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Analysis of FY 2005 System Operational Failures

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> The long-range contribution of statistics depends not so much upon getting a lot of highly trained statisticians into industry as it does in creating a statistically minded generation of physicists, chemists, engineers, and others who will in any way have a hand in developing and directing the production processes of tomorrow. - ***W.A.Shewhart & W.E.Deming***

Introduction

Brookhaven National Laboratory's Collider-Accelerator complex is comprised of a very large number of sophisticated systems, all of which must be fully functional during the 24/7 operational periods. Although system failures are anticipated due to the complicated nature of the facility, the total failure downtime is typically higher than desired. According to operations data for the Collider-Accelerator FY 2005 facility operating period, 13% of the downtime was due to failures. The failure data for the fiscal year 2005 running period will be analyzed and presented in this report. The data analysis includes identifying specific systems and/or procedures that may be improved in order to limit the overall downtime due to failures.

Description of the Data

Throughout the 24/7 operational running period, the main control room operations coordinator generates a chronological journal of machine status. At any given time, machine status is categorized into one of the following states:

- Unscheduled Shutdown
- Scheduled Shutdown
- Scheduled Maintenance
- Machine Setup
- Machine Development
- Physics Running
- Failure
- Experimental Setup
- Accelerator Physics Beam Experiments

This report, which is limited to analyzing the *Failure* state from the list above, will present a statistical analysis of the number of failures, duration of failures, and total system failure times for the FY 2005 facility operational period. Each operations journal failure entry includes the start time, end time, and specific accelerator and system within the accelerator that has caused the downtime.

Description of the Analysis

The recorded failure data journal provided by the Collider-Accelerator Operations group has been imported into an excel spreadsheet and failure duration times have been computed. Each failure was assigned to one of the three daily shifts according to the time that the failure began. An overall assumption by members of the department is that more failure downtime occurs during the day shift while personnel work to improve systems, but inadvertently cause failures. Analysis of the data herein will prove this notion to be correct or incorrect.

The failures were grouped and analyzed by accelerator and by system to determine if a specific accelerator or system is more prone to failure, and where to concentrate improvement efforts in order to decrease failure downtime. An important note is that the failure data journal entries include cases where multiple failures occurred during the same time period. Therefore, the total failure time calculated by adding the duration time of all failures is not equivalent to the total time that the facility state was *Failure*.

Discussion of the Analysis Results

Total Failures

A total of 1006 failures occurred during the FY 2005 operating period, with a total failure time of 1393.20 hours. The average time per failure was 1.38 hours, while the failure median time was 0.57 hours. Half of the failure times were less than 0.57 hours and half were greater than 0.57 hours.

The histogram of all failures shown in Appendix B (tab Histogram2) indicates that 45%, or 455 of the total 1006 failures occurred in the 0-0.5 hour range. One would therefore expect the average time to be close to the 0.5 hours. However, the histogram shows a severely skewed right distribution instead of a standard normal distribution. Since the distribution is not symmetric, the average will not be close to the median. “The *median* of a histogram is the value with half the area to the left and half to the right” (Friedman, et al 60). The large skewness value of 11.69 also provides an indication that the data are skewed right and that a large difference exists between the average and the median failure times. “Skewed data often occur due to lower or upper bounds on the data” (Histogram Interpretation). Since Failure data must be non-negative, a lower bound of 0 is created, thus causing the skewed right distribution.

Using the standard deviation value in skewed data sets can not be used to accurately describe the percent of occurrences around the mean value. If the standard deviation were used in this case to determine the number of failures greater than 1 sigma from the average, the result would be 1.38 + 3.91 = 5.29 hours. If the data were normally distributed, this would indicate that 84.1% of the failures are less than 5.29 hours, and 15.9% of the failures are greater than 5.29 hours. This is clearly incorrect because according to the histogram bins, only 34 failures, or 3.4% were greater than 5 hours.

A transformation of the data was performed in attempt to create a normal distribution by taking the log10 of each failure time. As shown in Appendix C, the histogram of the logarithm data does in fact follow the normal distribution (tab HistogramLog1). This will now allow statements to be made based on the standard deviation of the log10 data. Using this data, we can state that 68.2% of failure times have occurred in the range of 0.161 hours (9.7 minutes) to

2.035 hours. The 3-bin histogram in Appendix D (tab HistogramCheck) proves that this statement is correct.

Failures by Shift

The notion that more failure downtime occurs during the day shift was found to be incorrect. The results shown in Appendix E (tab ShiftFailureSummary) reveal that of the 1393.2 total system failure hours, 495.9 began during the day shift (8am to 4pm), 402.62 began during the evening shift (4pm to 12am), and 494.68 began during the owl shift (12am to 8am). The total system failure hours for the day shift and owl shift are nearly identical. The total system failure occurrences however, were 26% less than the day shift occurrences – 392 occurrences during the day shift, 325 occurrences during the evening shift and 289 occurrences during the owl shift.

The average duration of failures beginning during the day shift was 1.27 hours, very similar to the average 1.24 hour duration of failures beginning during the evening shift. On the other hand, the owl shift average failure duration was 1.71 hours, or 35% longer than the day shift. This is not surprising since travel time is required when personnel are called during the night to resolve issues, and although some problems are diagnosed via remote login, personnel require time to focus after being awoken during the night.

Shift failures vary significantly between systems, as shown in the Appendix F table. Total Linac failure time was 5.8 hours with 10 failures during the day shift, and 76.5 hours with 10 failures during the owl shift. This is a tremendous difference and should be further studied. Other systems had more failures during the day shift than during the evening and owl shifts. For example the RF system had 118.9 hours with 59 failures during the day shift, 57.5 hours with 40 failures during the evening shift, and 103.6 hours of downtime with 42 failures during the owl shift.

Failures by System

A statistics summary of all failures by system is provided in Appendix F (tab Statistics Summary), including a summary of the system failures categorized by shift. Statistics are also provided for failures of subsystems within each system in Appendix G (tab Statistics All), and a breakdown by shift in Appendix H (tabs Statistics 8am-4pm, Statistics 4pm-12am, Statistics 12am-8am).

Histograms of the failures for each system are provided in Appendix I (tab Histogram by System). The time interval with the greatest number of Polarized Proton failures was in the 0.5 to 1 hour range. For all other systems the time interval with the greatest number of failures was in the range of 0 to 0.5 hours.

Charts comparing failures between systems are provided in Appendix J (tab SystemCharts1). The 84.1% and 97.7% failure charts use the logarithm calculated +1 sigma and +2 sigma values computed in Appendix K (tab Anova by System). A pie chart of system failure counts is provided in Appendix L (tab PieFailureCounts by System), and a pie chart of system failure hours is provided in Appendix M (tab PieFailureHours by System).

Failures by Accelerator

Histograms of the failures for each accelerator are provided in Appendix N (tab Histogram by Accelerator). The time interval with the greatest number of Polarized Proton failures was in the 0.5 to 1 hour range. For all other accelerators the time interval with the greatest number of failures was in the range of 0 to 0.5 hours.

Charts comparing failures between accelerators are provided in Appendix O (tab AcceleratorCharts1). The 84.1% and 97.7% failure charts use the logarithm calculated +1 sigma and +2 sigma values computed in Appendix P (tab Anova by Accelerator). A pie chart of accelerator failure counts is provided in Appendix Q (tab PieFailureCounts by Accel), and a pie chart of accelerator failure hours is provided in Appendix R (tab PieFailureHours by Accel).

RHIC (Relativistic Heavy Ion Collider) has the largest number of failures (200, or 41% of the total failures), and the largest number of total failure hours (324 hours, or 37% of total failure hours). AGS (Alternating Gradient Synchrotron) follows with 125 failures or 26% of the total failures, and 265 failure hours or 30% of the total failure hours. This is not surprising since RHIC is the largest, most complex machine in the facility and AGS is the second largest. Linac however, has a disproportionate number of failure hours (20% of the total) with respect to its size and complexity when compared with the Booster (8% of the total), Tandem (4% of the total) and Polarized Protons (1% of the total).

F-value results

Two Analysis of Variance (ANOVA) calculations were performed – one using the system failure times (Appendix K, tab Anova by System), and another using the accelerator failure times (Appendix P, tab Anova by accelerator). The F-value for the source of variation between system failures is 10.51, while the F-value for the source of variation between accelerator failures is 0.23 (3.07 for logarithm calculation). "When an F test turns out to be significant, we know, with some specified degree of confidence that there is a real difference somewhere among our means" (Philips 138).

This indicates that significant variations in failure times exist between systems, but a fairly small variation in failure times exists between accelerators. This result can also be used to conclude that a focus on limiting system failures may provide greater overall benefit than focusing directly on limiting the failures of each accelerator. This conclusion is very understandable since most systems have common components in each of the accelerators.

Recommendations

Based on the statistical analysis performed in this report, the following actions are recommended:

1. Determine the reason for large Linac failure time during the owl shift. 24/7 on-site support for the Linac should be considered, but may require that additional personnel be trained.
2. Determine why the total Vacuum failure time is more than double during the owl shift as compared to the day shift (43.8 hours during the owl shift, 16.0 hours during the day shift). Cooling/Electrical Services have a similar issue (49.7 hours failure time during the owl shift, 22.4 hours during the day shift). Additional overnight support may be beneficial.
3. Determine why the number of Controls failures is more than two times larger and the total Controls failure time is more than four times larger during the day shift as compared to the owl shift (48 failures totaling 83.2 hours during the day shift, 22 failures totaling 19.1 hours during the owl shift). Controls development may require more stringent procedural control.
4. The Power Supply system and the RF system have caused the most downtime due to failures (351.8 hours and 280.0 hours respectively). These are critical systems where even minor failures cause downtime. Studies should be performed to determine methods for further increasing reliability and robustness of these systems.

5. 38 operator errors caused 36 hours of downtime in FY 2005. With such a complex system, operator errors are not unexpected. Although significant automation has been incorporated into operating the machines, specific causes of recent operator errors should be studied to determine new automation methods that may help prevent downtime.

According to the article Lean Maintenance Maximizes Cost Savings, author Howard Cooper encourages any and all to consider lean maintenance reliability methodologies to "preserve uptime for the systems, machine tools and equipment you have and those you will acquire. It will increase your competitiveness by reducing the cost of doing business" (16). Cooper goes on further to state that eliminating machine downtime and unscheduled maintenance requires preventive maintenance, where in today's world, the cost of downtime is 10-20 times higher than it was thirty years ago. "Too often, maintenance professionals are called upon to fix equipment only after there is a problem" (16). Downtime won't go away until you eliminate the stresses that cause it. Cooper's answer to increasing the reliability and uptime of equipment used can be derived from Six Sigma's Y=f(x) analysis. This function is "an effective way to view the whole concept of true preventative maintenance" (16). Cooper's proof of this function lies with his years at John Deere where he used Y=f(x) and five years of maintenance-log information to determine the seven root causes of most unscheduled downtime. Furthermore, he used Six Sigma's DMAIC (define the problem, measure the problem, analyze how the problem can be eliminated, implement the solution, control the solution to ensure its continuance and improvement) to determine ways to eliminate or protect against each root cause. Working as a consultant, he has helped eliminate root causes in many facilities, resulting in a 70-92% reduction of unscheduled downtime.

We recommend that the Collider-Accelerator explore options for the use of Six Sigma, and further study Howard Cooper's success with statistics to reduce downtime. This is a proven success story that should not go ignored. Application of these techniques at the Collider-Accelerator has real potential for reducing downtime due to failures.

We also recommend that scheduled preventative maintenance be performed efficiently and effectively. One article, Simple Checks help Prevent Complex Problems, emphasizes that "maintenance protects your investment, and helps keep the project on schedule and helps ensure the safety of the operator and other workers." This article also makes a great point – that proper maintenance is critical to ensure machine performance and longer life. "All too often, operators presume that a machine that was working at the end of the previous day is ready to go the following morning. That, unfortunately, is not always true. In order to detect potential problems, daily walk around inspections are highly recommended." It is very important to continually look for fluid leaks, and signs of wear, damage, and loose or missing parts, not just during the one or two times a year that scheduled maintenance occurs – but daily.

Another recommendation is to report machine performance and downtime statistics with online analytical processing (OLAP) technology. According to Wikipedia, OLAP is "an approach to quickly provide the answer to analytical queries that are dimensional in nature." "Databases configured for OLAP employ a multidimensional data model, allowing for complex analytical and ad-hoc queries with a rapid execution of time" (http://en.wikipedia.org/wiki/OLAP).

According to an article from Computerworld, Bill Lang of GAF Materials Corporation has had success with OLAP. Lang began using OLAP to tie reporting systems of numerous different plants together and effectively report their production statistics. The system enabled

Lang and other managers to "analyze shift-by-shift manufacturing efficiency, costs, machine downtime, and other issues" (Stedman), and create an enormous savings. The Collider-Accelerator could introduce OLAP with hopes of similar results, thus easing the accessibility of data related to machine effectiveness, downtime statistics, and failure analysis. These techniques can also be used to link data between other Collider-Accelerator facilities around the world including Fermi National Lab, CERN, Thomas Jefferson and Cebaf. By doing so, users across all servers can track downtime and produce reports and queries on machine effectiveness.

Lastly, there has been success with advanced compressor, combustor, and turbine technology, which have been reducing maintenance costs and downtime while at the same time shortening installation time of equipment. Engineers at ABB, located in Richmond, Virginia, were able to "equip the gas turbines with a single top-mounted silo combustor that allows maintenance personnel to physically enter the combustion chamber for inspection, reducing maintenance downtime" (Valenti). This allows for a reduction in maintenance of compressor blades thus saving them from corrosion problems. Benefits to the Collider-Accelerator through the use of these technological advances may include reduced downtime, increased efficiency, and monetary savings.

Conclusion

Performing a statistical analysis on data as performed and presented in this report is only one part of the process. The more difficult task is determining how to intelligently use the data to determine general and system specific process, procedural, and/or design changes that may be implemented to decrease the total downtime due to failure. "One of the things that makes decision making such a difficult task is that a manager usually does not know what the future holds" (Kroeber and LaForge 8). The Collider-Accelerator at BNL is a very complex facility. Very often a series of seemingly unrelated failures result in large downtime periods. Sometimes, after focusing efforts on one specific issue and resolving a problem, a totally new problem develops.

A detailed analysis of FY 2005 Collider-Accelerator failures and recommendations for decreasing downtime was presented herein. However, analysis of earlier and later operational fiscal years is also important to determine overall failure trends and the affect of changes that are implemented. Analysis followed by enhancements is an ongoing process that will continue for as long as the facility operates.

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Appendix A

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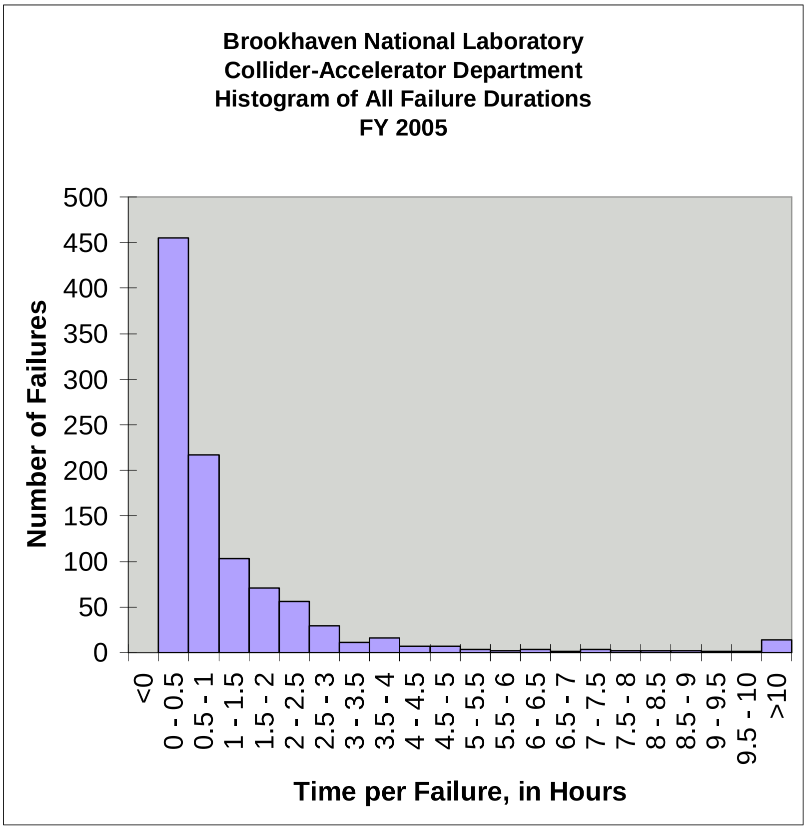
Appendix B – All Failures Histogram

(Excel spreadsheet tab 'Histogram2')

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Histogram of All Failure Durations
(Spreadsheet tab 'Histogram2')

Bin	*Failures*
<0	0
0 - 0.5	455
0.5 - 1	217
1 - 1.5	103
1.5 - 2	71
2 - 2.5	56
2.5 - 3	29
3 - 3.5	11
3.5 - 4	16
4 - 4.5	7
4.5 - 5	7
5 - 5.5	3
5.5 - 6	2
6 - 6.5	3
6.5 - 7	1
7 - 7.5	3
7.5 - 8	2
8 - 8.5	2
8.5 - 9	2
9 - 9.5	1
9.5 - 10	1
>10	14
Total:	1006

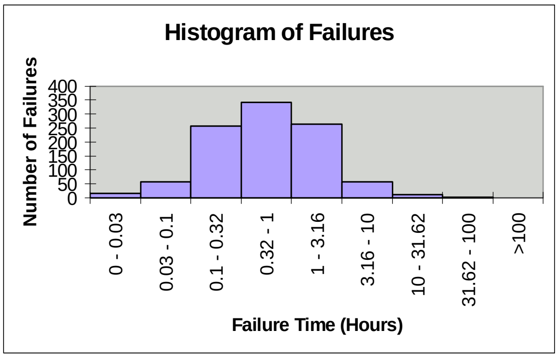


Appendix C – All Failures Log Histogram

(Excel spreadsheet tab 'HistogramLog1')

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Histogram and statistics summary using Log10 of Failure Hours
(Spreadsheet tab 'HistogramLog1')

Hours	*Failures*
0 - 0.03	17
0.03 - 0.1	58
0.1 - 0.32	256
0.32 - 1	341
1 - 3.16	263
3.16 - 10	57
10 - 31.62	11
31.62 - 100	3
>100	0
Total:	1006



Failure Time Statstics using Log(hours)	
Mean	-0.2420404
Standard Error	0.01736066
Median	-0.2466723
Mode	-0.7781513
Standard Deviation	0.5506367
Sample Variance	0.30320078
Kurtosis	0.50214891
Skewness	0.03671256
Range	3.64038205
Minimum	-1.7781513
Maximum	1.86223079
Sum	-243.49269
Count	1006

10^mean	
0.572742685	
10^(mean-sd)	10^(mean+sd)
0.161184341	2.035149

When the log10 is taken of each value, the histogram results in a standard normal distribution.
Probabilities and confidence levels may be calculated using the log data, then converting back to hours.

mean to +/- 1 sigma = 10^(LogMean - LogStdDev) to 10^(LogMean + LogStdDev)
= 10^(-.24204-.550637) to 10^(-.24204+0.550637)
= 0.161 hours to 2.035 hours
= 9.7 min to 2.035 hours

Note that the 10^(LogMean) = 10^(-.24204) = 0.573 hours is now very close to the
0.5667 median value that was computed using the non-log data set.
This is further evidence that the log data for the statistics summary provides more accurate values for probability and confidence level predictions.

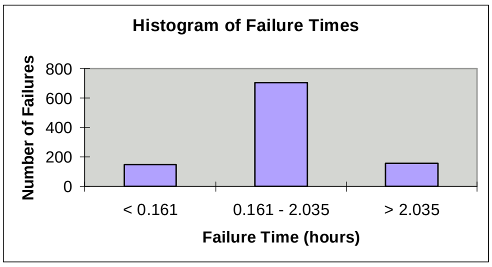
The mean of the log calculation is close to the median, and the skewness value is small,
further indicating that the data are not skewed, and fit into the standard normal curve

Appendix D – Log Histogram Check

(Excel spreadsheet tab 'HistogramCheck')

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Histogram of Failure Hours to check Log calculations
(Spreadsheet tab 'HistogramCheck')

Hours	*Failures*	*Percent*
< 0.161	149	0.148111
0.161 - 2.035	702	0.697813
> 2.035	155	0.154076
Total:	1006	



This is a histogram of the non-log data using the bin values 0.161 and 2.035 to determine if the log statistics produces the expected result.
Note that the number of failures below .161 (-1 sigma) is very close to the number of failures above 2.035 (+1 sigma).
The expected percent of values within the 0.161 to 2.035 range (+/- 1 sigma) is 68%. Considering rounding errors, the 69.8% value determined is very close to the expected value.
We conclude that the log statistics produces the expected result.

Appendix E – Summary of Failures by Shift

(Excel spreadsheet tab 'ShiftFailureSummary')

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Summary of failures beginning during each shift
(spreadsheet tab 'ShiftFailureSummary')

	Day Shift (8am to 4pm)	**Evening Shift (4pm to 12am)**	**Owl Shift (12am to 8am)**	**Total**
Total failure hours	495.90	402.62	494.68	1393.20
Failure occurrences beginning during shift	392	325	289	1006
Average duration of failures (Hours)	1.27	1.24	1.71	

Appendix F – Statistics Summary by System

(Excel spreadsheet tab ‘Statistics Summary’)

Brookhaven National Laboratory Collider-Accelerator Department
FY 2005 Failure Analysis
Statistics Summary of ALL Failures by System
(Spreadsheet tab 'Statistics Summary')

All Failures

System	Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Sum	Count
Power Supplies	1.54	0.14	0.92	0.58	2.07	4.30	20.40	0.02	20.42	351.83	229
Instrumentation	0.92	0.37	0.62	#N/A	0.92	0.84	2.23	0.10	2.33	5.53	6
RF	1.99	0.59	0.50	0.27	7.03	49.37	72.80	0.02	72.82	279.97	141
Vacuum	1.59	0.73	0.36	0.27	4.59	21.04	28.45	0.08	28.53	63.43	40
Cryogenic System	1.30	0.16	1.30	0.13	1.07	1.15	4.67	0.02	4.68	58.57	45
Controls	1.29	0.22	0.72	0.17	2.14	4.58	16.82	0.02	16.83	127.25	99
Access Security	1.19	0.14	1.10	0.92	0.86	0.74	3.50	0.03	3.53	47.73	40
Linac	3.52	1.89	0.43	0.17	11.34	128.58	60.28	0.02	60.30	126.77	36
Polarized Protons	1.09	0.24	0.85	#N/A	0.81	0.65	2.42	0.22	2.63	11.97	11
Tandem	1.32	0.45	0.43	0.58	2.16	4.67	8.53	0.03	8.57	30.47	23
Services - Cooling/Electrical	2.67	0.84	1.51	1.75	4.76	22.63	27.12	0.17	27.28	85.52	32
Complex	0.67	0.06	0.32	0.17	1.12	1.24	11.98	0.02	12.00	204.17	304
All combined	1.38	0.12	0.57	0.17	3.91	15.29	72.80	0.02	72.82	1393.20	1006

Failures occurring during each shift

System	Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Sum	Count
Power Supplies (8am-4pm)	1.38	2.20	0.78	0.58	1.62	2.63	20.40	0.02	20.42	118.27	86
Power Supplies (4pm-12am)	1.75	0.00	1.01	2.50	1.47	2.17	10.93	0.02	10.95	133.00	76
Power Supplies (12am-8am)	1.50	0.87	1.12	0.27	1.03	1.06	7.05	0.08	7.13	100.57	67
Instrumentation (8am-4pm)	0.33	0.00	0.33	#N/A	0.14	0.02	0.00	0.33	0.33	0.33	1
Instrumentation (4pm-12am)	0.92	0.10	0.90	#N/A	0.70	0.49	1.53	0.17	1.70	2.77	3
Instrumentation (12am-8am)	1.22	1.65	1.22	#N/A	0.95	0.89	2.23	0.10	2.33	2.43	2
RF (8am-4pm)	2.02	9.48	0.50	1.07	6.14	37.70	72.80	0.02	72.82	118.92	59
RF (4pm-12am)	1.44	0.01	0.47	0.17	1.63	2.65	11.93	0.05	11.98	57.50	40
RF (12am-8am)	2.47	4.37	0.48	0.08	3.40	11.56	28.27	0.08	28.35	103.55	42
Vacuum (8am-4pm)	0.80	1.34	0.30	#N/A	1.03	1.06	5.98	0.08	6.07	16.00	20
Vacuum (4pm-12am)	0.61	0.04	0.58	#N/A	0.29	0.08	1.12	0.10	1.22	3.65	6
Vacuum (12am-8am)	3.13	7.63	0.43	#N/A	4.59	21.07	28.28	0.25	28.53	43.78	14
Cryogenic System (8am-4pm)	1.24	0.57	1.24	2.22	0.65	0.42	1.97	0.25	2.22	14.85	12
Cryogenic System (4pm-12am)	1.29	0.02	1.17	0.13	1.10	1.22	4.58	0.10	4.68	33.43	26
Cryogenic System (12am-8am)	1.47	1.50	1.30	#N/A	0.71	0.51	3.95	0.02	3.97	10.28	7
Controls (8am-4pm)	1.73	2.41	0.80	0.45	2.13	4.53	16.72	0.12	16.83	83.18	48
Controls (4pm-12am)	0.86	0.02	0.50	0.17	0.83	0.69	7.33	0.08	7.42	24.93	29
Controls (12am-8am)	0.87	0.52	0.71	#N/A	0.47	0.22	2.43	0.02	2.45	19.13	22
Access Security (8am-4pm)	1.15	0.81	1.12	1.20	0.84	0.70	3.42	0.12	3.53	20.68	18
Access Security (4pm-12am)	1.30	0.10	1.04	0.92	0.78	0.61	2.67	0.37	3.03	18.18	14
Access Security (12am-8am)	1.11	0.99	1.03	#N/A	0.59	0.35	2.77	0.03	2.80	8.87	8
Linac (8am-4pm)	0.58	0.80	0.17	0.17	0.52	0.27	2.53	0.08	2.62	5.80	10
Linac (4pm-12am)	2.78	0.00	0.42	0.87	5.83	34.03	35.12	0.02	35.13	44.48	16
Linac (12am-8am)	7.65	19.07	1.26	#N/A	10.04	100.79	60.13	0.17	60.30	76.48	10
Polarized Protons (8am-4pm)	1.51	0.95	1.33	#N/A	0.89	0.78	1.90	0.73	2.63	6.03	4
Polarized Protons (4pm-12am)	1.06	0.21	0.40	#N/A	0.72	0.52	2.05	0.37	2.42	3.18	3
Polarized Protons (12am-8am)	0.69	0.50	0.77	#N/A	0.39	0.15	0.78	0.22	1.00	2.75	4
Tandem (8am-4pm)	1.04	1.63	0.43	#N/A	1.15	1.32	5.17	0.17	5.33	10.38	10
Tandem (4pm-12am)	0.97	0.01	0.42	#N/A	1.02	1.03	4.85	0.03	4.88	6.82	7
Tandem (12am-8am)	2.21	3.50	0.58	0.58	1.87	3.50	8.45	0.12	8.57	13.27	6
Services - Cooling/Electrical (8am-4pm)	1.50	1.39	1.23	#N/A	1.21	1.47	5.40	0.17	5.57	22.43	15
Services - Cooling/Electrical (4pm-12am)	2.67	0.19	1.75	#N/A	1.29	1.65	5.58	0.43	6.02	13.37	5
Services - Cooling/Electrical (12am-8am)	4.14	7.88	1.58	#N/A	4.87	23.70	26.95	0.33	27.28	49.72	12
Complex (8am-4pm)	0.72	1.15	0.33	0.10	0.96	0.93	11.98	0.02	12.00	79.02	109
Complex (4pm-12am)	0.61	0.00	0.26	0.17	0.55	0.31	4.33	0.02	4.35	61.30	100
Complex (12am-8am)	0.67	0.51	0.45	0.17	0.56	0.31	4.92	0.02	4.93	63.85	95

Appendix G – Systems and Subsystems Statistics Summary

(Excel spreadsheet tab 'Statistics All')

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Statistics Summary of All Failures
(Spreadsheet tab 'Statistics All')

System	Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Sum	Count
Power Supplies	1.54	0.14	0.92	0.58	2.07	4.30	20.40	0.02	20.42	351.83	229
AGS/Power Supplies	1.63	0.38	0.58	0.23	3.00	9.00	20.40	0.02	20.42	102.82	63
Booster/Power Supplies	1.26	0.22	0.77	3.88	1.21	1.47	3.75	0.13	3.88	37.88	30
RHIC Injection Power Supplies	1.13	0.20	0.62	0.17	1.06	1.12	3.55	0.10	3.65	30.48	27
RHIC/ Magnets/Power supplies	1.56	0.18	1.17	0.97	1.67	2.78	10.93	0.02	10.95	129.50	83
RHIC Quench Detection/Protection	1.97	0.41	1.22	2.00	2.09	4.38	9.30	0.42	9.72	51.15	26
Instrumentation	0.92	0.37	0.62	#N/A	0.92	0.84	2.23	0.10	2.33	5.53	6
RF	1.99	0.59	0.50	0.27	7.03	49.37	72.80	0.02	72.82	279.97	141
Linac RF	0.77	0.10	0.42	1.07	0.79	0.63	3.20	0.02	3.22	45.60	59
AGS/Booster RF	5.45	2.50	0.55	0.17	14.14	199.91	72.77	0.05	72.82	174.43	32
RHIC/RF	1.20	0.27	0.63	0.67	1.90	3.60	10.72	0.02	10.73	59.93	50
Vacuum	1.59	0.73	0.36	0.27	4.59	21.04	28.45	0.08	28.53	63.43	40
AGS/Booster Vacuum	0.40	0.06	0.28	0.25	0.32	0.10	1.17	0.08	1.25	10.68	27
RHIC Vacuum	4.06	2.12	1.62	0.33	7.64	58.34	28.37	0.17	28.53	52.75	13
Cryogenic System	1.30	0.16	1.30	0.13	1.07	1.15	4.67	0.02	4.68	58.57	45
Controls	1.29	0.22	0.72	0.17	2.14	4.58	16.82	0.02	16.83	127.25	99
Controls Network	0.61	0.15	0.50	#N/A	0.44	0.20	1.13	0.12	1.25	5.48	9
Controls Software	1.05	0.35	0.57	0.72	1.59	2.54	7.63	0.02	7.65	21.95	21
Controls Device Controller/Station/Timing	1.45	0.29	0.75	0.30	2.39	5.73	16.75	0.08	16.83	99.82	69
Access Security	1.19	0.14	1.10	0.92	0.86	0.74	3.50	0.03	3.53	47.73	40
Linac	3.52	1.89	0.43	0.17	11.34	128.58	60.28	0.02	60.30	126.77	36
Polarized Protons	1.09	0.24	0.85	#N/A	0.81	0.65	2.42	0.22	2.63	11.97	11
Tandem	1.32	0.45	0.43	0.58	2.16	4.67	8.53	0.03	8.57	30.47	23
Services - Cooling/Electrical	2.67	0.84	1.51	1.75	4.76	22.63	27.12	0.17	27.28	85.52	32
Complex	0.67	0.06	0.32	0.17	1.12	1.24	11.98	0.02	12.00	204.17	304
Beam Permit System interlock	0.46	0.12	0.25	#N/A	0.32	0.11	0.75	0.17	0.92	3.25	7
Chipmunk failure	0.98	1.78	0.75	0.17	4.70	22.08	72.80	0.02	72.82	6.88	7
Emergency Response/ES&FD/ES&H	1.56	0.24	1.08	0.37	1.63	2.65	9.10	0.12	9.22	70.03	45
Loss Induced Quench	0.78	0.08	0.67	0.98	0.45	0.21	2.22	0.20	2.42	27.32	35
Operator error	0.94	0.16	0.62	0.25	0.98	0.96	4.10	0.03	4.13	35.90	38
Power dip/Weather	1.29	0.62	0.32	0.12	2.70	7.26	11.92	0.08	12.00	24.50	19
Quench Link	0.42	0.07	0.33	0.10	0.37	0.14	1.33	0.02	1.35	11.87	28
Radiation Monitor Interlock	0.20	0.01	0.17	0.17	0.15	0.02	0.98	0.02	1.00	24.42	125
Total:	1.38	0.12	0.57	0.17	3.91	15.29	72.80	0.02	72.82	1393.20	1006

Appendix H – Statistics Summary by Shift

(Excel spreadsheet tabs ‘Statistics 8am-4pm’, ‘Statistics 4pm-12am’, ‘Statistics 12am-8am’)

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Statistics Summary of Failures that Occurred During the Day Shift (8am - 4pm)
(Spreadsheet tab 'Statistics 8am-4pm')

System	Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Sum	Count
Power Supplies	1.38	2.1998	0.78	0.58	1.62	2.63	20.40	0.02	20.42	118.27	86
AGS/Power Supplies	1.71	4.1641	0.58	0.58	2.72	7.41	20.40	0.02	20.42	41.02	24
Booster/Power Supplies	1.38	1.0022	1.34	#N/A	1.01	1.01	3.75	0.13	3.88	19.25	14
RHIC Injection Power Supplies	0.94	1.0704	0.50	#N/A	0.86	0.75	3.55	0.10	3.65	10.33	11
RHIC/ Magnets/Power supplies	1.17	0.5400	1.00	1.00	0.68	0.46	2.70	0.10	2.80	29.18	25
RHIC Quench Detection/Protection	1.54	1.8090	1.11	#N/A	1.38	1.91	6.27	0.60	6.87	18.48	12
Instrumentation	0.33	0.0000	0.33	#N/A	0.14	0.02	0.00	0.33	0.33	0.33	1
RF	2.02	9.4778	0.50	1.07	6.14	37.70	72.80	0.02	72.82	118.92	59
Linac RF	0.74	0.5697	0.50	1.07	0.54	0.29	2.48	0.02	2.50	13.97	19
AGS/Booster RF	5.59	18.7711	0.50	0.50	12.83	164.56	72.70	0.12	72.82	83.82	15
RHIC/RF	0.85	0.7133	0.50	0.13	0.76	0.58	3.57	0.02	3.58	21.13	25
Vacuum	0.80	1.3379	0.30	#N/A	1.03	1.06	5.98	0.08	6.07	16.00	20
AGS/Booster Vacuum	0.31	0.1941	0.23	#N/A	0.20	0.04	0.70	0.08	0.78	3.98	13
RHIC Vacuum	1.72	2.2300	1.62	#N/A	1.71	2.91	5.90	0.17	6.07	12.02	7
Cryogenic System	1.24	0.5677	1.24	2.22	0.65	0.42	1.97	0.25	2.22	14.85	12
Controls	1.73	2.4128	0.80	0.45	2.13	4.53	16.72	0.12	16.83	83.18	48
Controls Network	0.53	0.4559	0.34	#N/A	0.46	0.21	1.12	0.12	1.23	3.20	6
Controls Software	1.74	2.6634	1.03	#N/A	1.70	2.89	7.53	0.12	7.65	13.93	8
Controls Device Controller/Station/Timing	1.94	2.8583	0.92	0.50	2.37	5.59	16.67	0.17	16.83	66.05	34
Access Security	1.15	0.8053	1.12	1.20	0.84	0.70	3.42	0.12	3.53	20.68	18
Linac	0.58	0.8011	0.17	0.17	0.52	0.27	2.53	0.08	2.62	5.80	10
Polarized Protons	1.51	0.9500	1.33	#N/A	0.89	0.78	1.90	0.73	2.63	6.03	4
Tandem	1.04	1.6338	0.43	#N/A	1.15	1.32	5.17	0.17	5.33	10.38	10
Services - Cooling/Electrical	1.50	1.3943	1.23	#N/A	1.21	1.47	5.40	0.17	5.57	22.43	15
Complex	0.72	1.1478	0.33	0.10	0.96	0.93	11.98	0.02	12.00	79.02	109
Beam Permit System interlock	0.46	0.3583	0.39	#N/A	0.34	0.12	0.72	0.17	0.88	1.83	4
Chipmunk failure	1.19	32.5571	0.73	0.15	3.07	9.43	72.80	0.02	72.82	5.93	5
Emergency Response/ES&FD/ES&H	1.98	2.4321	1.33	#N/A	1.57	2.46	9.10	0.12	9.22	27.75	14
Loss Induced Quench	0.70	0.4472	0.55	0.50	0.40	0.16	1.48	0.20	1.68	7.73	11
Operator error	0.50	0.4422	0.33	0.33	0.33	0.11	1.47	0.03	1.50	5.53	11
Power dip/Weather	1.70	3.7631	0.51	0.20	2.72	7.41	11.90	0.10	12.00	16.98	10
Quench Link	0.39	0.2635	0.33	0.10	0.26	0.07	0.83	0.08	0.92	3.92	10
Radiation Monitor Interlock	0.21	0.1457	0.16	0.10	0.15	0.02	0.97	0.02	0.98	9.33	44
Total:	1.27	3.6770	0.57	0.10	2.61	6.80	72.80	0.02	72.82	495.90	392

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Statistics Summary of Failures that Occurred During the Evening Shift (4pm - 12am)
(Spreadsheet tab 'Statistics 4pm-12am')

System	Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Sum	Count
Power Supplies	1.75	0.0019	1.01	2.50	1.47	2.17	10.93	0.02	10.95	133.00	76
AGS/Power Supplies	1.68	0.0238	0.77	0.12	1.58	2.50	8.30	0.12	8.42	40.38	24
Booster/Power Supplies	1.27	0.0766	0.57	#N/A	0.96	0.91	3.67	0.22	3.88	10.18	8
RHIC Injection Power Supplies	1.27	0.0503	0.82	#N/A	0.90	0.81	2.88	0.17	3.05	14.02	11
RHIC/ Magnets/Power supplies	1.97	0.0033	1.36	0.02	1.55	2.39	10.93	0.02	10.95	51.13	26
RHIC Quench Detection/Protection	2.47	0.1575	1.23	#N/A	1.95	3.80	9.30	0.42	9.72	17.28	7
Instrumentation	0.92	0.0962	0.90	#N/A	0.70	0.49	1.53	0.17	1.70	2.77	3
RF	1.44	0.0079	0.47	0.17	1.63	2.65	11.93	0.05	11.98	57.50	40
Linac RF	0.96	0.0301	0.78	1.80	0.55	0.30	1.97	0.12	2.08	14.37	15
AGS/Booster RF	2.70	0.0158	0.39	0.17	2.74	7.50	11.93	0.05	11.98	27.00	10
RHIC/RF	1.08	0.0258	0.25	0.67	1.52	2.31	10.63	0.10	10.73	16.13	15
Vacuum	0.61	0.0408	0.58	#N/A	0.29	0.08	1.12	0.10	1.22	3.65	6
AGS/Booster Vacuum	0.52	0.0447	0.17	#N/A	0.30	0.09	1.12	0.10	1.22	2.62	5
RHIC Vacuum	1.03	1.0333	1.03	#N/A	0.29	0.08	0.00	1.03	1.03	1.03	1
Cryogenic System	1.29	0.0196	1.17	0.13	1.10	1.22	4.58	0.10	4.68	33.43	26
Controls	0.86	0.0155	0.50	0.17	0.83	0.69	7.33	0.08	7.42	24.93	29
Controls Network	0.88	0.3536	0.88	#N/A	0.43	0.18	0.75	0.50	1.25	1.75	2
Controls Software	0.64	0.0680	0.64	#N/A	0.33	0.11	0.93	0.17	1.10	3.83	6
Controls Device Controller/Station/Timing	0.92	0.0182	0.38	0.75	0.97	0.94	7.33	0.08	7.42	19.35	21
Access Security	1.30	0.0980	1.04	0.92	0.78	0.61	2.67	0.37	3.03	18.18	14
Linac	2.78	0.0042	0.42	0.87	5.83	34.03	35.12	0.02	35.13	44.48	16
Polarized Protons	1.06	0.2117	0.40	#N/A	0.72	0.52	2.05	0.37	2.42	3.18	3
Tandem	0.97	0.0126	0.42	#N/A	1.02	1.03	4.85	0.03	4.88	6.82	7
Services - Cooling/Electrical	2.67	0.1938	1.75	#N/A	1.29	1.65	5.58	0.43	6.02	13.37	5
Complex	0.61	0.0017	0.26	0.17	0.55	0.31	4.33	0.02	4.35	61.30	100
Beam Permit System interlock	0.47	0.1443	0.25	#N/A	0.34	0.11	0.67	0.25	0.92	1.42	3
Chipmunk failure			0.70	0.17	1.84	3.37	35.12	0.02	35.13	0.00	0
Emergency Response/ES&FD/ES&H	1.46	0.0516	1.15	0.37	0.99	0.99	4.15	0.20	4.35	21.85	15
Loss Induced Quench	0.91	0.0818	0.82	0.98	0.55	0.31	2.13	0.28	2.42	10.88	12
Operator error	1.04	0.0693	0.77	#N/A	0.76	0.58	3.88	0.25	4.13	13.53	13
Power dip/Weather	1.24	0.0825	1.24	#N/A	0.54	0.29	2.25	0.12	2.37	2.48	2
Quench Link	0.44	0.0315	0.17	#N/A	0.30	0.09	1.27	0.08	1.35	3.08	7
Radiation Monitor Interlock	0.17	0.0024	0.15	0.17	0.10	0.01	0.45	0.02	0.47	8.05	48
Total:	1.24	0.0009	0.52	0.17	1.56	2.43	35.12	0.02	35.13	402.62	325

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
Statistics Summary of Failures that Occurred During the Owl Shift (12am - 8am)
(Spreadsheet tab 'Statistics 12am-8am')

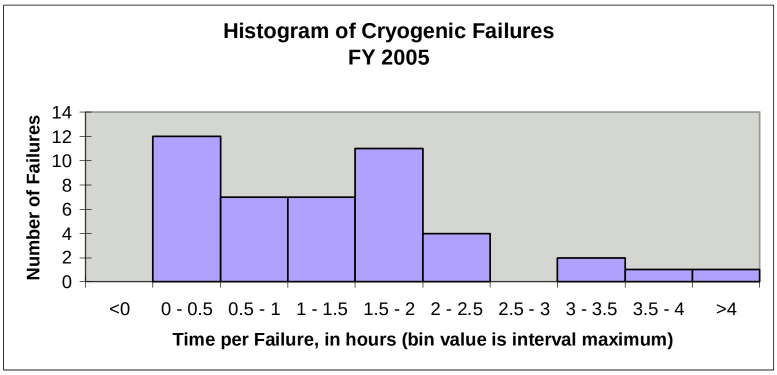
System	Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Sum	Count
Power Supplies	1.50	0.87	1.12	0.27	1.03	1.06	7.05	0.08	7.13	100.57	67
AGS/Power Supplies	1.43	0.97	0.57	#N/A	0.91	0.83	3.50	0.25	3.75	21.42	15
Booster/Power Supplies	1.06	1.30	0.60	#N/A	0.75	0.57	3.45	0.22	3.67	8.45	8
RHIC Injection Power Supplies	1.23	1.01	1.33	#N/A	0.63	0.40	2.08	0.17	2.25	6.13	5
RHIC/ Magnets/Power supplies	1.54	1.26	1.21	#N/A	1.24	1.53	7.05	0.08	7.13	49.18	32
RHIC Quench Detection/Protection	2.20	1.57	2.42	#N/A	1.16	1.35	3.58	0.58	4.17	15.38	7
Instrumentation	1.22	1.65	1.22	#N/A	0.95	0.89	2.23	0.10	2.33	2.43	2
RF	2.47	4.37	0.48	0.08	3.40	11.56	28.27	0.08	28.35	103.55	42
Linac RF	0.69	0.64	0.35	0.08	0.66	0.44	3.13	0.08	3.22	17.27	25
AGS/Booster RF	9.09	10.72	1.58	#N/A	6.83	46.62	28.23	0.12	28.35	63.62	7
RHIC/RF	2.27	2.25	1.97	0.75	1.30	1.68	6.85	0.25	7.10	22.67	10
Vacuum	3.13	7.63	0.43	#N/A	4.59	21.07	28.28	0.25	28.53	43.78	14
AGS/Booster Vacuum	0.45	0.42	0.42	#N/A	0.28	0.08	1.00	0.25	1.25	4.08	9
RHIC Vacuum	7.94	12.76	4.50	#N/A	7.88	62.15	28.20	0.33	28.53	39.70	5
Cryogenic System	1.47	1.50	1.30	#N/A	0.71	0.51	3.95	0.02	3.97	10.28	7
Controls	0.87	0.52	0.71	#N/A	0.47	0.22	2.43	0.02	2.45	19.13	22
Controls Network	0.53	0.53	0.53	#N/A	0.18	0.03	0.00	0.53	0.53	0.53	1
Controls Software	0.60	0.54	0.47	#N/A	0.38	0.15	1.40	0.02	1.42	4.18	7
Controls Device Controller/Station/Timing	1.03	0.65	1.02	#N/A	0.51	0.26	2.28	0.17	2.45	14.42	14
Access Security	1.11	0.99	1.03	#N/A	0.59	0.35	2.77	0.03	2.80	8.87	8
Linac	7.65	19.07	1.26	#N/A	10.04	100.79	60.13	0.17	60.30	76.48	10
Polarized Protons	0.69	0.50	0.77	#N/A	0.39	0.15	0.78	0.22	1.00	2.75	4
Tandem	2.21	3.50	0.58	0.58	1.87	3.50	8.45	0.12	8.57	13.27	6
Services - Cooling/Electrical	4.14	7.88	1.58	#N/A	4.87	23.70	26.95	0.33	27.28	49.72	12
Complex	0.67	0.51	0.45	0.17	0.56	0.31	4.92	0.02	4.93	63.85	95
Beam Permit System interlock			#NUM!	#N/A	0.00	0.00	0.00	0.00	0.00	0.00	0
Chipmunk failure	0.48	42.64	0.85	0.75	3.34	11.17	60.28	0.02	60.30	0.95	2
Emergency Response/ES&FD/ES&H	1.28	1.23	0.92	0.58	0.92	0.85	4.67	0.27	4.93	20.43	16
Loss Induced Quench	0.73	0.41	0.62	#N/A	0.39	0.16	1.20	0.23	1.43	8.70	12
Operator error	1.20	1.09	0.63	2.45	0.91	0.83	3.83	0.25	4.08	16.83	14
Power dip/Weather	0.72	0.95	0.32	0.92	0.62	0.38	2.43	0.08	2.52	5.03	7
Quench Link	0.44	0.40	0.47	0.62	0.32	0.10	1.30	0.02	1.32	4.87	11
Radiation Monitor Interlock	0.21	0.17	0.17	0.17	0.13	0.02	0.98	0.02	1.00	7.03	33
Total:	1.71	3.55	0.58	0.17	2.71	7.34	60.28	0.02	60.30	494.68	289

Appendix I – System Failure Histograms

(Excel spreadsheet tab ‘Histogram by System’)

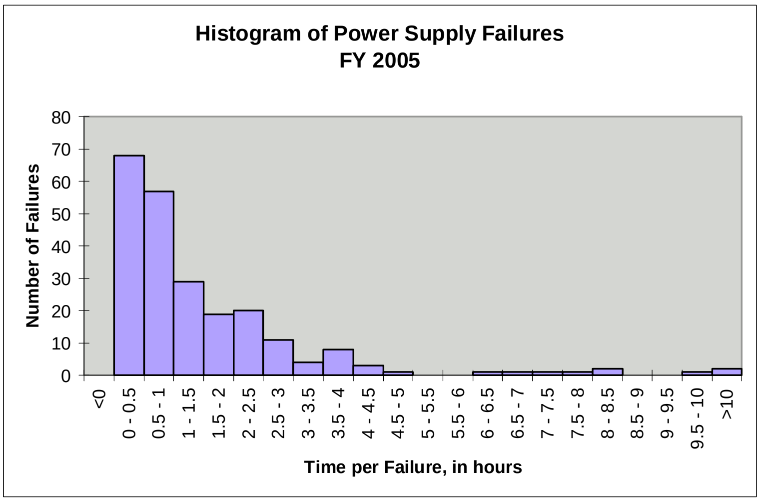
Cryogenic System

Time	Failures
<0	0
0 - 0.5	12
0.5 - 1	7
1 - 1.5	7
1.5 - 2	11
2 - 2.5	4
2.5 - 3	0
3 - 3.5	2
3.5 - 4	1
>4	1
Total:	45



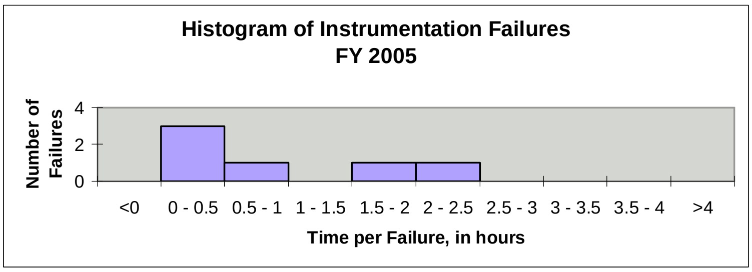
Power Supplies

Time	Failures
<0	0
0 - 0.5	68
0.5 - 1	57
1 - 1.5	29
1.5 - 2	19
2 - 2.5	20
2.5 - 3	11
3 - 3.5	4
3.5 - 4	8
4 - 4.5	3
4.5 - 5	1
5 - 5.5	0
5.5 - 6	0
6 - 6.5	1
6.5 - 7	1
7 - 7.5	1
7.5 - 8	1
8 - 8.5	2
8.5 - 9	0
9 - 9.5	0
9.5 - 10	1
>10	2
Total:	229



Instrumentation

Time	Failures
<0	0
0 - 0.5	3
0.5 - 1	1
1 - 1.5	0
1.5 - 2	1
2 - 2.5	1
2.5 - 3	0
3 - 3.5	0
3.5 - 4	0
>4	0
Total:	6

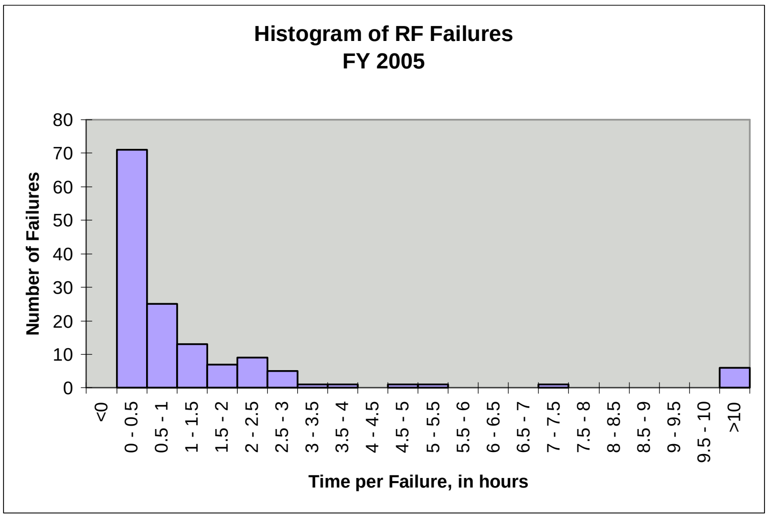


RF

Time	Failures

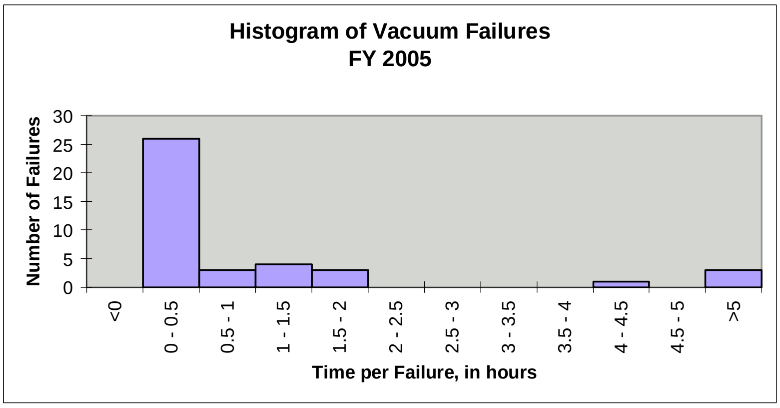
RF

Time	Failures
<0	0
0 - 0.5	71
0.5 - 1	25
1 - 1.5	13
1.5 - 2	7
2 - 2.5	9
2.5 - 3	5
3 - 3.5	1
3.5 - 4	1
4 - 4.5	0
4.5 - 5	1
5 - 5.5	1
5.5 - 6	0
6 - 6.5	0
6.5 - 7	0
7 - 7.5	1
7.5 - 8	0
8 - 8.5	0
8.5 - 9	0
9 - 9.5	0
9.5 - 10	0
>10	6
Total:	141



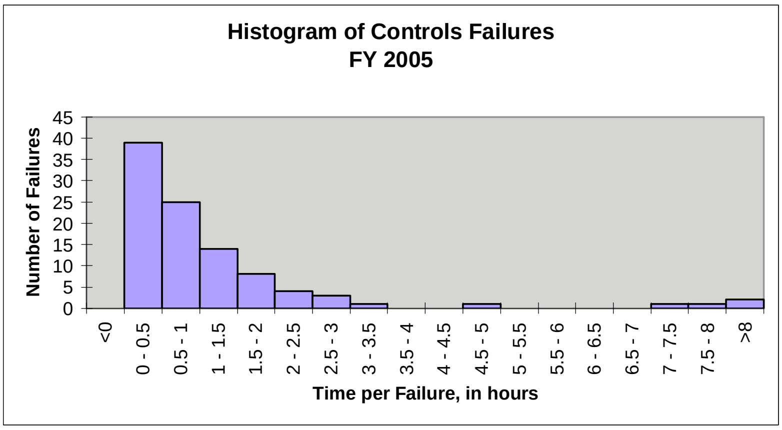
Vacuum

Time	Failures
<0	0
0 - 0.5	26
0.5 - 1	3
1 - 1.5	4
1.5 - 2	3
2 - 2.5	0
2.5 - 3	0
3 - 3.5	0
3.5 - 4	0
4 - 4.5	1
4.5 - 5	0
>5	3
Total:	40



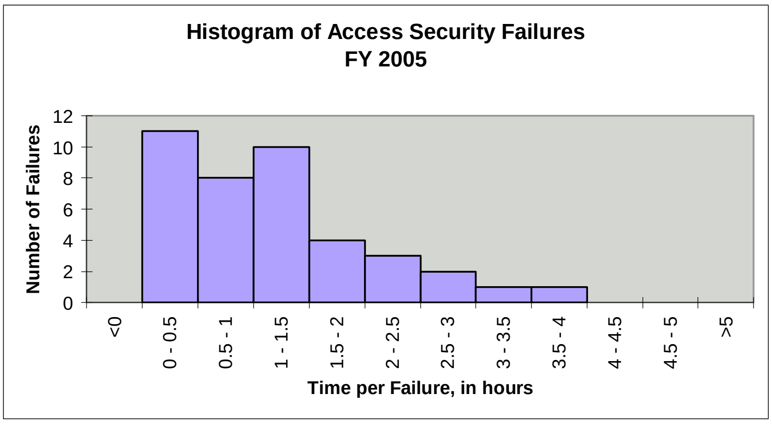
Controls

Time	Failures
<0	0
0 - 0.5	39
0.5 - 1	25
1 - 1.5	14
1.5 - 2	8
2 - 2.5	4
2.5 - 3	3
3 - 3.5	1
3.5 - 4	0
4 - 4.5	0
4.5 - 5	1
5 - 5.5	0
5.5 - 6	0
6 - 6.5	0
6.5 - 7	0
7 - 7.5	1
7.5 - 8	1
>8	2
Total:	99



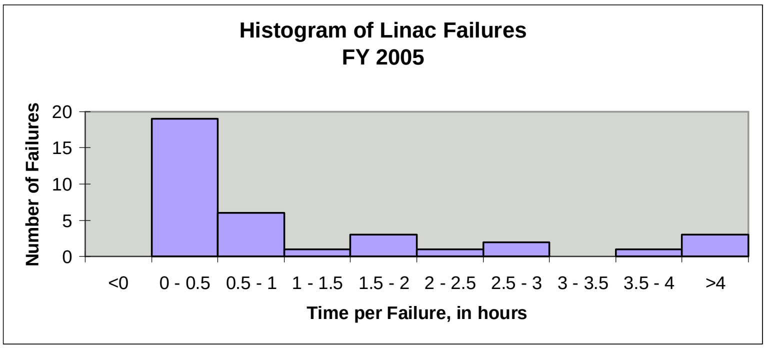
Access Security

Time	Failures
<0	0
0 - 0.5	11
0.5 - 1	8
1 - 1.5	10
1.5 - 2	4
2 - 2.5	3
2.5 - 3	2
3 - 3.5	1
3.5 - 4	1
4 - 4.5	0
4.5 - 5	0
>5	0
Total:	40



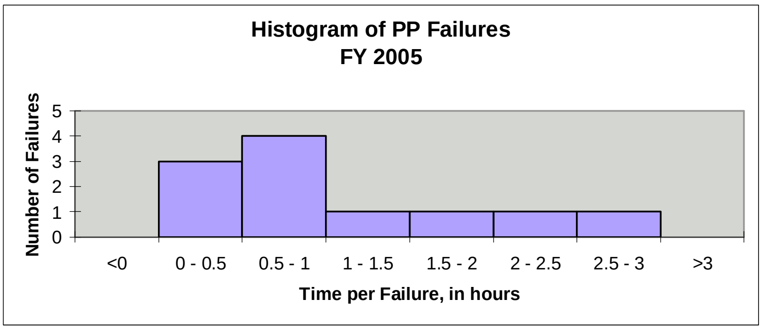
Linac

Time	Failures
<0	0
0 - 0.5	19
0.5 - 1	6
1 - 1.5	1
1.5 - 2	3
2 - 2.5	1
2.5 - 3	2
3 - 3.5	0
3.5 - 4	1
>4	3
Total:	36



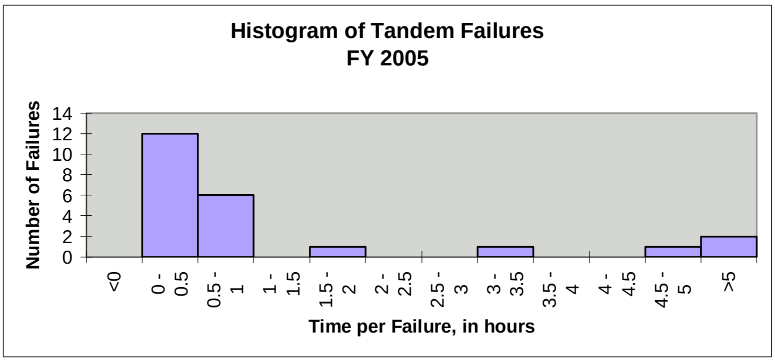
Polarized Protons

Time	Failures
<0	0
0 - 0.5	3
0.5 - 1	4
1 - 1.5	1
1.5 - 2	1
2 - 2.5	1
2.5 - 3	1
>3	0
Total:	11



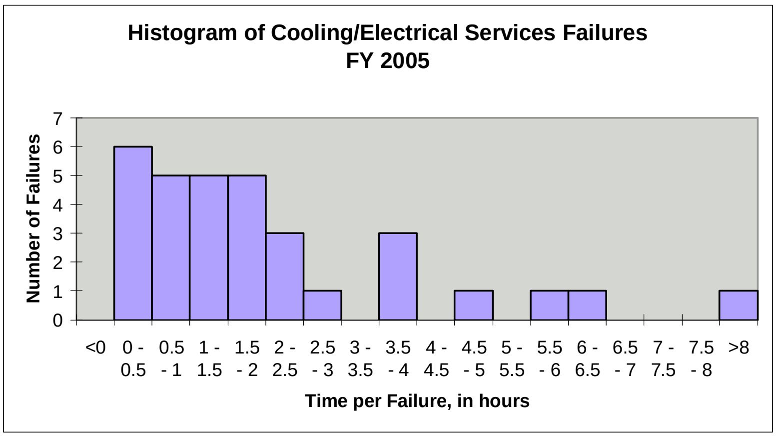
Tandem

Bin	Frequency
<0	0
0 - 0.5	12
0.5 - 1	6
1 - 1.5	0
1.5 - 2	1
2 - 2.5	0
2.5 - 3	0
3 - 3.5	1
3.5 - 4	0
4 - 4.5	0
4.5 - 5	1
>5	2
Total:	23



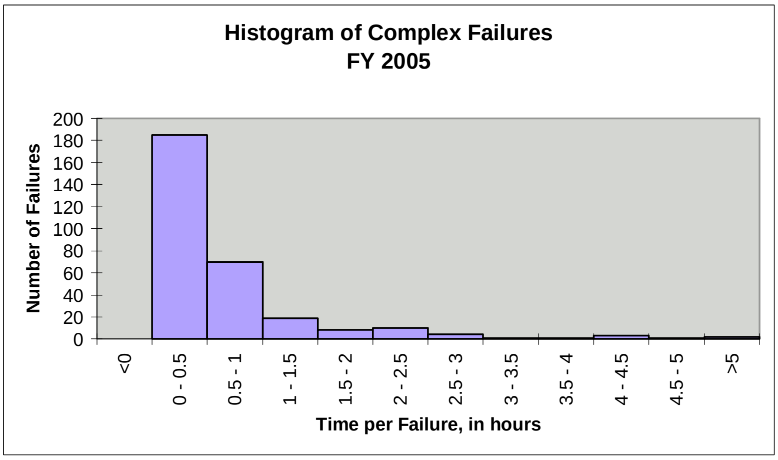
Services - Cooling/Electrical

Time	Failures
<0	0
0 - 0.5	6
0.5 - 1	5
1 - 1.5	5
1.5 - 2	5
2 - 2.5	3
2.5 - 3	1
3 - 3.5	0
3.5 - 4	3
4 - 4.5	0
4.5 - 5	1
5 - 5.5	0
5.5 - 6	1
6 - 6.5	1
6.5 - 7	0
7 - 7.5	0
7.5 - 8	0
>8	1
Total:	32



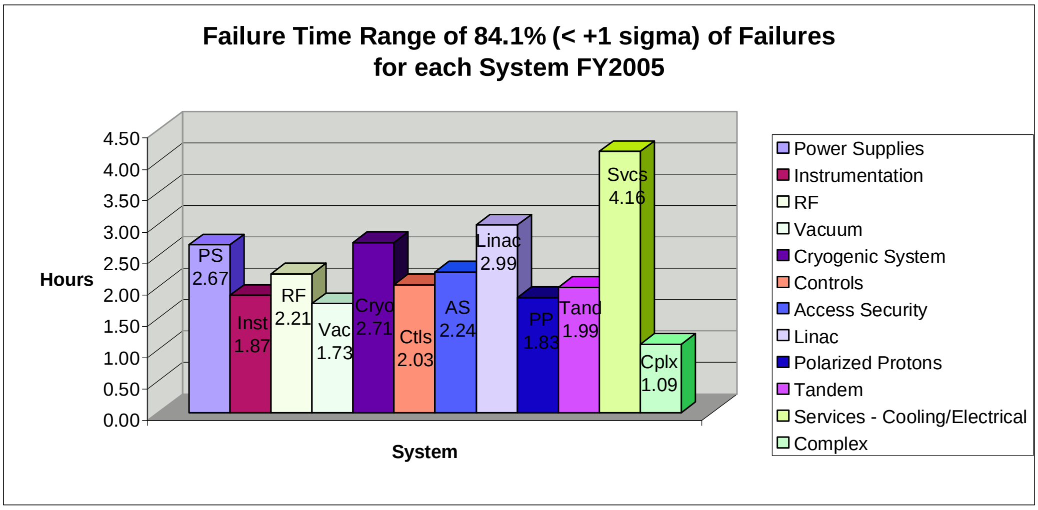
Complex

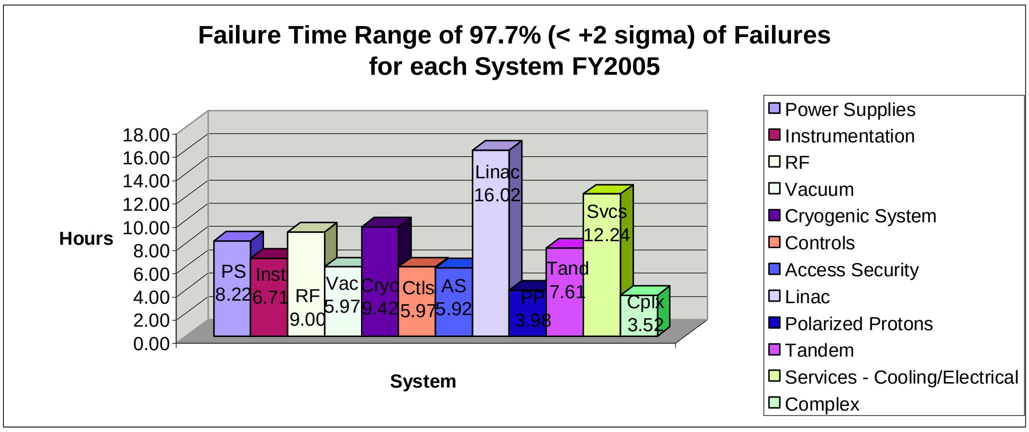
Time	Failures
<0	0
0 - 0.5	185
0.5 - 1	70
1 - 1.5	19
1.5 - 2	8
2 - 2.5	10
2.5 - 3	4
3 - 3.5	1
3.5 - 4	1
4 - 4.5	3
4.5 - 5	1
>5	2
Total:	304

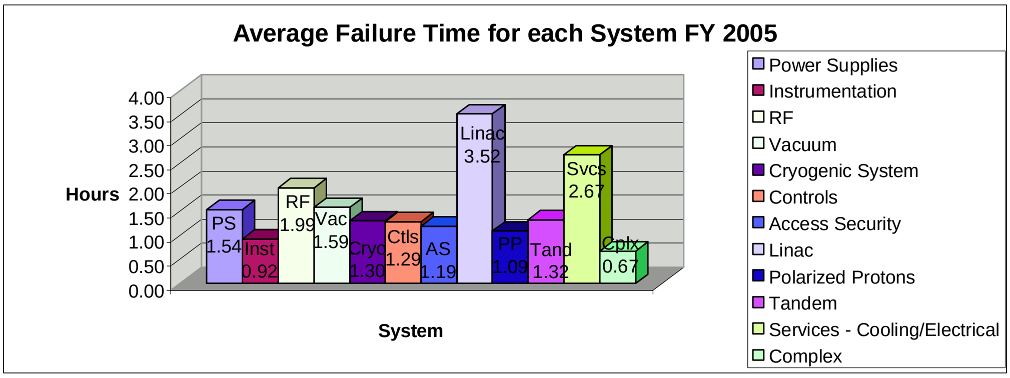


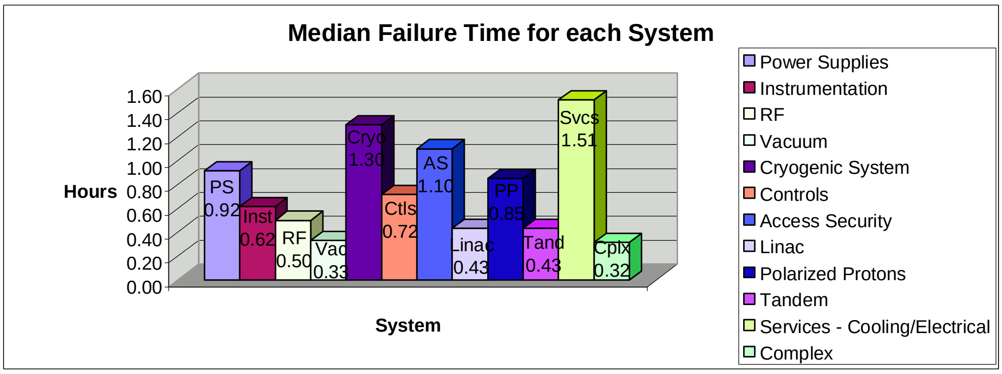
Appendix J – System Failures Charts

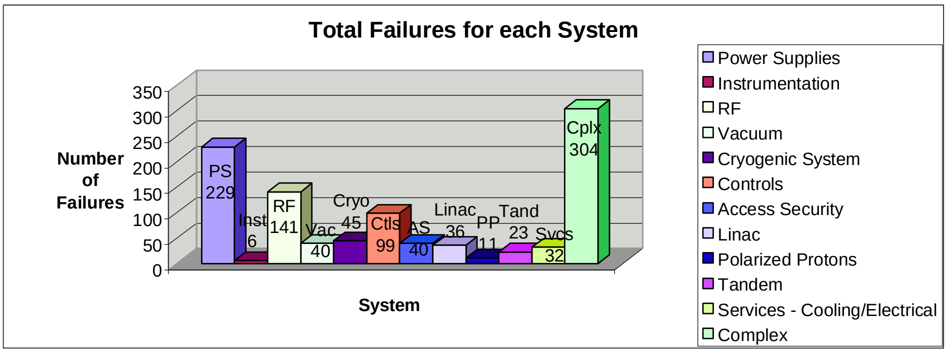
(Excel spreadsheet tab ‘SystemCharts1’)

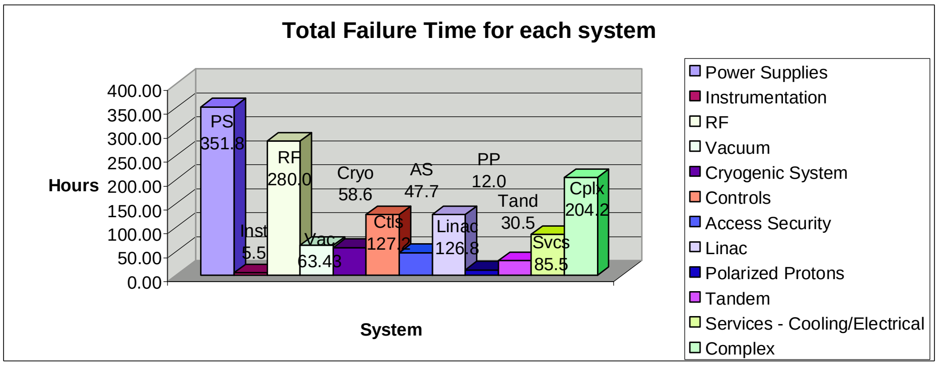





Average Failure Time for each System FY 2005
Hours
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
System
PS 1.54
Inst 0.92
RF 1.99
Vac 1.59
Cryo 1.30
Ctls 1.29
AS 1.19
Linac 3.52
PP 1.09
Tand 1.32
Svcs 2.67
Cplx 0.67
Power Supplies
Instrumentation
RF
Vacuum
Cryogenic System
Controls
Access Security
Linac
Polarized Protons
Tandem
Services - Cooling/Electrical
Complex


Median Failure Time for each System
Hours
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
System
PS 0.92
Inst 0.62
RF 0.50
Vac 0.33
Cryo 1.30
Ctls 0.72
AS 1.10
Linac 0.43
PP 0.85
Tand 0.43
Svcs 1.51
Cplx 0.32
Power Supplies
Instrumentation
RF
Vacuum
Cryogenic System
Controls
Access Security
Linac
Polarized Protons
Tandem
Services - Cooling/Electrical
Complex


Total Failures for each System
Number of Failures
350
300
250
200
150
100
50
0
PS 229
Inst 6
RF 141
Vac 40
Cryo 45
Ctls 99
AS 40
Linac 36
PP 11
Tand 23
Svcs 32
Cplx 304
System
Power Supplies
Instrumentation
RF
Vacuum
Cryogenic System
Controls
Access Security
Linac
Polarized Protons
Tandem
Services - Cooling/Electrical
Complex


Total Failure Time for each system
Hours
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
PS 351.8
Inst 5.5
RF 280.0
Vac 63.43
Cryo 58.6
Ctls 127.2
AS 47.7
Linac 126.8
PP 12.0
Tand 30.5
Svcs 85.5
Cplx 204.2
System
Power Supplies
Instrumentation
RF
Vacuum
Cryogenic System
Controls
Access Security
Linac
Polarized Protons
Tandem
Services - Cooling/Electrical
Complex

Appendix K – ANOVA and Log Sigma Calculation by System

(Excel spreadsheet tab 'Anova by System')

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
ANOVA and Statistics Summary by System
(Spreadsheet tab 'Anova by System')

Anova: Single Factor

SUMMARY

System	Count	Sum	Average	Median	Variance	Std Dev		Count*((Var-grandMean)^2)	Count*Var
Power Supplies	229	351.83	1.54	0.92	4.296716	2.072852		0.674627067	983.9479094
Instrumentation	6	5.53	0.92	0.62	0.838074	0.915464		2.680909643	5.028444444
RF	141	279.97	1.99	0.50	49.37284	7.026581		21.98975788	6961.570183
Vacuum	40	63.43	1.59	0.33	21.03572	4.586471		0.000934531	841.4288034
Cryogenic System	45	58.57	1.30	1.30	1.146993	1.070977		3.763269022	51.61467172
Controls	99	127.25	1.29	0.72	4.580132	2.140124		9.228408206	453.4330612
Access Security	40	47.73	1.19	1.10	0.74212	0.861464		6.314958209	29.68478632
Linac	36	126.77	3.52	0.43	128.5793	11.33928		134.1838766	4628.855206
Polarized Protons	11	11.97	1.09	0.85	0.650561	0.806573		2.780754632	7.156166667
Tandem	23	30.47	1.32	0.43	4.672396	2.161573		1.627745419	107.465101
Services - Cooling/Electrical	32	85.52	2.67	1.51	22.62845	4.756937		37.44440022	724.110457
Complex	304	204.17	0.67	0.32	1.243281	1.115025		256.7834301	377.9575468
		Grand Mean:	1.590667			SS(TR):	477.4730715	SS(ER):	15172.25234

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups SS(TR)	434.8751	11	39.5341	2.631642	0.002559	1.79827
Within Groups SS(ER)	14932.47	994	15.0226			
Total	15367.34	1005				

SS(TOT): = SS(TR) + SS(ER)
SS(TOT): 15649.72541
This value is close to but not exactly equivalent to the excel calculated value.

SS(TR) = sum of squares of each element minus Grand Mean
SS(ER) = sum of squares of each element minus group mean

Anova: Single Factor using Logarithm of failure hours

SUMMARY

System	Count	Sum	Average	Variance	Std Dev	-2 sigma (hours) (10^(Avg-2*StdDev)	-1 sigma (hours) (10^(Avg-StdDev)	Average converted back to hours (10^Avg)	+1 sigma (hours) (10^(Avg+StdDev)	+2 sigma (hours) (10^(Avg+2*StdDev)
Power Supplies	229	-13.85	-0.06	0.237828	0.487676	0.09	0.28	0.87	2.67	8.22
Instrumentation	6	-1.70	-0.28	0.308126	0.555091	0.04	0.14	0.52	1.87	6.71
RF	141	-37.37	-0.27	0.371566	0.609562	0.03	0.13	0.54	2.21	9.00
Vacuum	40	-11.91	-0.30	0.288385	0.537015	0.04	0.15	0.50	1.73	5.97
Cryogenic System	45	-4.85	-0.11	0.292684	0.541003	0.06	0.22	0.78	2.71	9.42
Controls	99	-15.80	-0.16	0.218996	0.467971	0.08	0.24	0.69	2.03	5.97
Access Security	40	-2.85	-0.07	0.177859	0.421733	0.12	0.32	0.85	2.24	5.92
Linac	36	-9.14	-0.25	0.531805	0.72925	0.02	0.10	0.56	2.99	16.02
Polarized Protons	11	-0.83	-0.08	0.114188	0.337917	0.18	0.39	0.84	1.83	3.98
Tandem	23	-6.50	-0.28	0.338693	0.581974	0.04	0.14	0.52	1.99	7.61
Services - Cooling/Electrical	32	4.80	0.15	0.219882	0.468916	0.16	0.48	1.41	4.16	12.24
Complex	304	-143.48	-0.47	0.259529	0.50944	0.03	0.10	0.34	1.09	3.52
		Grand Mean:	-0.181654							

ANOVA

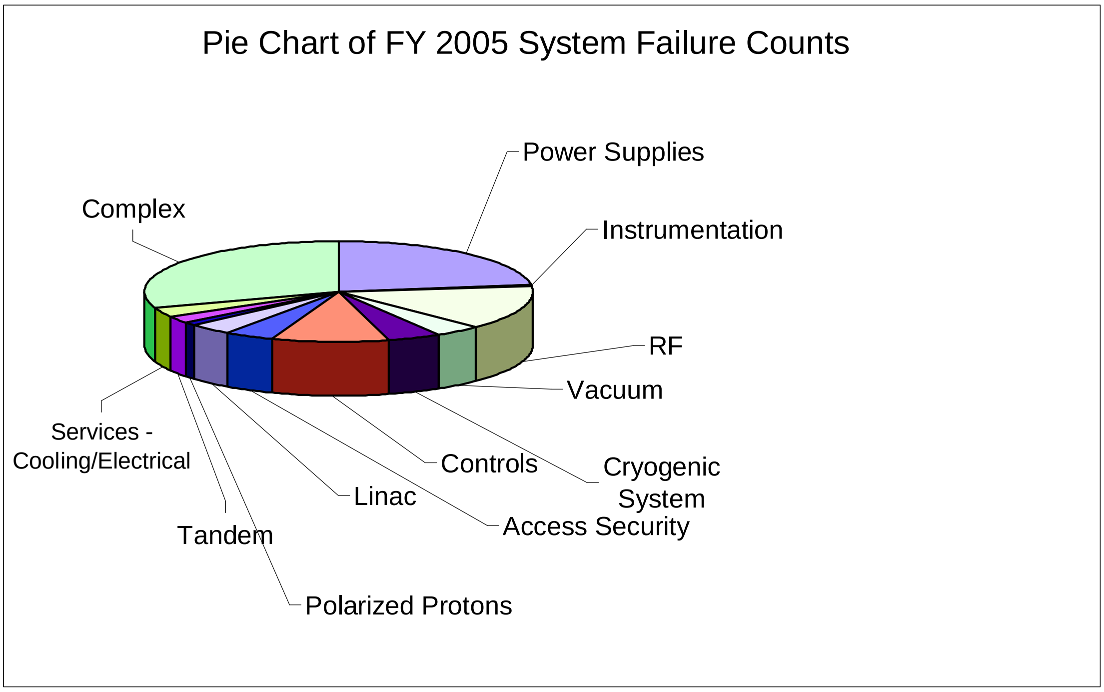
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	31.7491	11	2.886282	10.51027	1.95E-18	1.79827
Within Groups	272.9677	994	0.274615			
Total	304.7168	1005				

	Median compared with Average			Median compared with Average of Log value		
System	Median	Average	Diff	Median	Average of Log values 10^(LogAvg)	Diff
Power Supplies	0.92	1.54	0.62	0.92	0.87	0.05
Instrumentation	0.62	0.92	0.31	0.62	0.52	0.10
RF	0.50	1.99	1.49	0.50	0.54	-0.04
Vacuum	0.33	1.59	1.25	0.33	0.50	-0.17
Cryogenic System	1.30	1.30	0.00	1.30	0.78	0.52
Controls	0.72	1.29	0.57	0.72	0.69	0.02
Access Security	1.10	1.19	0.09	1.10	0.85	0.25
Linac	0.43	3.52	3.09	0.43	0.56	-0.12
Polarized Protons	0.85	1.09	0.24	0.85	0.84	0.01
Tandem	0.43	1.32	0.89	0.43	0.52	-0.09
Services - Cooling/Electrical	1.51	2.67	1.16	1.51	1.41	0.10
Complex	0.32	0.67	0.35	0.32	0.34	-0.02

The log calculation of average and standard deviation provides a good approximation for most systems since the differences between the median and log calculated averages are small.
The log calculation of average and standard deviation may not be accurate for the Cryogenic System and Access Security since the differences between the median and log calcuated averages are fairly large (.52 and .25 respectively).

Appendix L – Pie Chart of System Failure Counts

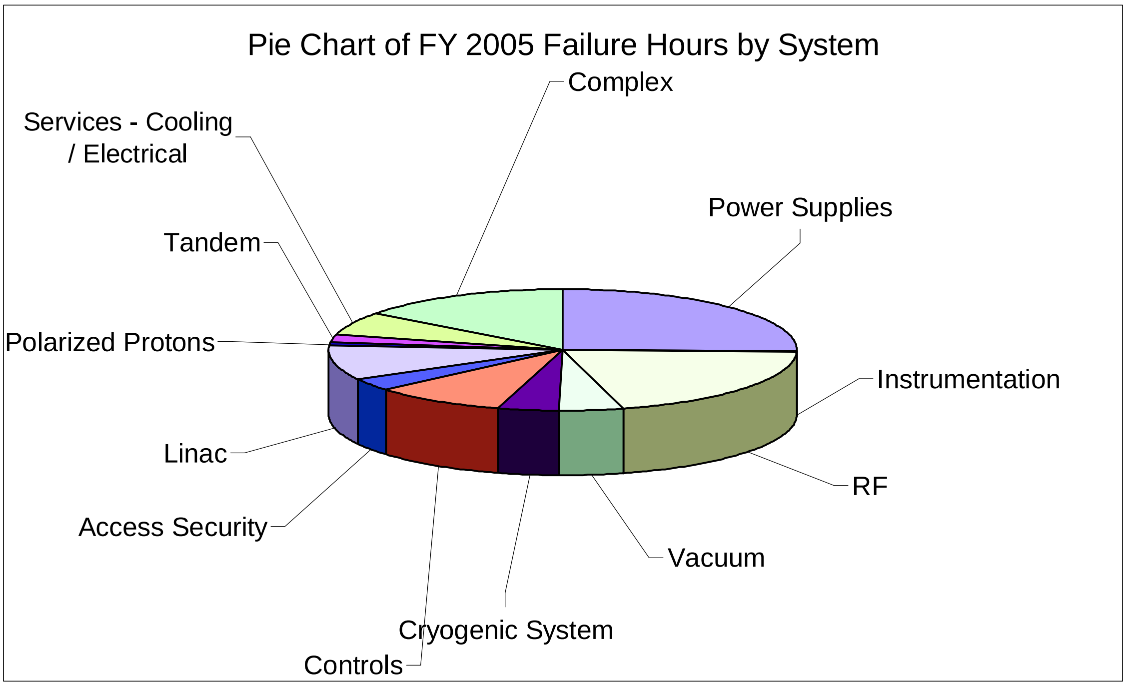
(Excel spreadsheet tab 'PieFailureCounts by System')



SYSTEM	Failure Count	% of Total
Power Supplies	229.00	22.76%
Instrumentation	6.00	0.60%
RF	141.00	14.02%
Vacuum	40.00	3.98%
Cryogenic System	45.00	4.47%
Controls	99.00	9.84%
Access Security	40.00	3.98%
Linac	36.00	3.58%
Polarized Protons	11.00	1.09%
Tandem	23.00	2.29%
Services - Cooling/Electrical	32.00	3.18%
Complex	304.00	30.22%
TOTAL:	1006.00	

Appendix M – Pie Chart of System Failure Hours

(Excel spreadsheet tab 'PieFailureHours by System')



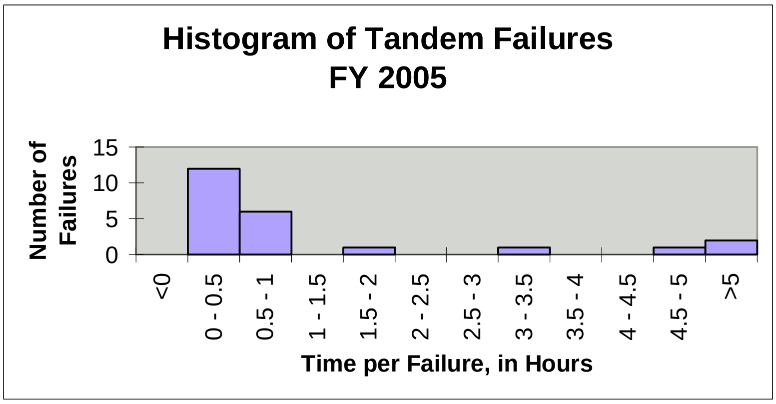
SYSTEM	Failure Hours	% of Total
Power Supplies	351.83	25.25%
Instrumentation	5.53	0.40%
RF	279.97	20.10%
Vacuum	63.43	4.55%
Cryogenic System	58.57	4.20%
Controls	127.25	9.13%
Access Security	47.73	3.43%
Linac	126.77	9.10%
Polarized Protons	11.97	0.86%
Tandem	30.47	2.19%
Services - Cooling/Electrical	85.52	6.14%
Complex	204.17	14.65%
TOTAL:	1393.20	

Appendix N – Accelerator Failure Histograms

(Excel spreadsheet tab ‘Histogram by Accelerator’)

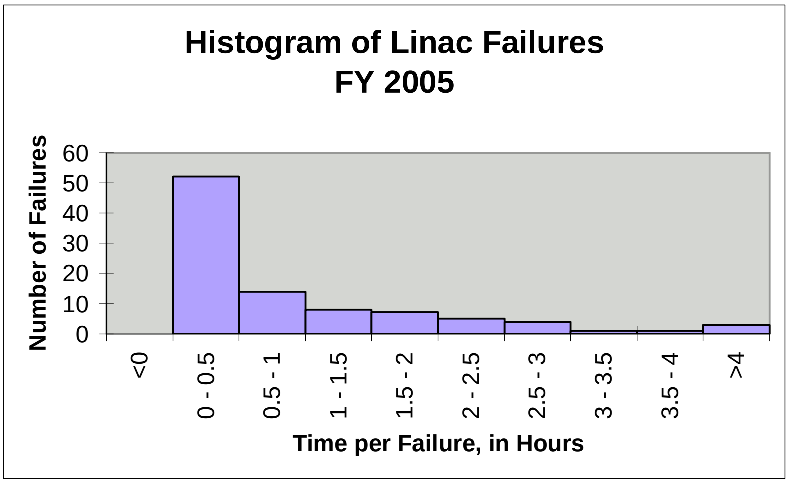
Tandem

Time	*Failures*
<0	0
0 - 0.5	12
0.5 - 1	6
1 - 1.5	0
1.5 - 2	1
2 - 2.5	0
2.5 - 3	0
3 - 3.5	1
3.5 - 4	0
4 - 4.5	0
4.5 - 5	1
>5	2
Total:	23



Linac

Time	*Failures*
<0	0
0 - 0.5	52
0.5 - 1	14
1 - 1.5	8
1.5 - 2	7
2 - 2.5	5
2.5 - 3	4
3 - 3.5	1
3.5 - 4	1
>4	3
Total:	95



NOTE: The following systems are not included in indicated values:

-Cryogenic

-Controls

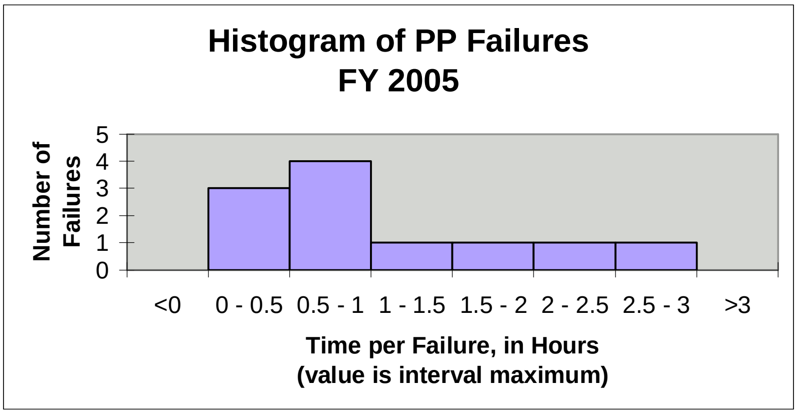
-Access Security

-Services -Cooling/Electrical

-Complex

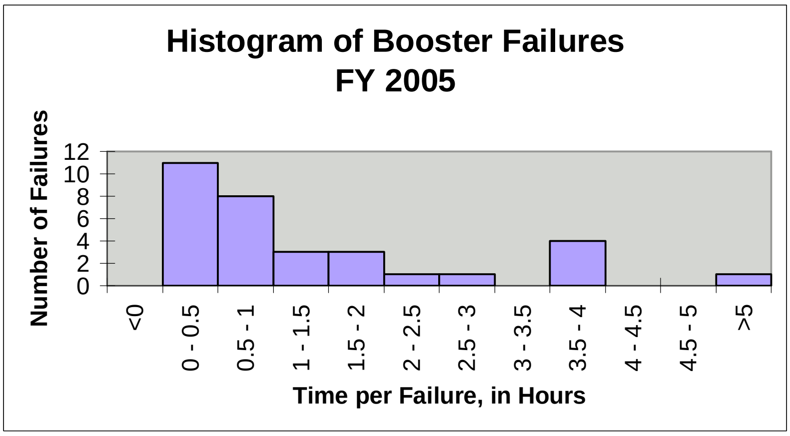
Polarized Protons

Time	*Failures*
<0	0
0 - 0.5	3
0.5 - 1	4
1 - 1.5	1
1.5 - 2	1
2 - 2.5	1
2.5 - 3	1
>3	0
Total:	11



Booster

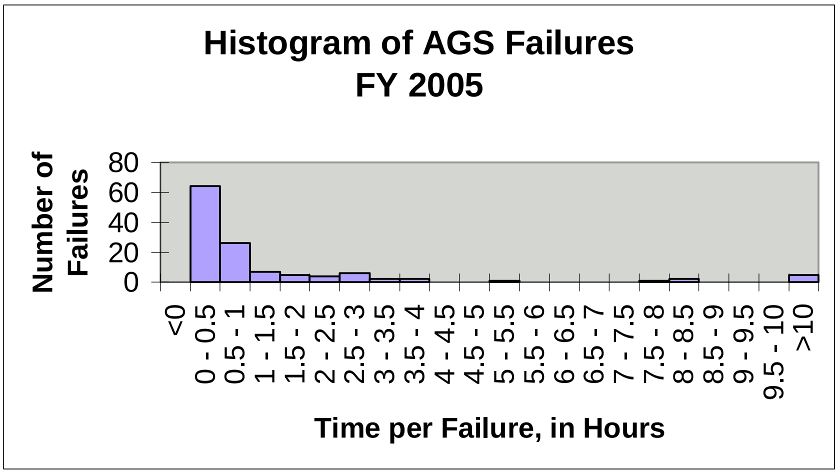
Time	*Failures*
<0	0
0 - 0.5	11
0.5 - 1	8
1 - 1.5	3
1.5 - 2	3
2 - 2.5	1
2.5 - 3	1
3 - 3.5	0
3.5 - 4	4
4 - 4.5	0
4.5 - 5	0
>5	1
Total:	32



NOTE: The following systems are not included in indicated values:
- -Cryogenic
- -Controls
- -Access Security
- -Services -Cooling/Electrical
- -Complex

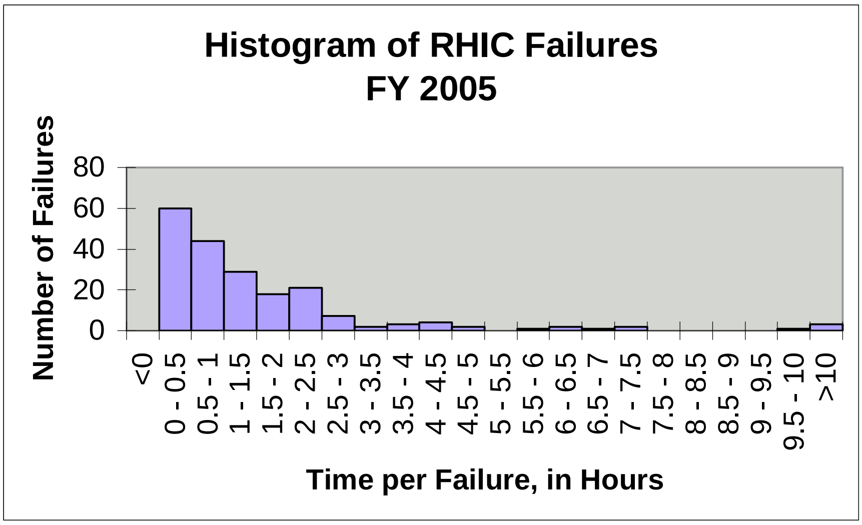
AGS

Time	*Failures*
<0	0
0 - 0.5	64
0.5 - 1	26
1 - 1.5	7
1.5 - 2	5
2 - 2.5	4
2.5 - 3	6
3 - 3.5	2
3.5 - 4	2
4 - 4.5	0
4.5 - 5	0
5 - 5.5	1
5.5 - 6	0
6 - 6.5	0
6.5 - 7	0
7 - 7.5	0
7.5 - 8	1
8 - 8.5	2
8.5 - 9	0
9 - 9.5	0
9.5 - 10	0
>10	5
Total:	125



RHIC

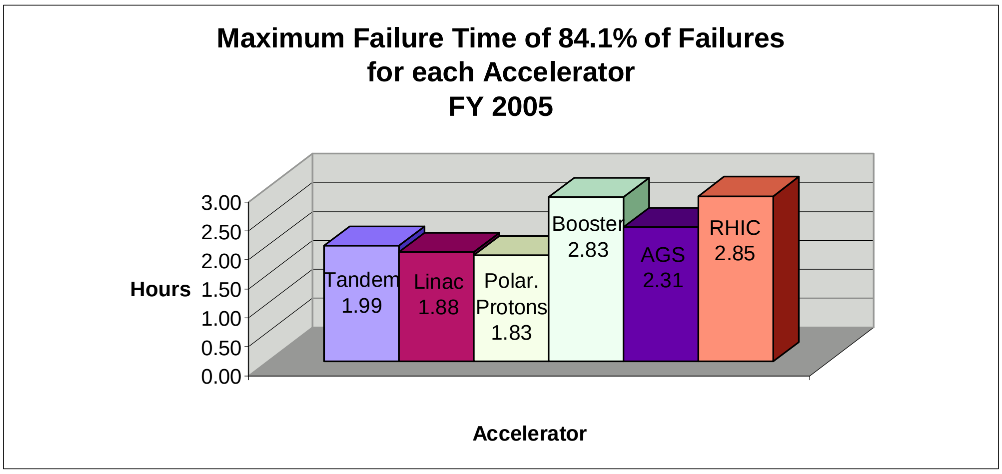
Time	*Number*
<0	0
0 - 0.5	60
0.5 - 1	44
1 - 1.5	29
1.5 - 2	18
2 - 2.5	21
2.5 - 3	7
3 - 3.5	2
3.5 - 4	3
4 - 4.5	4
4.5 - 5	2
5 - 5.5	0
5.5 - 6	1
6 - 6.5	2
6.5 - 7	1
7 - 7.5	2
7.5 - 8	0
8 - 8.5	0
8.5 - 9	0
9 - 9.5	0
9.5 - 10	1
>10	3
Total:	200

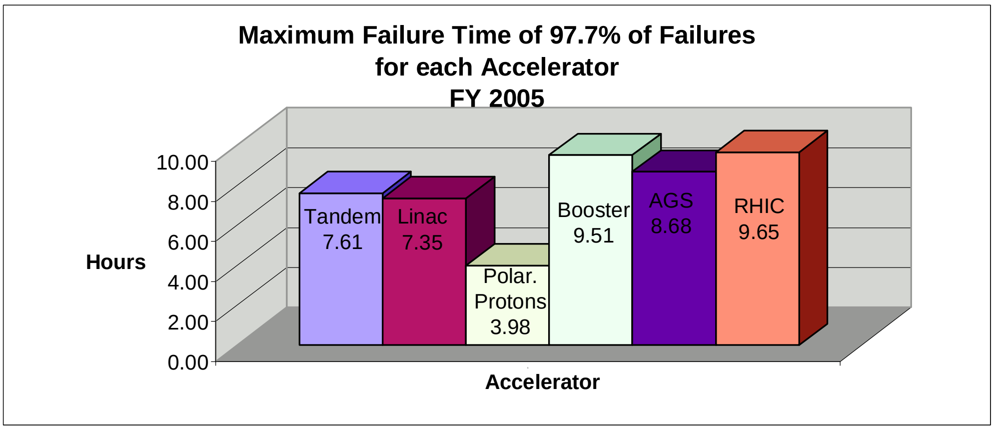


NOTE: The following systems are not included in indicated values:
- -Cryogenic
- -Controls
- -Access Security
- -Services -Cooling/Electrical
- -Complex

Appendix O – Accelerator Failure Charts

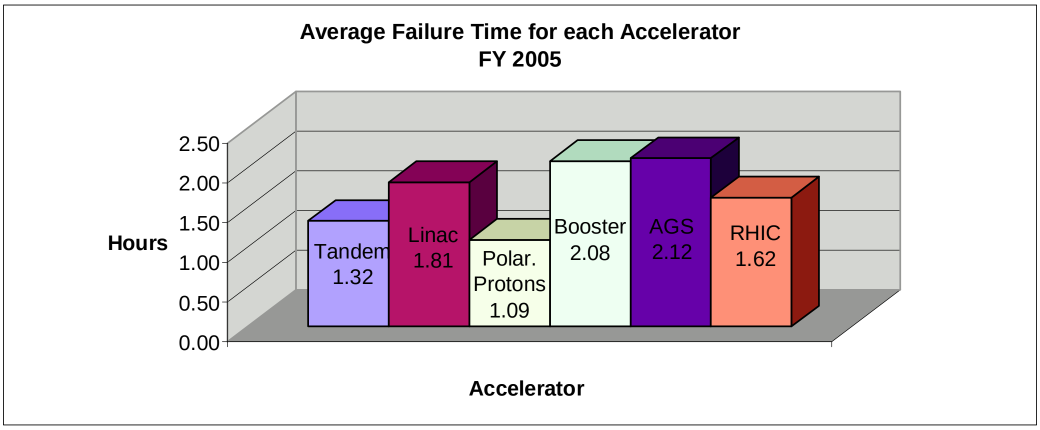
(Excel spreadsheet tab 'AcceleratorCharts1')

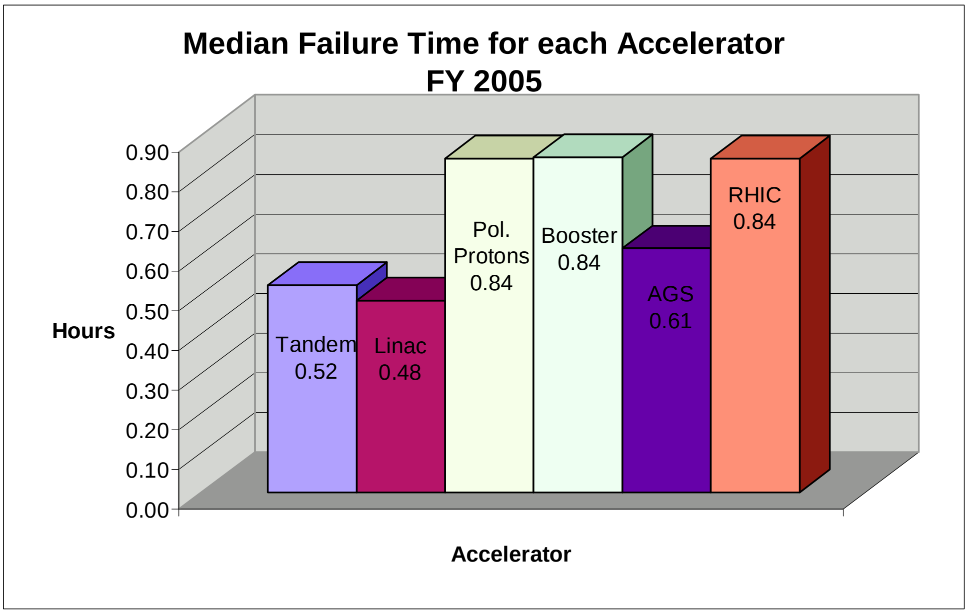




NOTE: The following systems are not included in indicated values:

-Cryogenic
-Controls
-Access Security
-Services -Cooling/Electrical
-Complex





NOTE: The following systems are not included in indicated values:

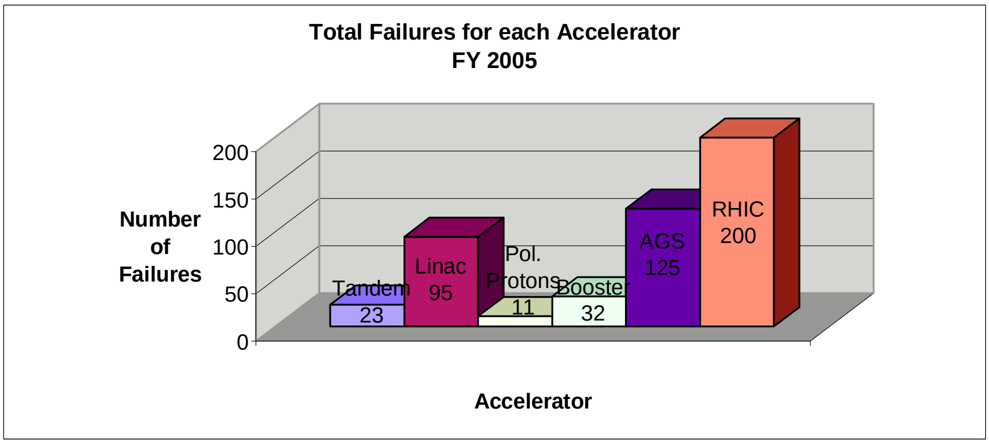
-Cryogenic

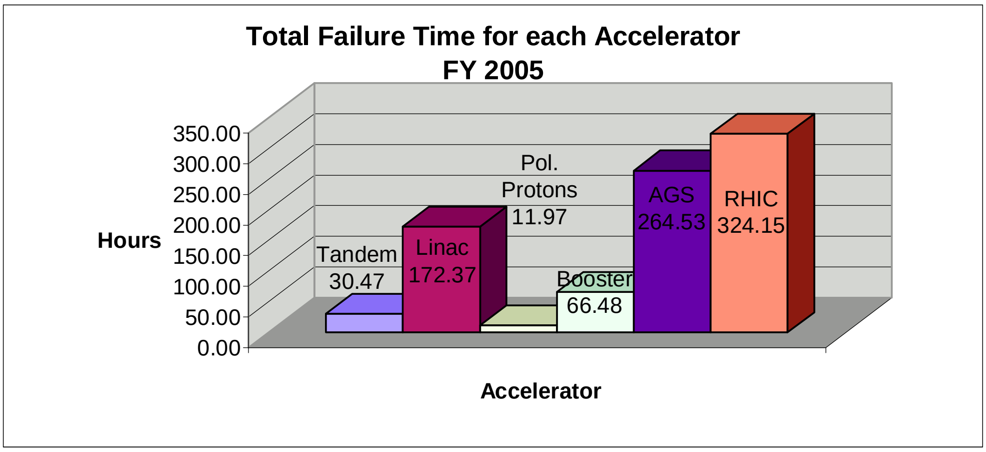
-Controls

-Access Security

-Services -Cooling/Electrical

-Complex





NOTE: The following systems are not included in indicated values:
-Cryogenic
-Controls
-Access Security
-Services -Cooling/Electrical
-Complex

Appendix P – ANOVA and Log Sigma Calculation by Accelerator

(Excel spreadsheet tab 'Anova by Accelerator')

Brookhaven National Laboratory
Collider-Accelerator Department
FY 2005 Failure Analysis
ANOVA and Statistics Summary by Accelerator
(Spreadsheet tab 'Anova by System')

Anova: Single Factor

SUMMARY

Accelerator	*Count*	*Sum*	*Average*	*Median*	*Variance*	*Std Dev*	*%Total Hours*
Tandem	23	30.47	1.32	0.43	4.672396	2.161573	3.50%
Linac	95	172.37	1.81	0.42	50.06071	7.07536	19.81%
Polarized Protons	11	11.97	1.09	0.85	0.650561	0.806573	1.38%
Booster	32	66.48	2.08	0.77	24.39171	4.938797	7.64%
AGS	125	264.53	2.12	0.50	52.63253	7.254828	30.41%
RHIC	200	324.15	1.62	0.97	6.738187	2.595802	37.26%
Total:	486	869.9667					

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	32.14241	5	6.428482	0.229615	0.949557	2.232795
Within Groups	13438.48	480	27.99684			
Total	13470.62	485				

Anova: Single Factor using the logarithm of failure times

SUMMARY

Accelerator	*Count*	*Sum*	*Average*	*Variance*	*Std Dev*	-2 sigma (hours) (10^(Avg-2*StdDev)	-1 sigma (hours) (10^(Avg-StdDev)	Average converted back to hours (10^Avg)	+1 sigma (hours) (10^(Avg+StdDev)	+2 sigma (hours) (10^(Avg+2*StdDev)
Tandem	23	-6.50	-0.28	0.338693	0.581974	0.04	0.14	0.52	1.99	7.61
Linac	95	-30.00	-0.32	0.349304	0.59102	0.03	0.12	0.48	1.88	7.35
Polarized Protons	11	-0.83	-0.08	0.114188	0.337917	0.18	0.39	0.84	1.83	3.98
Booster	32	-2.36	-0.07	0.276554	0.525884	0.07	0.25	0.84	2.83	9.51
AGS	125	-26.48	-0.21	0.330798	0.575151	0.04	0.16	0.61	2.31	8.68
RHIC	200	-15.14	-0.08	0.280968	0.530065	0.07	0.25	0.84	2.85	9.65

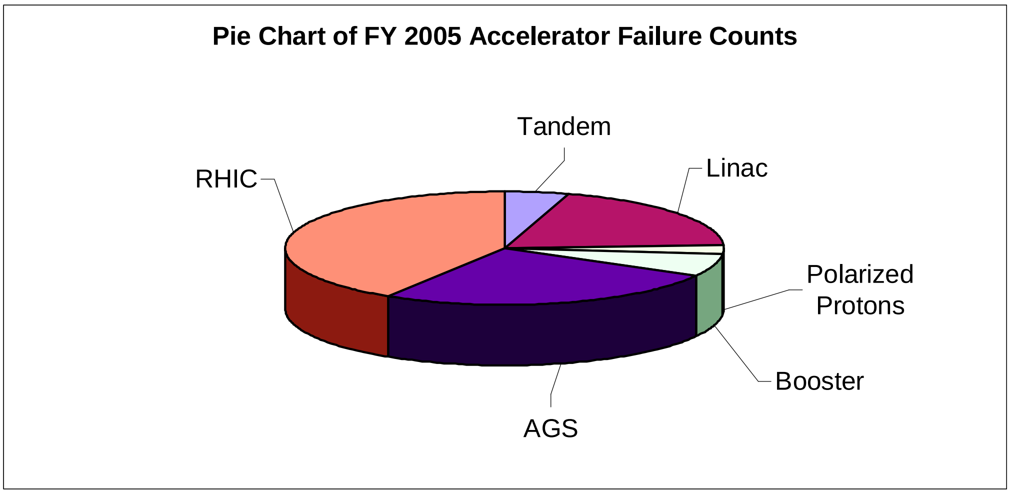
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.698569	5	0.939714	3.06986	0.009716	2.232795
Within Groups	146.9326	480	0.30611			
Total	151.6312	485				

NOTE: The following systems are not included in indicated values:
-Cryogenic
-Controls
-Access Security
-Services -Cooling/Electrical
-Complex

Appendix Q – Pie Chart of Accelerator Failure Counts

(Excel spreadsheet tab 'PieFailureCounts by Accel')

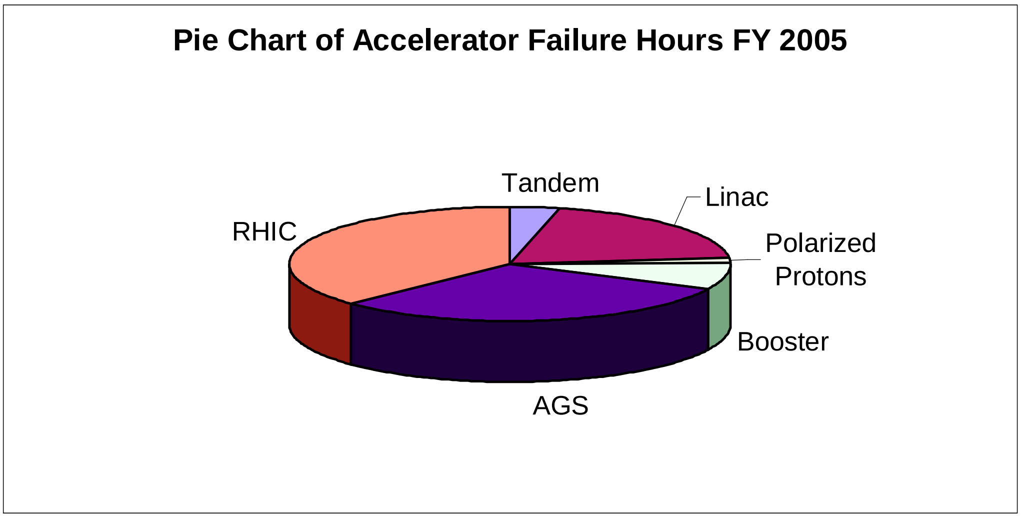


Accelerator	Failure Count	% of Total
Tandem	23	4.73%
Linac	95	19.55%
Polarized Protons	11	2.26%
Booster	32	6.58%
AGS	125	25.72%
RHIC	200	41.15%
Total:	486	

NOTE: The following systems are not included in indicated values:
-Cryogenic
-Controls
-Access Security
-Services -Cooling/Electrical
-Complex

Appendix R – Pie Chart of Accelerator Failure Hours

(Excel spreadsheet tab 'PieFailureHours by Accel')



Accelerator	Failure Hours	% of Total
Tandem	30.47	3.50%
Linac	172.37	19.81%
Polarized Protons	11.97	1.38%
Booster	66.48	7.64%
AGS	264.53	30.41%
RHIC	324.15	37.26%
Total:	869.97	

NOTE: The following systems are not included in indicated values:
- -Cryogenic
- -Controls
- -Access Security
- -Services -Cooling/Electrical
- -Complex