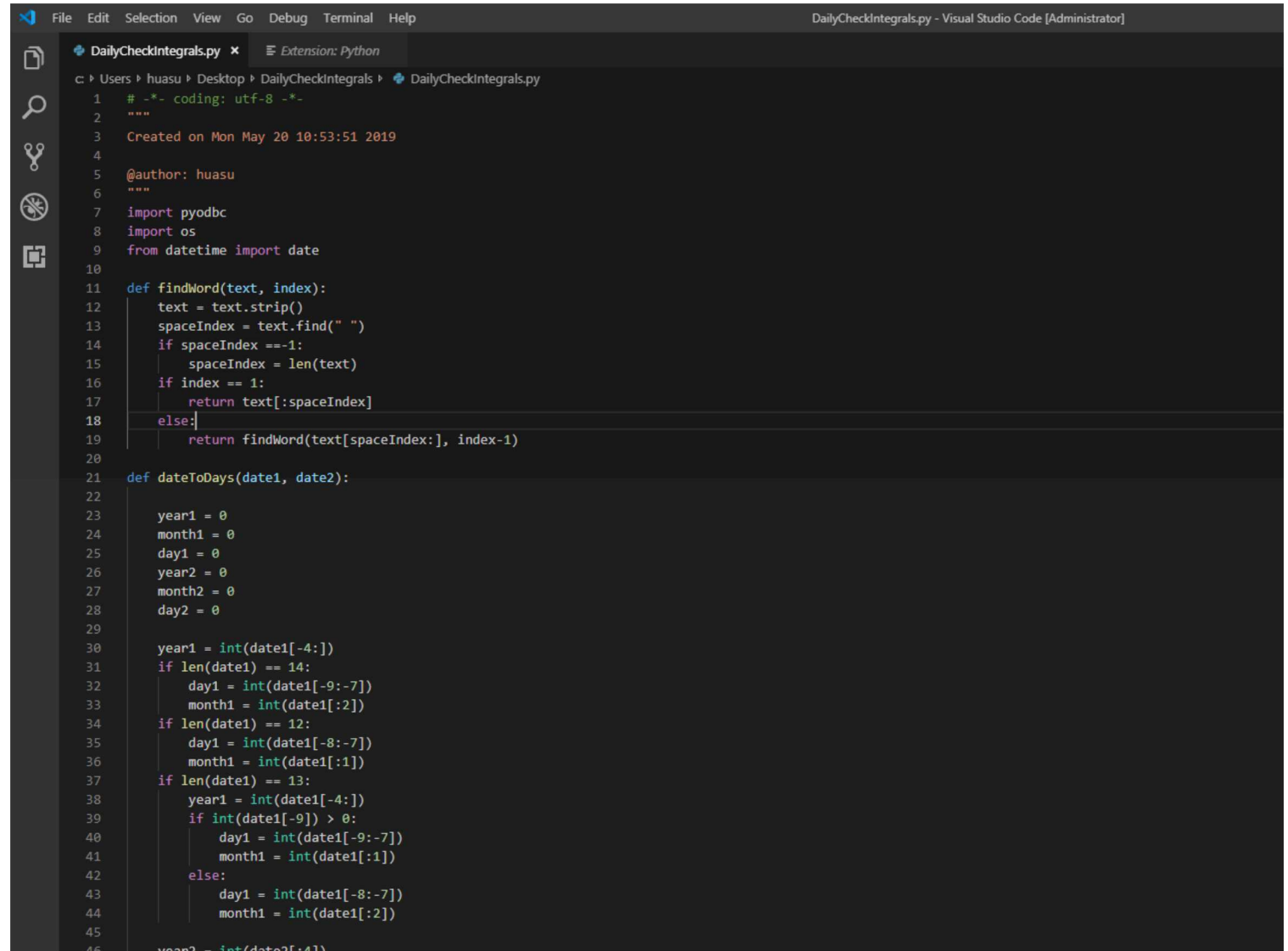
date ▾	StopTime ▾	Reader ▾	Batch ▾	NumTLDs ▾	StartNum ▾
03/2009	14:10	03	30	96	1
11/2016	14:06	01	36	8	1
03/2012	11:56	01	32	3	1
03/2012	11:56	01	32	3	1
03/2012	11:56	01	32	3	1
03/2012	11:56	01	32	3	1
03/2012	11:56	03	32	3	1
03/2012	11:56	03	32	3	1
03/2012	11:56	03	32	3	1
03/2012	11:56	03	32	3	1

Methodology

Python to combine MS Access SQL
with text files

Entries Omitted if corresponding text
file not found

New Access database with individual
readings



```
File Edit Selection View Go Debug Terminal Help
DailyCheckIntegrals.py - Visual Studio Code [Administrator]
DailyCheckIntegrals.py x Extension: Python
c:\Users\huasu\Desktop\DailyCheckIntegrals\DailyCheckIntegrals.py
1  -*- coding: utf-8 -*-
2  """
3  Created on Mon May 20 10:53:51 2019
4
5  @author: huasu
6  """
7  import pyodbc
8  import os
9  from datetime import date
10
11 def findWord(text, index):
12     text = text.strip()
13     spaceIndex = text.find(" ")
14     if spaceIndex == -1:
15         spaceIndex = len(text)
16     if index == 1:
17         return text[:spaceIndex]
18     else:
19         return findWord(text[spaceIndex:], index-1)
20
21 def dateToDays(date1, date2):
22
23     year1 = 0
24     month1 = 0
25     day1 = 0
26     year2 = 0
27     month2 = 0
28     day2 = 0
29
30     year1 = int(date1[-4:])
31     if len(date1) == 14:
32         day1 = int(date1[-9:-7])
33         month1 = int(date1[:2])
34     if len(date1) == 12:
35         day1 = int(date1[-8:-7])
36         month1 = int(date1[:1])
37     if len(date1) == 13:
38         year1 = int(date1[-4:])
39         if int(date1[-9]) > 0:
40             day1 = int(date1[-9:-7])
41             month1 = int(date1[:1])
42         else:
43             day1 = int(date1[-8:-7])
44             month1 = int(date1[:2])
45
46     year2 = int(date2[-4:])
```

Methodology

Removed entries with obvious errors

Order of magnitude errors

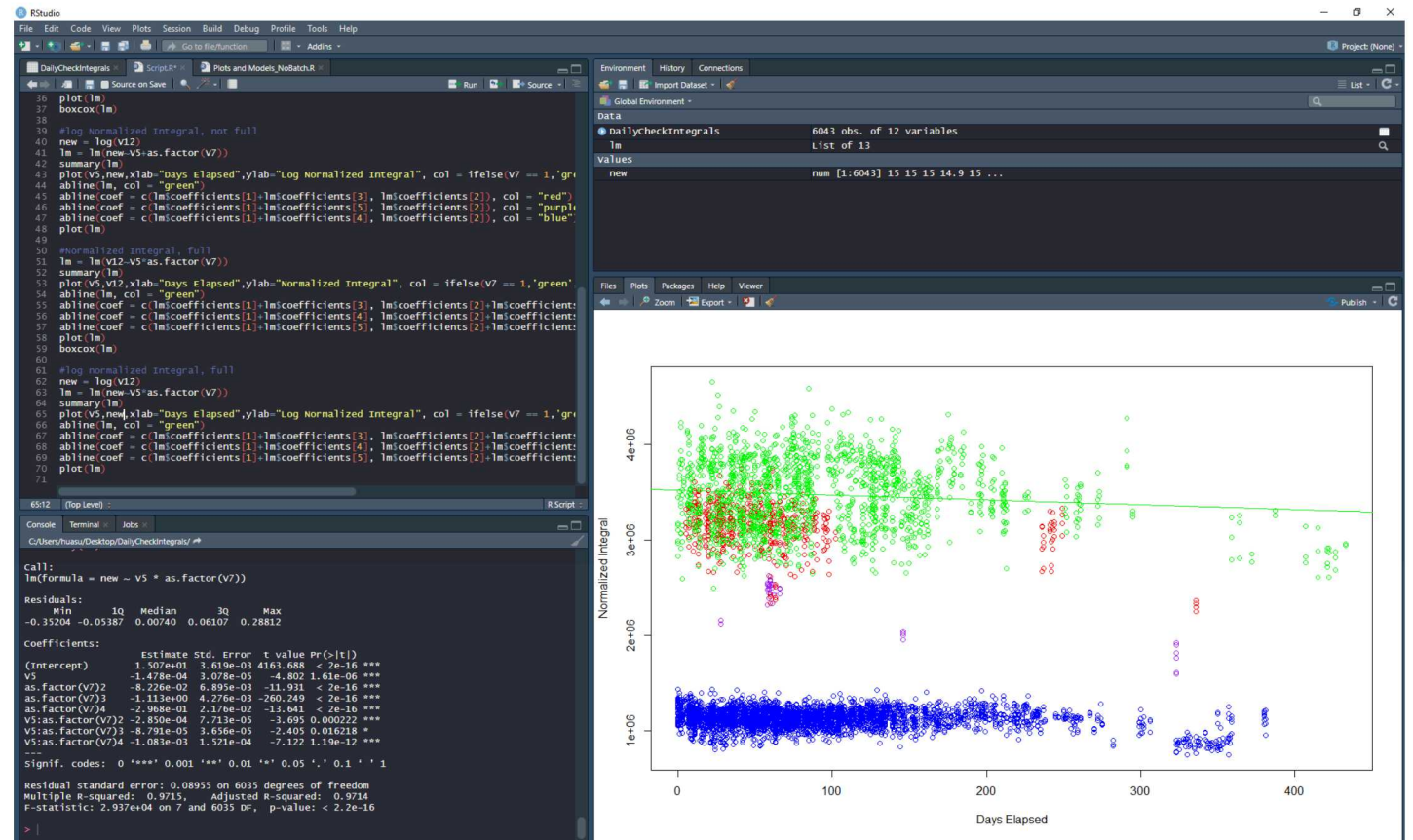
StartDate	StopDate	daysElapsed	Batch	Reader	expectedDo	Dose	Integral
6/18/2007	6/18/2007	25	99 4		100	5488000000	5072851617
6/18/2007	6/18/2007	25	99 4		100	5164000000	4773288588
8/17/2015	8/17/2015	115	99 4		98.83	512600000	464994966
7/23/2012	7/23/2012	143	99 2		100	471000000	426129001
7/23/2012	7/23/2012	143	99 2		100	468100000	423528284
7/23/2012	7/23/2012	143	99 2		100	449300000	406500171
7/23/2012	7/23/2012	143	99 2		100	447100000	404489918
3/13/2013	3/13/2013	29	99 2		100.5	435500000	401809488
3/13/2013	3/13/2013	29	99 2		100.5	417700000	385461492
3/13/2013	3/13/2013	29	99 2		100.5	386100000	356275760
3/13/2013	3/13/2013	29	99 2		100.5	370900000	342217321

Methodology

Used R to analyze data

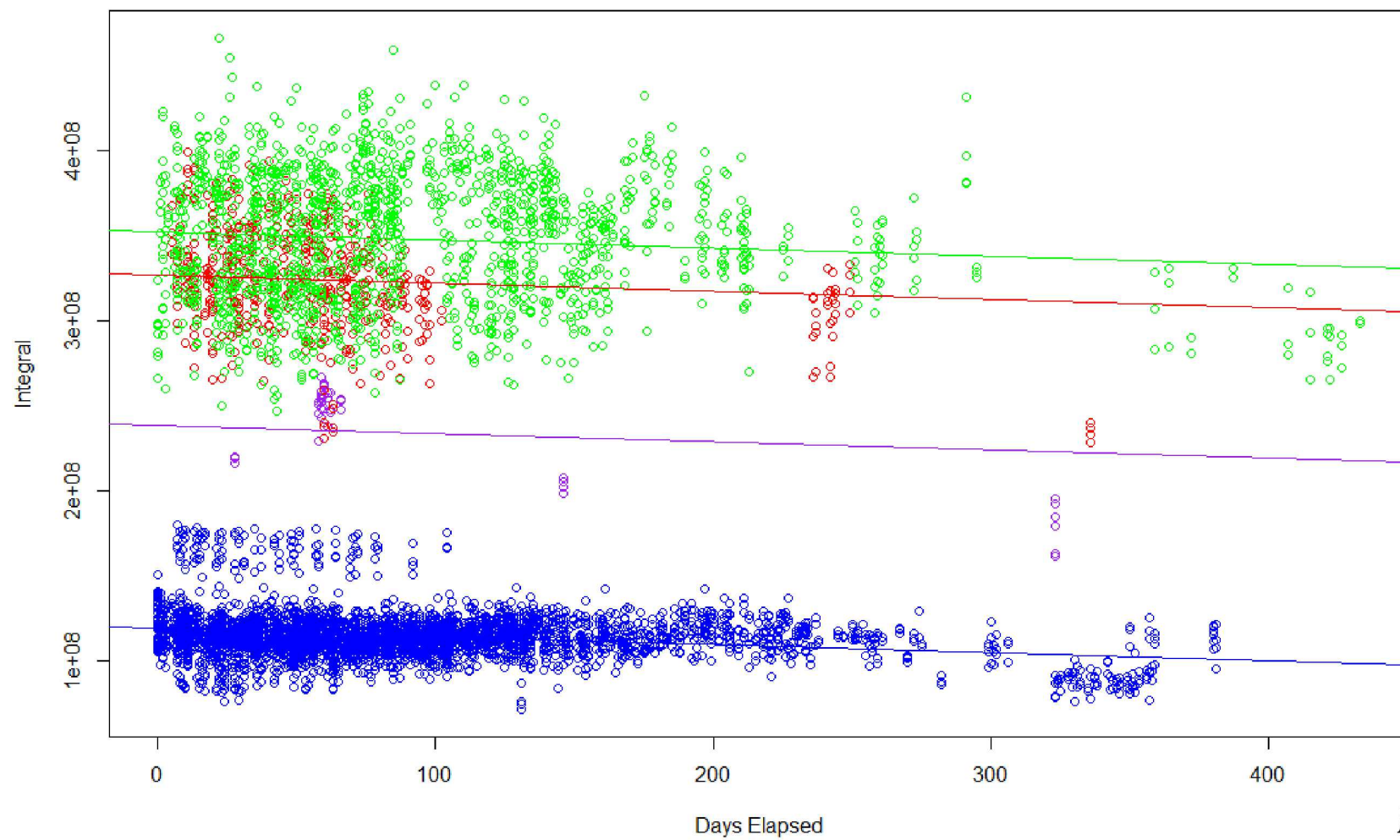
6043 individual daily checks

(9 batches, 4 machines)



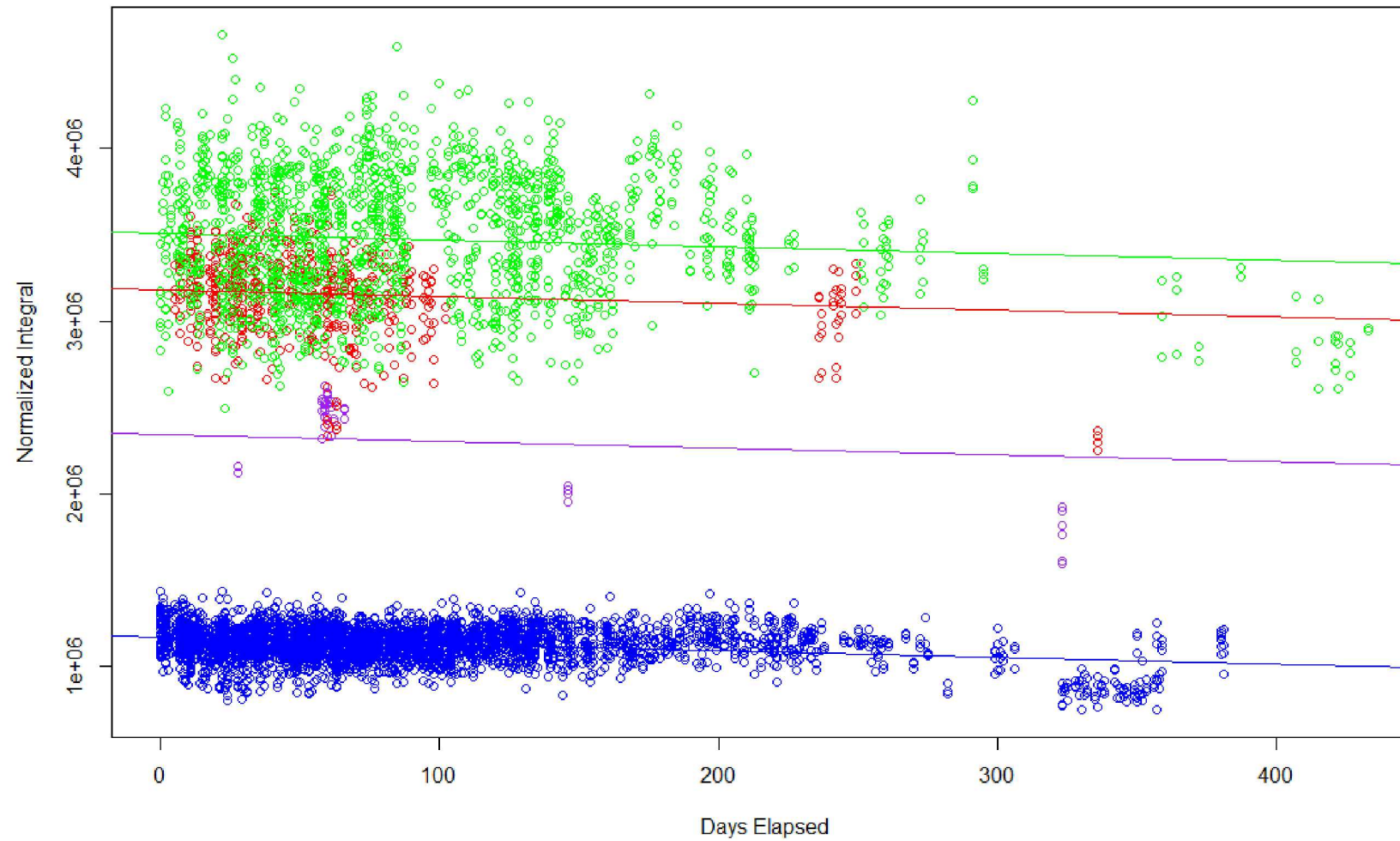


Results



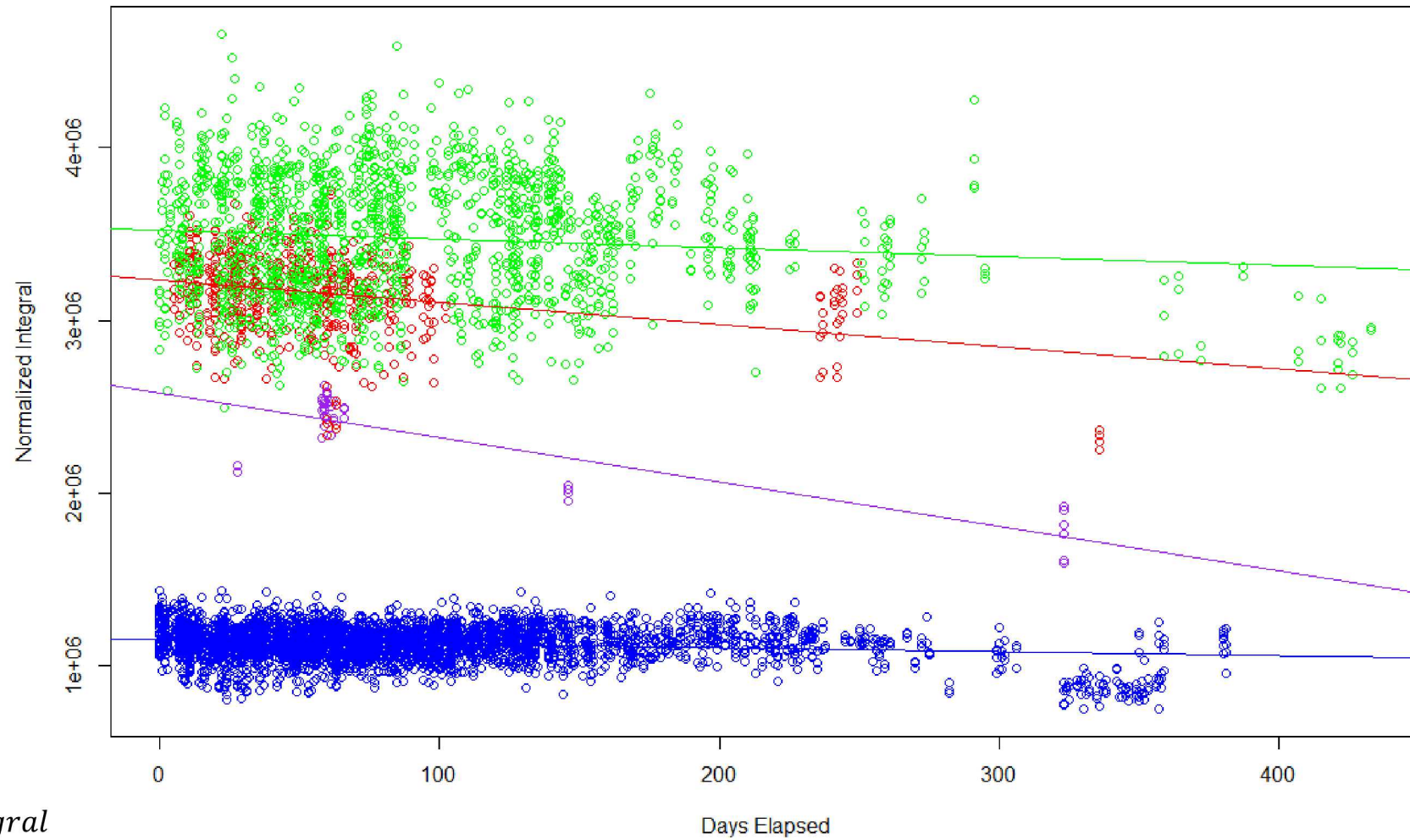
$$R^2 = 0.9548$$

$$Integral = 31996703 - 47894(Days\ Elapsed) - 25373815(Machine2) - 232943793(Machine3) - 113465308(Machine4)$$



$$R^2 = 0.9637$$

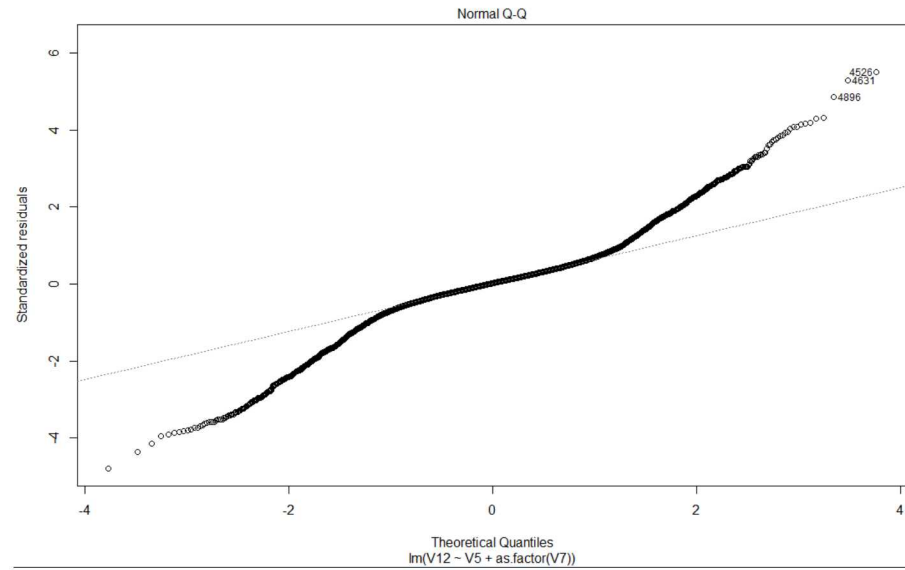
$$\text{Normalized Integral} = 3512000 - 390.6(\text{Days Elapsed}) - 334000(\text{Machine2}) - 2345000(\text{Machine3}) - 1167000(\text{Machine4})$$



$$R^2 = 0.9641$$

Normalized Integral

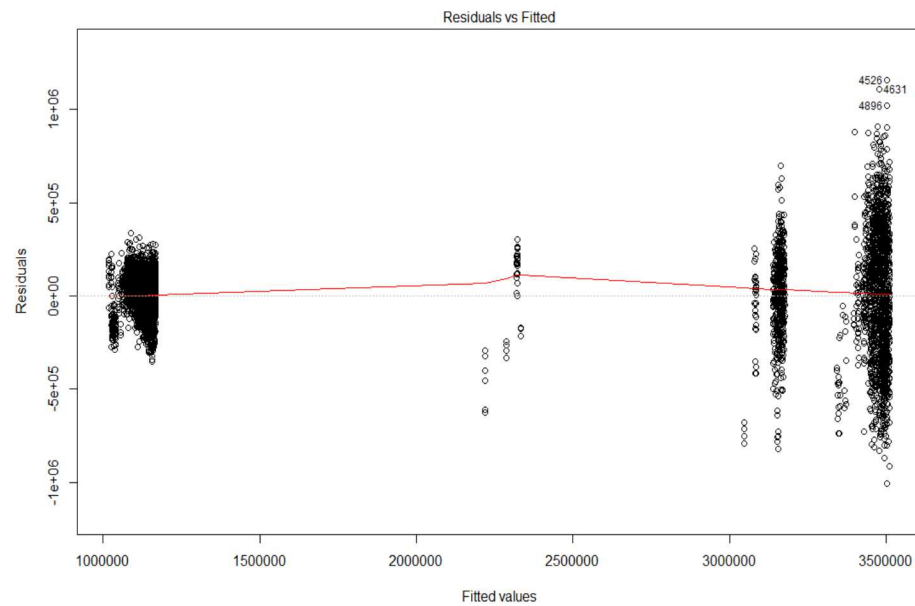
$$= 3522000 - 499.6(\text{Days Elapsed}) - 773.8(\text{Days Elapsed})(\text{Machine2}) + 260.7(\text{Days Elapsed})(\text{Machine3}) - 2072(\text{Days Elapsed})(\text{Machine4}) \\ - 290900(\text{Machine2}) - 2369000(\text{Machine3}) - 943400(\text{Machine4})$$



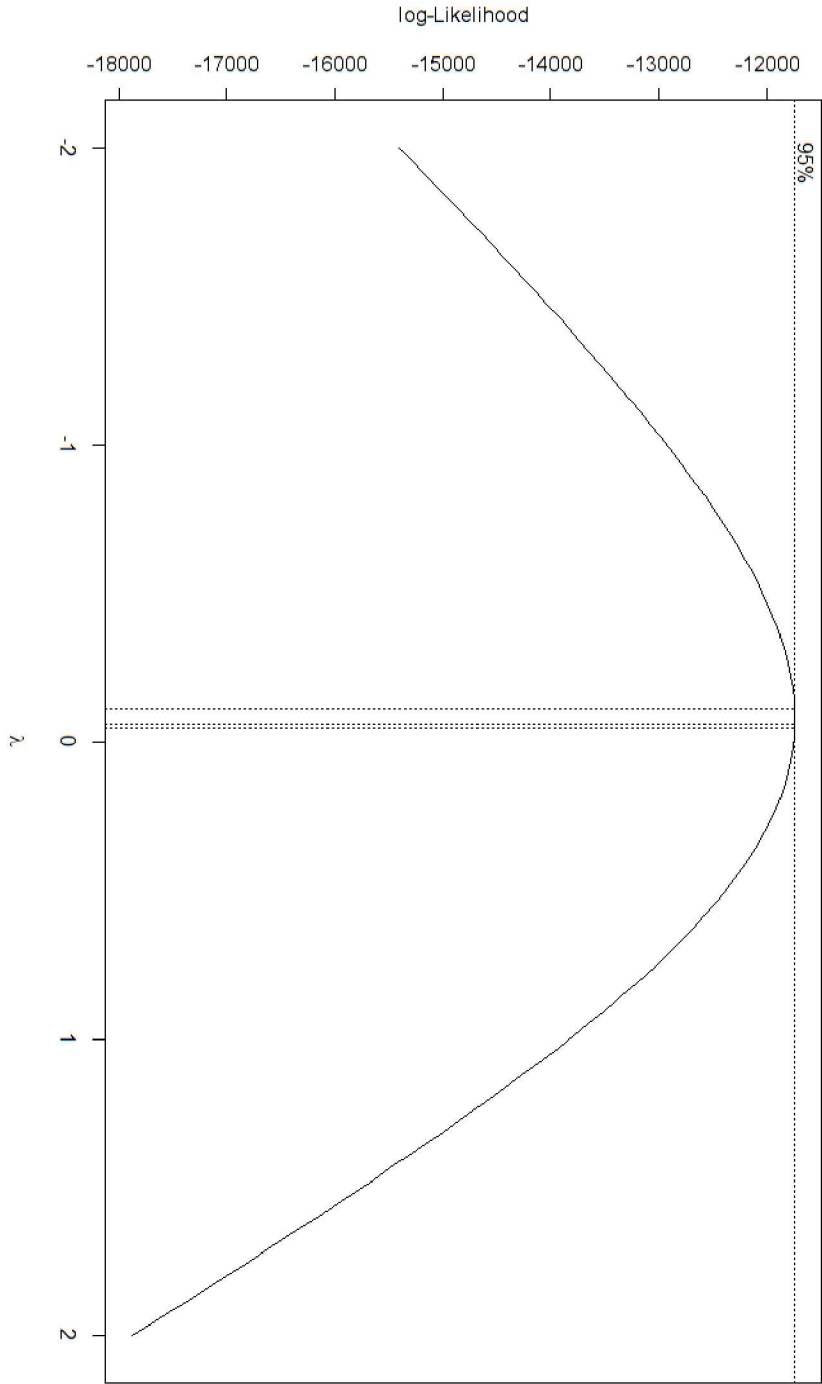
Problem

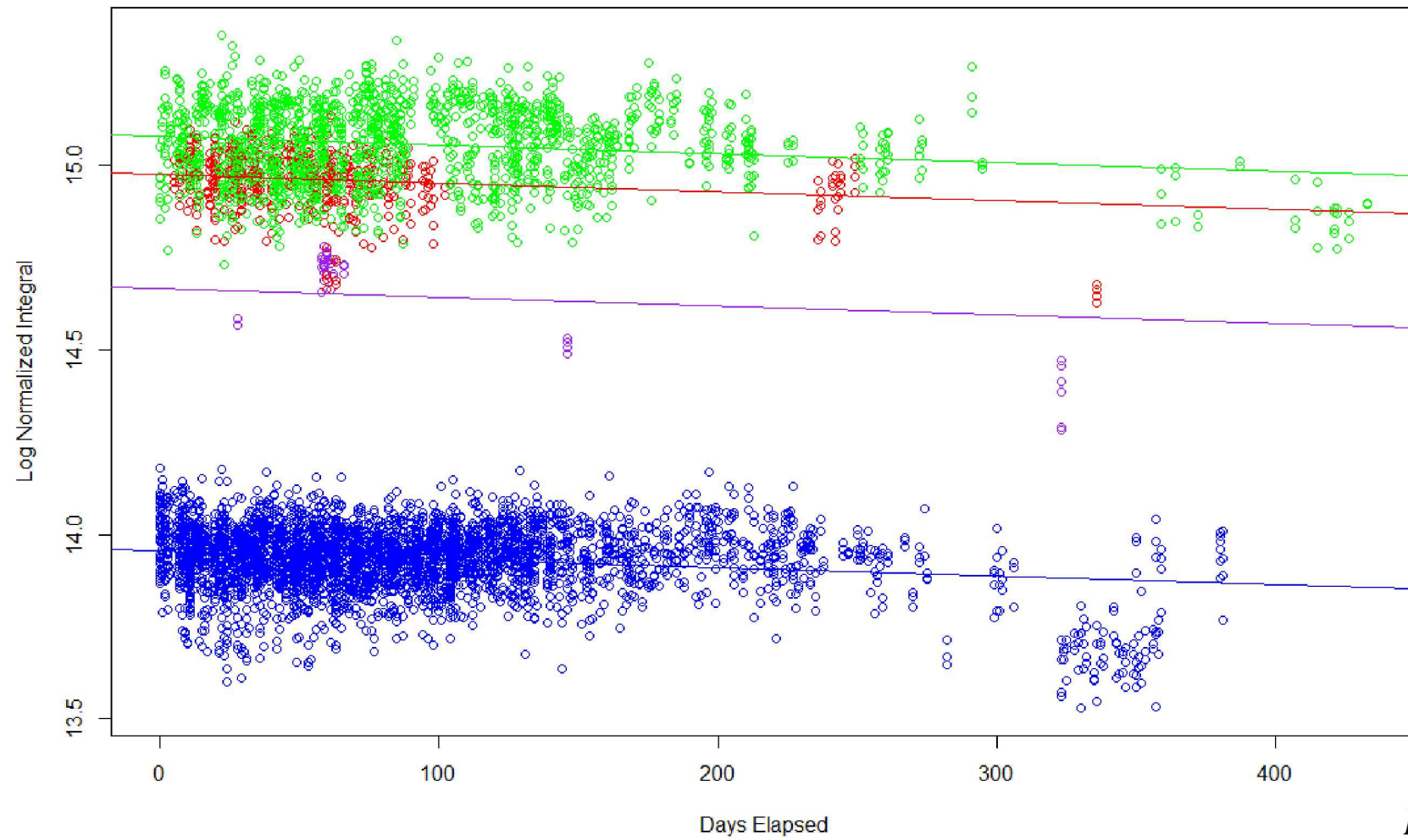
Residuals Not Normal

Linear Model Incorrect



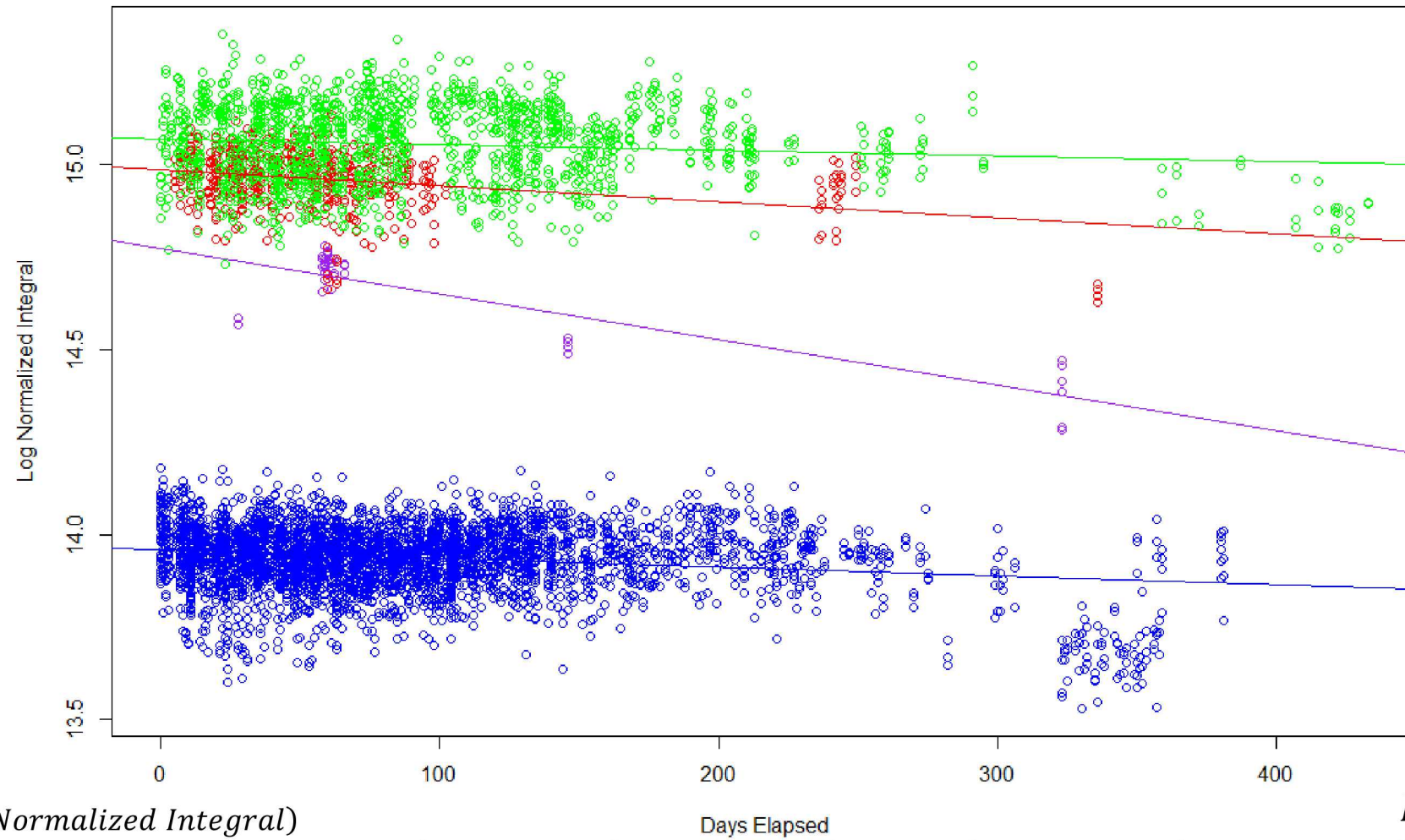
Box-Cox recommends a log transform





$$R^2 = 0.9712$$

$$\text{Log(Normalized Integral)} = 15.08 - 0.0002335(\text{Days Elapsed}) - 0.1022(\text{Machine2}) - 1.121(\text{Machine3}) - 0.4115(\text{Machine4})$$



$$R^2 = 0.9715$$

$$\begin{aligned} \text{Log(Normalized Integral)} &= 15.07 - 0.0001478(\text{Days Elapsed}) - 0.000285(\text{Days Elapsed})(\text{Machine2}) + 0.0000891(\text{Days Elapsed})(\text{Machine3}) \\ &\quad - 0.001083(\text{Days Elapsed})(\text{Machine4}) - 0.08226(\text{Machine2}) - 1.113(\text{Machine3}) - 0.2968(\text{Machine4}) \end{aligned}$$

Conclusions

- Observed Fading effect
 - Likely exponential
- Recommended Formula:
 - $R(t) = R_0 e^{-0.0002335(t)}$, where t is in days



Daily Check Control Chart

			Normalized Dose				
	-3sigma	-1sigma	mean	+1sigma	+3sigma	sigma	
All	0.838026	0.959451	1.020164	1.080877	1.202302	0.060713	
machine 1	0.849305	0.97609	1.039483	1.102876	1.229661	0.063393	
machine 2	0.808638	0.930359	0.9912195	1.05208	1.173801	0.060861	
machine 3	0.847507	0.959897	1.016092	1.072287	1.184677	0.056195	
machine 4	0.628018	0.881989	1.008974	1.135959	1.38993	0.126985	

Results



Distribution

THE USE OF ROBUST ESTIMATORS FOR REDUCING UNCERTAINTIES
IN THERMOLUMINESCENCE DOSIMETER MEASUREMENTS¹

David W. Vehar, Patrick J. Griffin, Charles V. Holm

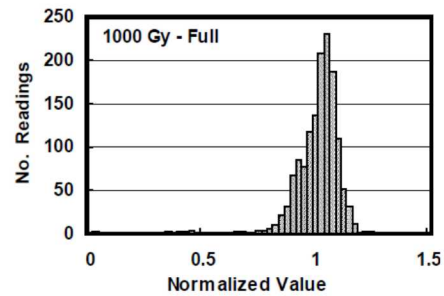
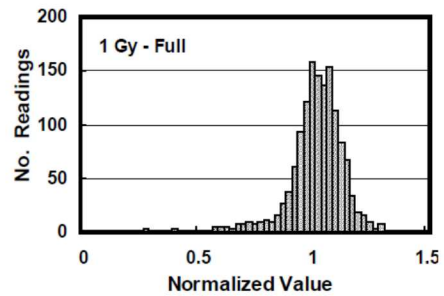
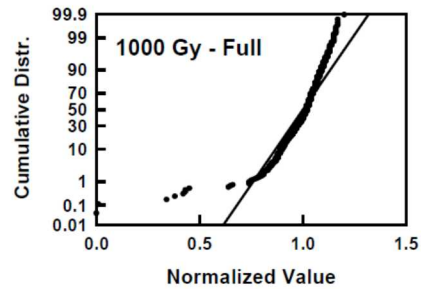
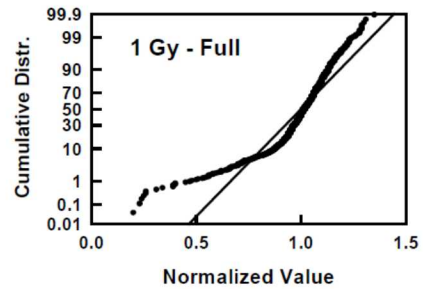
Sandia National Laboratories, P.O. Box 5800

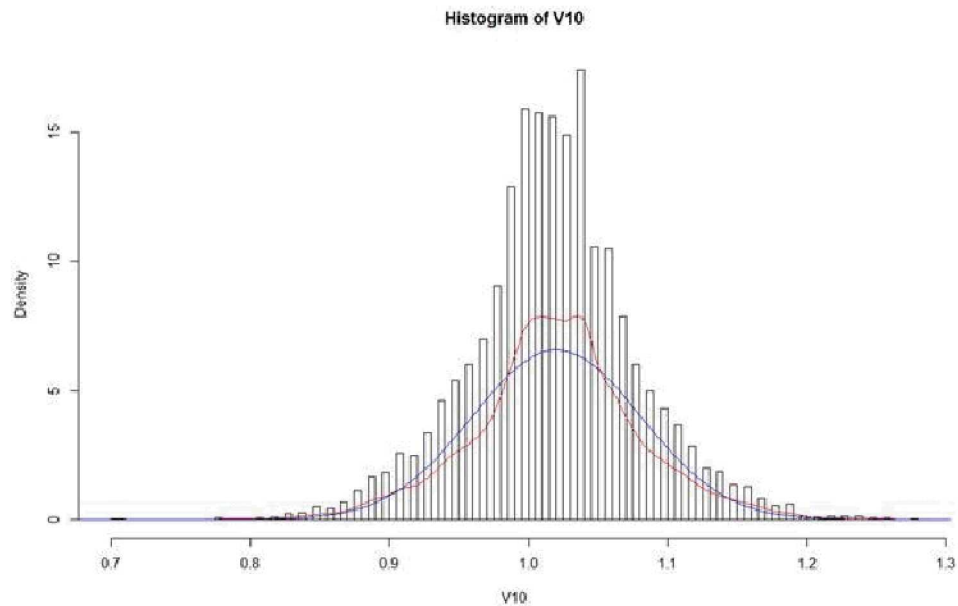
Albuquerque, NM 87185, USA

E-mail: dwvehar@sandia.gov

Past Research

- Not Normally Distributed
- Negatively Skewed





Results

- Not Normally Distributed
- No Negative Skew
- Also not:
 - Lognormal
 - Cauchy
 - Logistic
 - Weibull

One-sample Kolmogorov-Smirnov test

```
data: v10
D = 0.072122, p-value < 2.2e-16
alternative hypothesis: two-sided
```

Anderson-Darling normality test

```
data: v10
A = 27.223, p-value < 2.2e-16
```

```
> skewness(v10)
[1] -0.006713459
```

```
> ks.test(v10, "plnorm", meanlog = 0.01817916, sdlog = 0.05989488)
```

One-sample Kolmogorov-Smirnov test

```
data: v10
D = 0.080911, p-value < 2.2e-16
alternative hypothesis: two-sided
```

```
> ks.test(v10, "pcauchy", location = 1.02014017, scale = 0.03203468)
```

One-sample Kolmogorov-Smirnov test

```
data: v10
D = 0.063708, p-value < 2.2e-16
alternative hypothesis: two-sided
```

```
> ks.test(v10, "pweibull", shape = 16.660814, scale = 1.048745 )
```

One-sample Kolmogorov-Smirnov test

```
data: v10
D = 0.11903, p-value < 2.2e-16
alternative hypothesis: two-sided
```

```
> ks.test(v10, "plogis", location = 1.02015771, scale = 0.03321825)
```

One-sample Kolmogorov-Smirnov test

```
data: v10
D = 0.054938, p-value = 3.331e-16
alternative hypothesis: two-sided
```

Acknowledgements

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Questions