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Integrated Data Collection Analysis Project: Friction Correlation Study

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14. ABSTRACT The friction sensitivity of new main-charge explosive formulations must be understood while investigating and characterizing a new material and for qualification/fielding purposes. Sensitivity is measured in comparison to Composition B or a similarly qualified main charge material (such as PETN or RDX). The methods authorized in AOP-7 include Pendulum Friction, Rotary Friction, Sliding Friction (ABL), BAM Friction and Steel/Fiber Shoe Methods. The purpose of this study was to quantify a general correlation between the BAM Friction and ABL Sliding Friction apparatuses across main-charge high explosive materials and formulations, to further the general understanding of friction sensitivity in main charge high explosive ingredients and formulations and to maintain the utility of historical data while transitioning from mortar and pestle to steel pinch point friction sensitivity. This project provides an experimental methodology which results in a statistical correlation between the BAM Friction and ABL Sliding Friction apparatuses. Prediction of ABL values from BAM data is significantly more accurate with 89% accuracy for μ and 83% accuracy for σ using the derived correlation expressions. Prediction of BAM μ is only possible with 57% accuracy and σ with 62% accuracy. The observations in this study are based solely on the sensitivity of the energetics, and do not take into account any of the variation in ability to initiate due to mixture properties, or any interactions between the test apparatus and the energetic material. Any measureable characteristics of the initiation methods of the test apparatus (such as roughness of the interface) have not been explored as factors of the experiment and are classified as one of two levels in a single categorical factor: BAM or ABL friction apparatus. This study serves as a solid starting point for further research efforts in the ability to predict energetic sensitivity amongst disparate testing methods.					
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1. OBJECTIVE

The objective of this project is to quantify a general and widely applicable correlation between the Bundesanstalt für Materialprüfung (BAM) Friction and Allegheny Ballistics Laboratory (ABL) Sliding Friction apparatuses across main-charge high explosive materials and formulations, to further the general understanding of friction sensitivity in main charge high explosive ingredients and formulations and to maintain the utility of historical data while transitioning from mortar and pestle (such as the BAM) to steel pinch point (such as the ABL) friction sensitivity measurements.

2. INTRODUCTION/BACKGROUND

The energetic materials in filled end-items, experience a number of environments during their life cycle; from initial formulation and testing through production, item filling, transport and storage. As such, it is crucial that materials be safe to work with, handle and store. Transportation, storage and handling regulations for energetic materials require all new materials be qualified to ensure they have a similar sensitivity to the current inventory of compounds or formulations.^{1,2} This generally begins with small-scale safety testing to understand the sensitivity of a new compound or formulation. Sensitivity testing includes ignition temperature, response when ignited, electrostatic discharge, impact, friction and shock. There are a number of authorized methods to obtain each of these; friction sensitivity can be obtained by Pendulum Friction, Rotary Friction, Sliding Friction (such as the ABL), BAM Friction and Steel/Fiber Shoe Methods.^{3,4} Within each of these accepted methods, there are countless nuances amongst laboratories which make direct comparison between locales extremely challenging. By comparing a new material to high-purity well-understood standard materials, such as PETN, Composition B and/or RDX, laboratories can better account for variability in these types of measurements; however, meaningful correlations are lacking between the various tests.

Recently, there have been a number of efforts and discussions aimed towards standardizing and correlating methods to improve data sharing.^{5,6} This research effort falls within the larger Integrated Data Collection and Analysis (IDCA) program which was funded and initiated by the Department of Homeland Security to facilitate standardization and data sharing between DoD, DOE, other US and international government laboratories and commercial partners. The IDCA group primarily focuses on the study of improvised or homemade explosive materials and has performed a large round robin exchange amongst DoD and DOE laboratories with 16 homemade explosive materials and 3 standard military explosive materials. Efforts such as these have called attention and garnered support for standardization and the need to correlate small-scale safety testing methods.⁷

The Air Force Research Laboratory at Eglin AFB has historically used the BAM friction apparatus for all safety testing and qualification and has a wealth of historical data using this apparatus.⁸ This friction sensitivity method mimics the antiquated mortar and pestle environment which is no longer utilized in the formulation and processing of energetic material formulation. Until recently, this was the preferred method of friction testing and continues to be a standard method in Europe.⁹ In 2014, the United Nations established the ABL friction apparatus as a

recommended method for obtaining friction sensitivity.¹⁰ The ABL apparatus mimics the stainless steel pinch points which are experienced by energetic materials during formulation and processing and is rapidly gaining in popularity, particularly in the U.S.¹¹

The literature does not have many examples of attempts to develop correlations between disparate small-scale safety testing methods. Those that have tried, resulted in limited success; some degree of correlation was found for high explosive materials in impact testing and another group was able to develop a translational function linking Rotary and BAM friction.¹²⁻¹⁴ The most recent study looked at 19 homemade explosives in an attempt to find a translational function or to develop a general correlation between the ABL and BAM apparatuses. Unfortunately, they were only able to highlight some phenomenological relationships and concluded that the methods are too dissimilar for correlation.¹⁵ This study differs in that it is isolated to high explosives of interest for military applications, it simplifies the complex characteristics of the initiation process for the test methods into two discrete factors and it utilizes statistical analysis to assist in development of the correlation. This study is a first attempt to develop a meaningful and useful correlation between these disparate methods so that the Air Force Research Laboratory Munitions Directorate (AFRL/RWM) can move forward with the ABL friction testing apparatus while maintaining useful historical data and to provide a statistical experimental methodology for further standardization amongst other research and production laboratories.

3. EXPERIMENTAL METHODOLOGY

3.1 Experimental Apparatuses

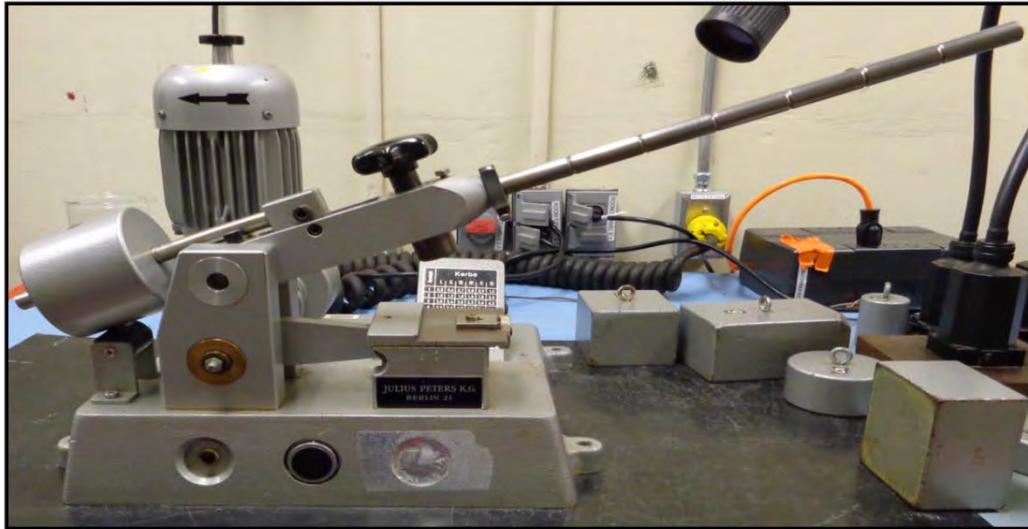


Figure 1. BAM Friction Apparatus

The BAM friction apparatus, Figure 1, is the standard sized friction load table manufactured by Julius Peters Company of Berlin, Germany (no longer in operation).¹⁶ It measures the friction sensitivity response of an energetic material placed between a porcelain plate and pin, Figure 2, with some force being exerted down as a result of a weight, Table 1, placed on the friction arm at discrete notches (corresponding to some load/force N, Table 2). The plate is then moved at a fixed speed (10 mm in 1 sec) with a single unidirectional motion. The two porcelain surfaces are roughened with finish lines normal to the direction of motion. This test apparatus mimics the friction environment of a mortar and pestle which is typically no longer utilized during energetic material formulation and processing, such as high shear mixing.⁸

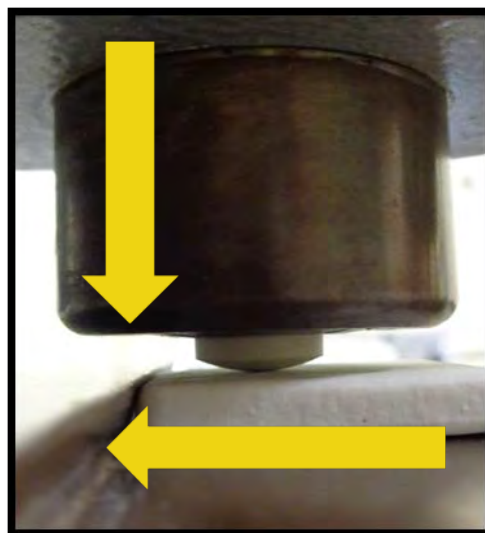


Figure 2. Porcelain pin and plate of BAM Friction Apparatus

Table 1. Mass of Weights No. 1-9⁸

Weight No.	1	2	3	4	5	6	7	8	9
Mass (g)	213	493	1053	1614	2174	3293	4414	6655	10005

Table 2. Loads for Weights No. 1-9 at Positions 1-6⁸

Weight No.	Notch	Load (N)	Weight No.	Notch	Load (N)
1	1	5	4	6	60
1	2	6	5	4	64
1	3	7	5	5	72
1	4	8	5	6	80
1	5	9	6	3	84
1	6	10	6	4	96
2	2	12	6	5	108
2	3	14	7	3	112
2	4	16	6	6	120
2	5	18	7	4	128
2	6	20	7	5	144
3	2	24	7	6	160
3	3	28	8	3	168
4	1	30	9	1	180
3	4	32	8	4	192
3	5	36	8	5	216
3	6	40	8	6	240
4	3	42	9	3	252
4	4	48	9	4	288
4	5	54	9	5	324
5	3	56	9	6	360

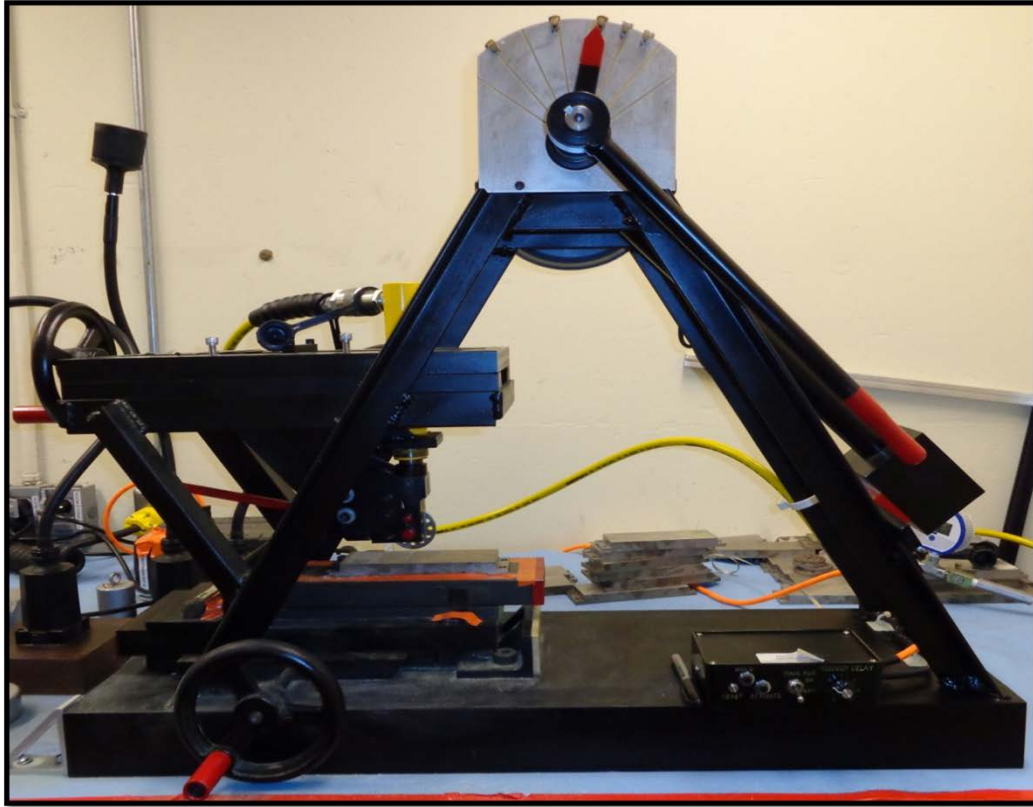


Figure 3. ABL Sliding Friction Apparatus

The ABL sliding friction apparatus, Figure 3, measures the friction sensitivity response of an energetic material placed between a fixed steel wheel and steel anvil with finish lines normal to the direction of motion, Figure 4.¹⁶ A variable compressive force is applied downward through the wheel hydraulically (50-1995 psi). The 5 kg pendulum impacts (8 ft/sec is the standard used herein) onto the edge of the anvil (60 mm by 165 mm steel plate), propelling it forward 25.4 mm at a known velocity perpendicular to the compressive force being applied through the non-rotating wheel. This test apparatus mimics the friction environment of steel pinch points which is seen extensively during the course of energetic material formulation and processing.¹¹

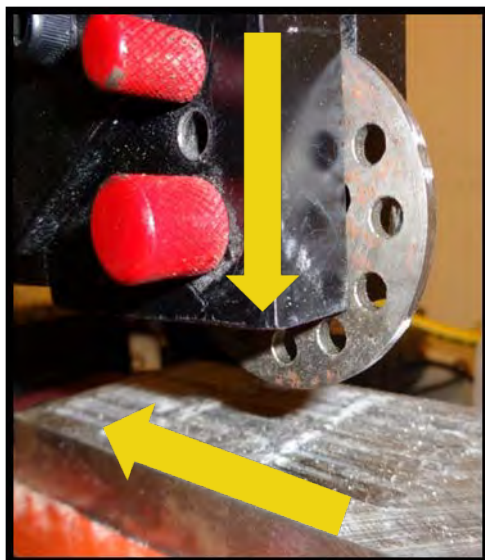


Figure 4. Anvil and non-rotating wheel of ABL Sliding Friction Apparatus

Friction sensitivity for both test apparatuses is the result of the test material either reacting (Go: reaction occurs – initiation in the form of detonation, deflagration, etc.) observed through smoke, fire, a pop or flash of light or not reacting (No-Go: no reaction occurs), reported in a binary manner with 1 representing a Go and 0 a No-Go. Traditionally, the experimentalist will report sensitivity by the Threshold Initiation Level (TIL). Qualification testing begins at a mid-value pressure or mass and works upward until a Go is achieved. Testing will then start moving down in pressure or mass, repeating at a given measurement until either a Go is achieved (followed by further steps down in pressure or mass) or 20 repetition results of No-Go responses.^{2,4} The sensitivity threshold is quantified by the estimate of the upper bound at which 20 trials result in No-Go results. This No-Go threshold is then compared to that of a high-purity and well-known standard material (PETN, RDX, Comp B, etc.).^{3,4}

3.2 Test Matrix

For traditional sensitivity testing, 10 Go responses at a particular level and 10 No-Go responses at a lower level establishes the bounds of sensitivity for acceptance or rejection. This method provides information at the tails of reaction distribution, but not necessarily much information about the reaction probability between the two zones. For this study, a new methodology was devised, Figure 5, in order to gain additional responses above and below the traditional threshold response. The test matrix in Figure 5 is designed to more thoroughly probe the zone of mixed results, where a Go or No-Go are equally likely to happen, by beginning testing in a zone where consistent Go responses are expected then moving down to the threshold (consistent No-Go is expected) then back up to where the upper limit of consistent Gos are expected. This matrix is explained thoroughly below and serves to map out the reaction probability distribution function for each material. The appendix contains completed test matrices from testing.

BAM	kg	Down						Up						Summary	
		1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
		36.0													
32.4														0	0
28.8														0	0
25.2														0	0
24.0														0	0
21.6														0	0
19.2														0	0
18.0														0	0
16.8														0	0
16.0														0	0
14.4														0	0
12.8														0	0
12.0														0	0
11.2														0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4														0	0
6.0														0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

ABL	psi	Down						Up						Summary	
		1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
		800													
660														0	0
560														0	0
420														0	0
370														0	0
320														0	0
240														0	0
180														0	0
130														0	0
100														0	0
50														0	0

Sample _____	<div style="display: inline-block; border: 1px solid blue; padding: 2px;">Down</div> <div style="display: inline-block; border: 1px solid red; padding: 2px; margin-left: 10px;">Up</div>	Overview 1 No-fire search 2 No-fire location 3 No-fire confirmation 4 All-fire search 5 All-fire location 6 All-fire confirmation 7 Mixed-results check
Date _____		
Temp _____		
RH _____		

Figure 5. Testing Matrix for BAM (left) and ABL (right) friction apparatuses

3.3 Test Matrix Procedures

1. Start testing using a stress (mass - kg or pressure - psi) that the experimentalist expects would induce 10 initiations out of 10 runs, recording data in the 'down' columns (1 for a Go, 0 for a No-Go).
2. Test a single sample, if an initiation is generated, continue to step down in single increments until a non-initiation is generated.
3. Continue testing at the non-initiation level until either 5 consecutive non-initiations are achieved; or a single initiation is generated.
- 4a. If a single initiation is generated, repeat step 2 and proceed.
- 4b. If 5 consecutive non-initiations are achieved, drop down one more step, and repeat 5 non-initiations.*

5. If 5 non-initiations are successfully achieved at this level, starting at two levels up (lowest level above 5 consecutive non-initiations), step back up in smallest increments possible (testing a single sample at each stress level) until an initiation is generated. Record data in the 'up' columns (1 for a Go, 0 for a No-Go).
 6. Continue testing at that level until either 5 consecutive initiations are achieved; or a single non-initiation is generated.
 7. If a single non-initiation is generated, continue to step up incrementally, testing a single sample at each stress level, until an initiation is generated.
 - 8a. If an initiation is generated, repeat step 6 and proceed.
 - 8b. If 5 consecutive initiations are generated, step one more level up, and repeat the 5 consecutive initiations.**
 9. Mixed Results: If the highest stress value which achieved a non-initiation is lower than the lowest stress value which achieved an initiation (no 'overlap' region), run additional tests at or between these stresses until an overlap region is achieved. This data can be recorded in either column.
- * If a single initiation occurs during testing the 5 confirmatory non-initiations, step down one more level and repeat from step 3.
- ** If a single non-initiation occurs during testing the 5 confirmatory initiations, step up one more level and repeat from step 7.

3.4 Material Selection

Polyurethane based-binder systems, melt-castable explosive formulations and raw explosive ingredients were utilized in this study in order to develop a correlation which would be applicable to a wide range of materials (raw and formulations) to include experimental or developmental materials. AFX-196, AFX-256, MNX-808, PBXN-109, PBXN-110, RDX (Class V, Type II), HMX (Class V, Type II) and FOX-7 were chosen to represent the broad range of materials for this study.

3.5 Statistical Analysis

A generalized linear model, was utilized for the statistical analysis of the binary response Go and No-Go friction sensitivity results (1 input for Go, 0 input for No-Go). This model assumes a cumulative normal distribution for the probability of an event occurring given a certain stress level (weight on the BAM or pressure on the ABL) defined by the parameters μ (mean) and σ (standard deviation), accounting for left- and right-censoring of the data, Figure 6. Empirical models were developed to relate the parameters, μ and σ , expected on the BAM from the ABL data and vice versa.¹⁷⁻¹⁹

The data was analyzed as the test results were performed to ensure that the regression curve had informative confidence bounds. In the event that the confidence bounds were uninformative (i.e. they diverged to 1 and 0, indicating that the probability of occurrence is somewhere between “never occurring” and “always occurring”) additional test points were proposed to improve the regression equation.

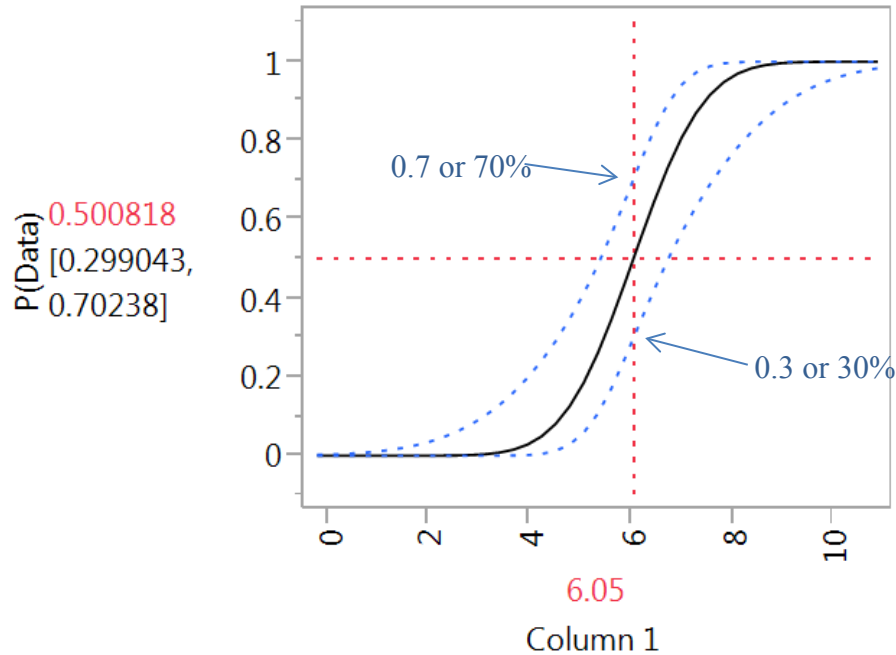


Figure 6. Example of the generalized linear model – Probit (Probability Unit) regression analysis with confidence bounds on the probability curve

From each set of Go/ No-Go data generated for a particular explosive, a logistic regression curve was generated (individual regression curves provided in the appendix). An example of the regression curve for HMX tested using the BAM friction apparatus is shown in Figure 7. The data points represent the response of the explosive given a certain stimulus (weight and position on the BAM friction apparatus). The curve is a maximum likelihood estimate of a fit line through the probability ratios.

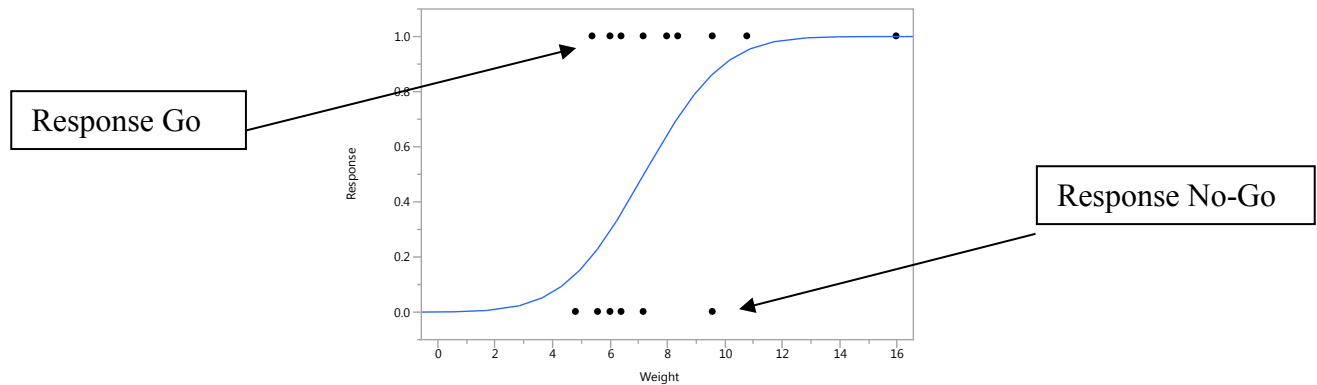


Figure 7. This graph highlights the lack of information in the zone of mixed results where the analysis is less meaningful due to low confidence between a Go and No-Go response

The curve shown in Figure 8 displays the same data, but this time with the confidence bounds of the curve fit included. This curve incorporates information from the zone of mixed results and provides information along the entire curve.

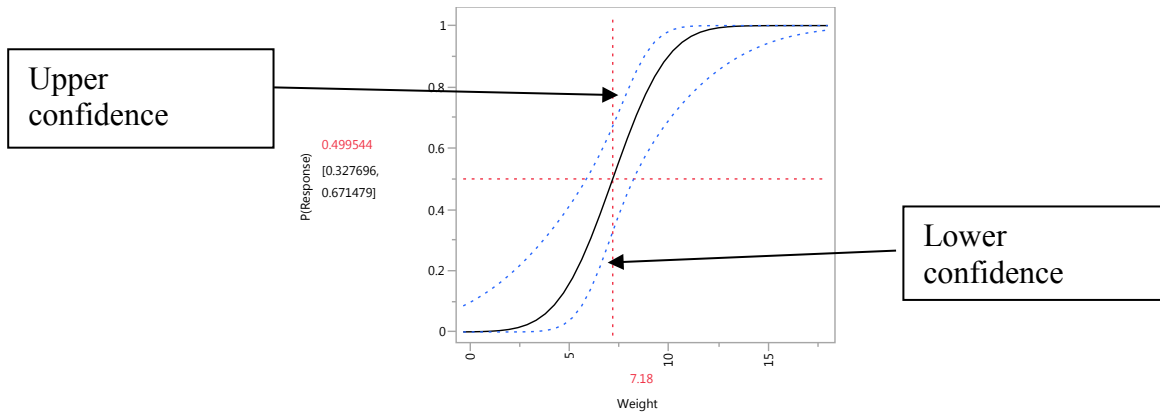


Figure 8. This graph highlights the more useful information provided through utilization of the new test matrix and use of the Probit regression model

In order to generate an estimate of probability, a link function must be used that follows the laws of probability; specifically that the probability can never be less than zero or greater than one. In this case, a Probit link function was used. The Probit regression analysis is based on the cumulative normal distribution with the parameters μ and σ .¹⁹

4. RESULTS AND ANALYSIS

4.1 Data Analysis

The data for each series was fit to the cumulative normal distribution function written in linear form with parameters β_0 and β_1 :

$$P(x) = \frac{1}{2} [1 + \operatorname{erf} (\beta_1 x + \beta_0)] \quad (1)$$

Where erf is the error function and x is the mass or the pressure independent variable of the BAM or ABL test, respectively. The parameters μ and σ were then calculated from the maximum likelihood fit parameters. The relationships between the linear fit parameters (β_0 and β_1) and the parameters of a normal distribution (μ and σ) are shown below in Equations 2 and 3.

$$\sigma = \frac{1}{\beta_1} \quad (2)$$

$$\mu = -\sigma \beta_0 \quad (3)$$

The parameters μ and σ are sufficient to describe a cumulative normal distribution, the results of which are shown in Table 3 for the materials tested. The parameters μ and σ are the factors which this study is attempting to predict. The objective is the prediction of the response parameters of one apparatus based upon the experimentally derived parameters of the other across the range of materials. After the parameters of each test were obtained experimentally, Table 3, the relationship between the BAM and the ABL test apparatuses was explored mathematically.

4.2 Selection of Parameters

It is noteworthy to point out that the modeled parameters were not either β_0 and β_1 or μ and σ but a combination of β_1 and μ . It was not possible to construct a mathematical model of β_0 for the ABL apparatus using the β_0 and β_1 values from the BAM apparatus or conversely for the β_0 for the BAM apparatus using the β_0 and β_1 values from the ABL apparatus. The experimentally collected data values were of a similar order of magnitude but varied too significantly amongst individual data pairs, shown in Figure 9. Discarding data pairs which differed too greatly in magnitude would have resulted in significant shrinkage of the data set due to the large relative differences between the majorities of the data pairs. The differences found in β_0 values when performing a matched pair's analysis were not statistically different in enough of the pairs to make an informative regression. The location parameter, β_0 , did not vary as expected (uniformly) to model without the effect of the scale parameter.

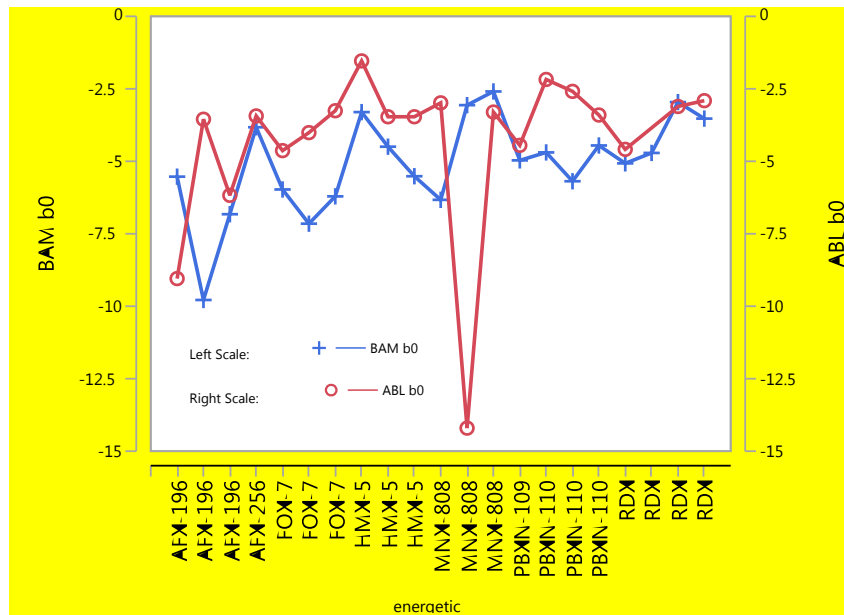


Figure 9. Comparison of experimentally derived values for β_0 on BAM (left) and ABL (right) for each sample tested

The β_0 term varied between the BAM and ABL apparatuses almost randomly and to such an extent that in order to construct a model that represented μ , a direct estimate of μ was necessary. Through modeling μ directly, the effect of the β_0 term was reduced. Otherwise, estimates of μ would have been based entirely on σ (or its negative inverse, β_I) which would be meaningless because the estimates of μ are orders of magnitude different. The downside to this type of approach is that the location effect (mean) is confounded with the scale effect. This effectively makes the assumption that it is a property of the individual apparatus and how each material interacts with a particular apparatus, which may not be an erroneous assumption.

4.3 Preliminary Correlation

A preliminary examination of how closely the experimentally derived signals for each material track to one another allows for a cursory look at the correlation and consistency in testing. The magnitude and direction of the differences in the experimentally obtained parameters for the BAM and ABL apparatuses are shown in Figure 10. The two lines in each graph are to different scales so direct comparison is not possible.

The overlay plots show divergence for some of the heterogeneous materials (especially apparent in the melt-castable materials) and more consistency in variation of direction and magnitude in the single component powder materials (RDX and HMX). When replicate samples are averaged, consistency in magnitude and direction is observed between the BAM and ABL apparatuses, Figure 11. Data for AFX-256 and PBXN-109 are excluded as they are derived from a single sample. This might indicate that variation is due to the heterogeneous nature of the melt-castable and polyurethane based formulations (natural variation of material) or an interaction between the fundamental function of the apparatus and the mixture properties of the materials.

In the case of melt-castable samples (AFX-196 and AFX-256), there was increased sample variability likely due to sample preparation procedures in which the samples are ground and sieved prior to testing. Polyurethane based formulations were cast into strips for friction testing and as a result samples were very uniform although in both cases the materials are heterogeneous mixtures. The data from these samples are included in the development of the correlation but should be explored further to identify sources of variability and to further strengthen the correlation.

Surprisingly, it appears that instrument variability is not as large as previously believed. Results from both instruments are reproducible from run to run in the short term (not necessarily on the time-scale to observe long term drift). It would be worthwhile to study this further to more accurately quantify instrument variability for the sensitivity testing community.

Table 3. Estimated maximum likelihood parameters for materials tested

Material	BAM β_0	BAM β_1	BAM μ	BAM σ	ABL β_0	ABL β_1	ABL μ	ABL σ
AFX 196	-6.83	0.629	10.85	1.59	-6.174	0.0045	1365.68	221.19
AFX-196*	-9.78	0.752	13.01	1.33	-3.549	0.0034	1029.46	290.05
AFX-196*	-5.53	0.343	16.15	2.92	-9.046	0.0087	1042.48	115.24
AFX-256	-3.83	0.196	19.55	5.11	-3.436	0.0092	375.22	109.21
FOX 7	-6.21	0.435	14.27	2.30	-3.255	0.0026	1259.34	386.85
FOX 7	-7.15	0.454	15.76	2.20	-4.011	0.0031	1277.11	318.4
FOX 7	-5.97	0.263	22.74	3.81	-4.632	0.0023	2011.33	434.2
HMX	-5.52	0.912	6.050	1.10	-3.464	0.019	178.21	51.45
HMX	-4.50	0.859	5.24	1.17	-3.464	0.019	178.21	51.45
HMX	-3.30	0.46	7.180	2.17	-1.537	0.012	125.45	81.61
MNX-808	-2.59	0.112	23.07	8.90	-3.302	0.0054	611.03	185.07
MNX-808**	-3.06	0.127	24.20	7.90	-14.20	0.014	1001.95	70.54
MNX-808	-6.33	0.267	23.69	3.74	-2.984	0.0025	1171.29	392.57
PBXN-109	-4.97	0.258	19.28	3.88	-4.449	0.0052	849.47	190.93
PBXN-110	-4.45	0.152	29.27	6.57	-3.404	0.0042	808.99	237.66
PBXN-110	-5.69	0.203	27.98	4.92	-2.588	0.0027	944.5	365
PBXN-110	-4.69	0.197	23.77	5.06	-2.177	0.0025	862.38	396.21
RDX	-3.53	0.369	9.560	2.71	-2.908	0.013	223.91	76.99
RDX	-2.96	0.331	8.931	3.02	-3.109	0.011	271.89	87.45
RDX**	-4.71	0.516	9.130	1.94	--	--	--	--
RDX	-5.07	0.626	8.110	1.60	-4.588	0.015	306.47	66.8

In some cases, data was found to have confidence bounds that failed to converge. In these cases, data was discarded or combined in order to eliminate excess variation in the statistical models. * Indicates that data was combined and ** indicates that data was discarded.

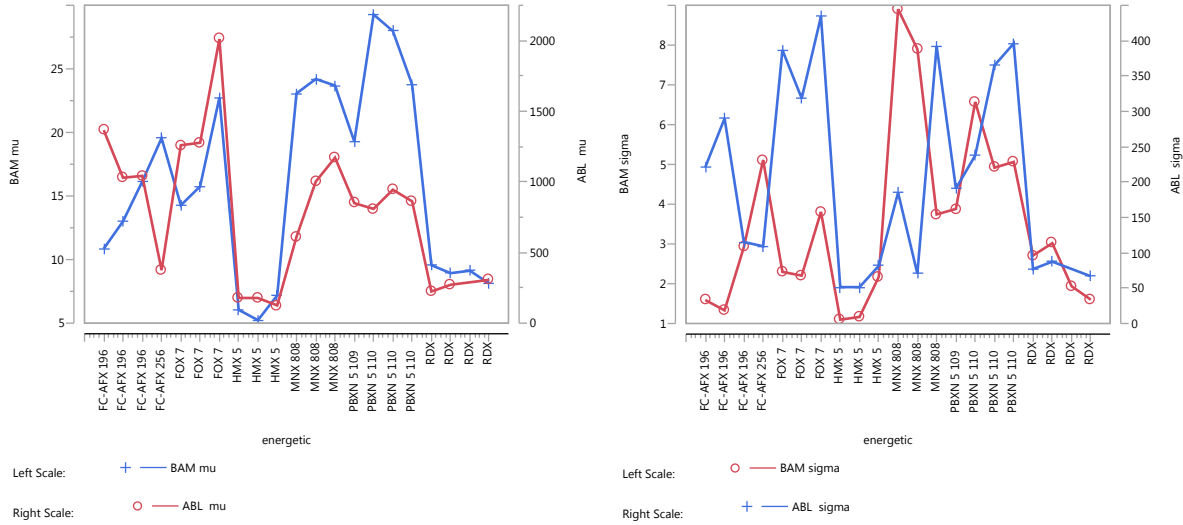


Figure 10. (Left) Overlay plots with the mu signal variation between ABL (red) and BAM (blue) friction apparatuses. (Right) Overlay plots with the sigma signal variation between ABL (blue) and BAM (red) friction apparatuses

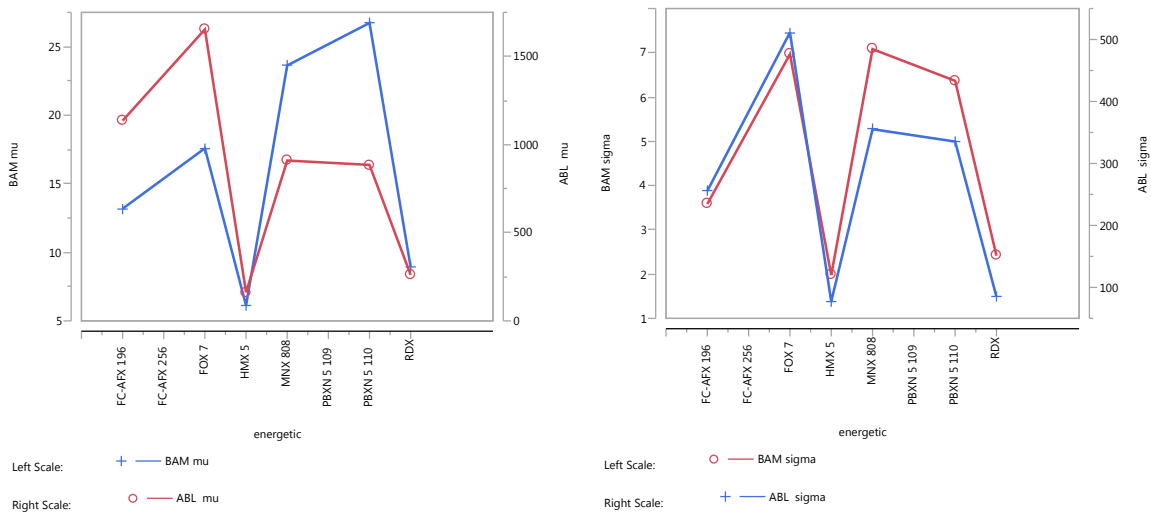


Figure 11. (Left) Overlay plots with the average mu signal responses between ABL (red) and BAM (blue) friction apparatuses. (Right) Overlay plots with the average sigma signal responses between ABL (blue) and BAM (red) friction apparatuses

While the goal of this effort was to provide a single broad and general correlation between the BAM and ABL friction apparatuses it is possible that different classes of materials correlate differently between the two methods. Further, it is worth emphasizing that the powdered energetic materials were sampled from strictly controlled, single-lot, well-characterized standard materials. In contrast, the polymer-based and melt-castable materials were sampled from single lot materials and are heterogeneous in nature. A cursory look at the mean and standard deviation responses of these three classes of materials is given in Figure 12. The groupings suggest that there may be a relationship between the mean response of powders, PBX

formulations and wax formulations. A relationship is not readily apparent in the BAM and ABL standard deviation responses for the three types of materials studied. These relationships may be of interest in future investigations.

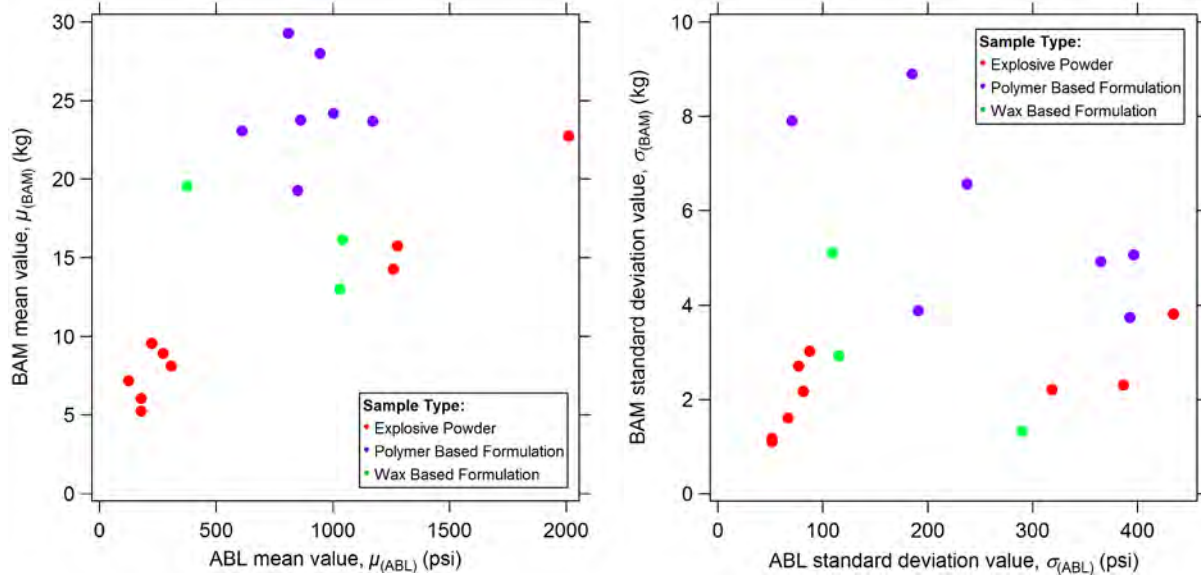


Figure 12. Graphical comparison of mean (left) and standard deviation (right) values for BAM (x -axis) and ABL (y -axis) measurements of explosive powders (red), polymer-based formulations (blue) and wax-based formulations (green)

4.4 Prediction of ABL Parameters from BAM Results

Prediction expressions were derived for the ABL apparatus from parameters of the BAM apparatus experiments using a combination of the parameters β_0 , β_1 , μ and σ . The β_0 and β_1 values from the experimental results for the BAM apparatus were used in the prediction expression, shown in Equation 4, to predict the β_1 value for the ABL apparatus. Figure 13 shows a graph of the predicted ABL β_1 values (x axis) plotted against the experimentally derived (actual) ABL β_1 values (y axis) as determined experimentally. All of the materials are within the confidence bounds with the polyurethane-based formulation, MNX-808, having the largest variability between replicate runs and being the furthest from the derived value line.

$$\begin{aligned}
 \beta_{1(ABL)} = & 0.01385394383951 + 0.00296270321481 \beta_{0(BAM)} \\
 & + 0.02004729198554 \beta_{1(BAM)} \\
 & + \{\beta_{0(BAM)} - (-5.1019597)\} \times \{[\beta_{0(BAM)} - (-5.019597)] \times 0.00037714265794\} \\
 & + \{\beta_{0(BAM)} - (-5.1019597)\} \times \{[\beta_{1(BAM)} - 0.39684075555556] \times 0.00762552928509\} \\
 & + \{(\beta_{1(BAM)} - 0.39684075555556) \\
 & \times [(\beta_{1(BAM)} - 0.39684075555556) \times 0.01380030525933]\}
 \end{aligned} \tag{4}$$

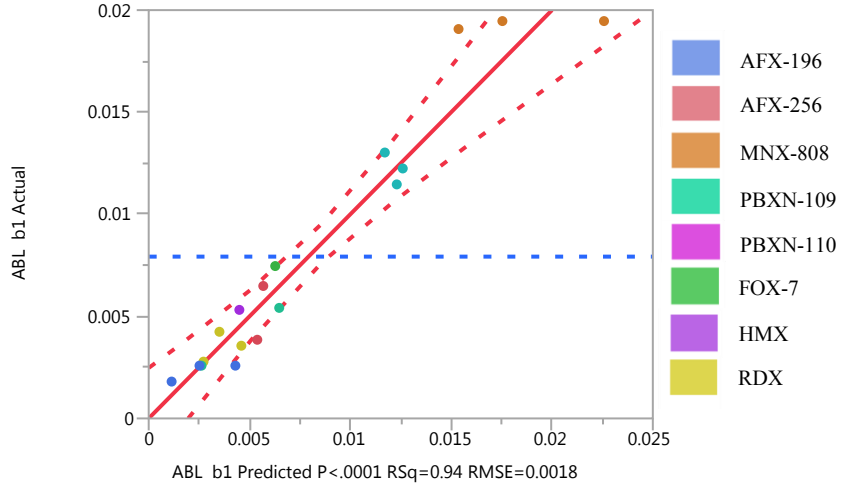


Figure 13. Predicted β_1 values (x axis) plotted versus actual β_1 values (y axis) for the ABL apparatus for all materials studied

The μ and σ values estimated from the actual ABL experiments were then used to calculate the ABL μ values using Equation 1, above, and the derived expression shown in Equation 5. Figure 14 shows a graph of the predicted ABL μ values (x axis) plotted against the actual ABL μ values (y axis) as determined experimentally. There is greater deviation in the μ values than seen in the derived β_1 values, with the melt-castable formulations having greatest variability and being furthest from the experimentally derived values.

$$\begin{aligned}
 \mu_{(ABL)} = & 404.636354868987 + 94.1860144503784 \mu_{(BAM)} & (5) \\
 & + (-321.54126535698) \sigma_{(BAM)} \\
 & + \{(\mu_{(BAM)} - 16.2242653429444) \\
 & \times [(\sigma_{(BAM)} - 3.54447654427778) \times (-27.350192500987)]\} \\
 & + \{(\sigma_{(BAM)} - 3.54447654427778) \\
 & \times [(\sigma_{(BAM)} - 3.54447654427778) \times 67.7607275547574]\}
 \end{aligned}$$

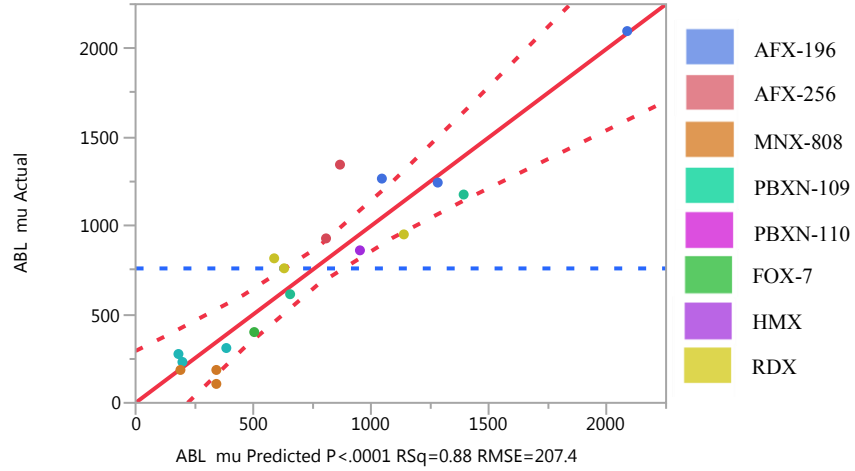


Figure 14. Predicted mu values (x axis) plotted versus actual mu values (y axis) for the ABL apparatus for all materials studied

4.5 Prediction of BAM Parameters from ABL Results

Prediction expressions were also derived for the BAM apparatus from parameters of the ABL apparatus using a combination of the parameters β_0 , β_1 , μ and σ . The β_0 and β_1 values from the experimental test results for the ABL apparatus were used in the prediction expression, shown in Equation 6, to predict the β_1 value for the BAM apparatus. Figure 15 shows a graph of the predicted BAM β_1 values (x axis) plotted against the actual BAM β_1 values (y axis) as determined experimentally. Again, the melt-castable formulations and MNX-808 show large variations between runs. The melt-castable samples also fall outside of the confidence bounds more frequently than the other materials.

$$\begin{aligned}
 \beta_{1(BAM)} = & (-0.1062755137965) + (-0.0862241340497 \beta_{0(ABL)}) & (6) \\
 & + 3.8754944002461 \beta_{1(ABL)} \\
 & + \{(\beta_{1(ABL)} - 0.0079254868889) \\
 & \times [(\beta_{1(ABL)} - 0.0079254868889) \times 4769.3489266296]\}
 \end{aligned}$$

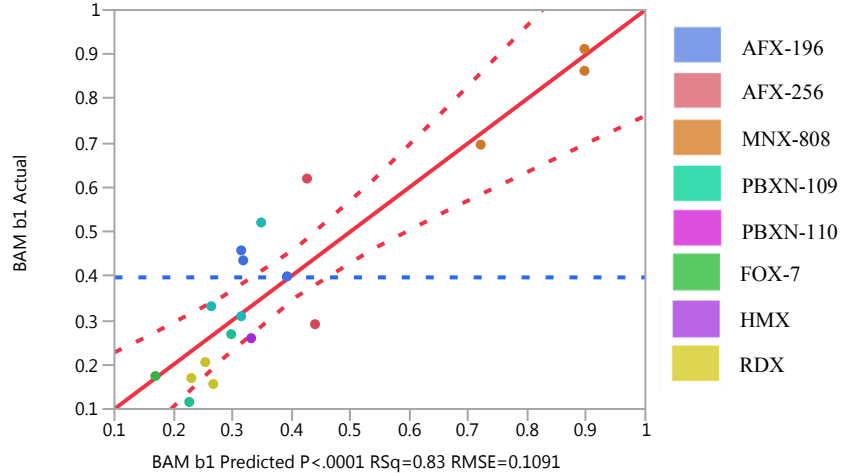


Figure 15. Predicted β_1 values (x axis) plotted versus actual β_1 values (y axis) for the BAM apparatus for all materials studied

The μ and σ values estimated from the actual BAM experiments were then used to calculate the BAM μ values using Equation 2, above, and the derived expression shown in Equation 7 (where β values refer to ABL β parameters). Figure 16 shows a graph of the predicted BAM μ values (x axis) plotted against the actual BAM μ values (y axis) as determined experimentally. The melt-castable formulations continue to show variability between runs. Further exploration of sample variability and additional runs of all materials would be very helpful in decreasing variability and improving derived expressions for both apparatuses.

$$\begin{aligned} \mu_{(BAM)} = & 8.77389626325093 + 0.04623799900042 \sigma_{(ABL)} & (7) \\ & + \{(\sigma_{(ABL)} - 220.139702508333) \\ & \times [(\sigma_{(ABL)} - 220.139702508333) \times (-0.0001236098308)]\} \end{aligned}$$

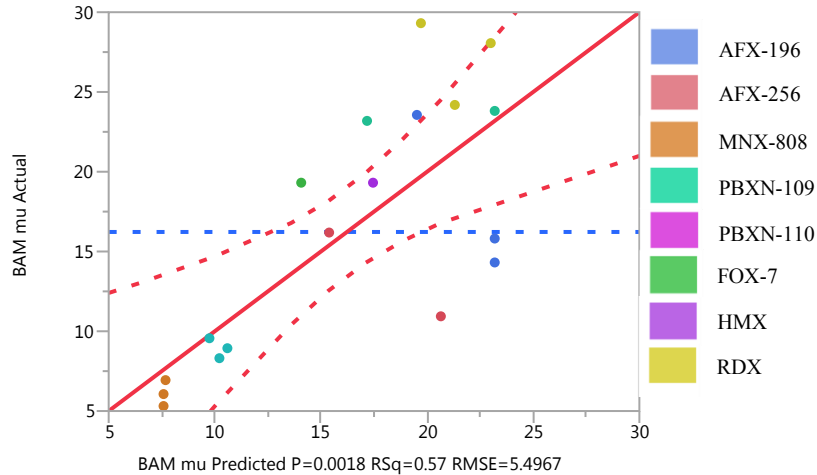


Figure 16. Predicted mu values (x axis) plotted versus actual mu values (y axis) for the BAM apparatus for all materials studied

4.6 Parameter Prediction Fitting

A comparison of how well the predicted (pred) parameter values compare to the parameter values estimated from the test data are shown in Figure 17 for the ABL apparatus and Figure 18 for the BAM apparatus. The sigma values were calculated using Equation 2, above. The 95% confidence interval is displayed in the dark blue shaded regions in the figures. This region represents a probability space associated with a non-random, unknown parameter and is computed as a probability from the data. The 95% prediction interval is displayed as the light blue regions in the graphs. It is associated with a random variable that has not yet been observed within the confines of these experiments, has a specified random probability associated with it at some point within the interval and provides the probability interval for future observations.

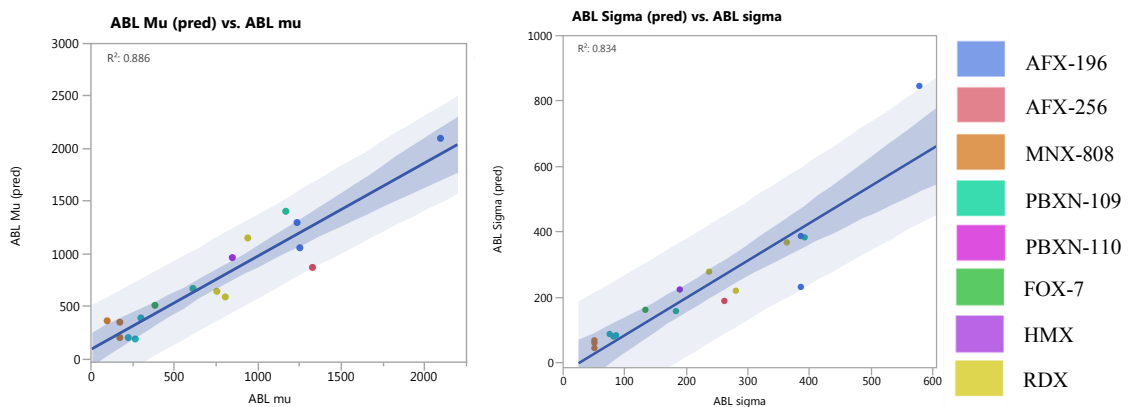


Figure 17. Predicted (pred) mu values (x axis) plotted versus actual mu values (y axis), left, and predicted (pred) sigma values (x axis) plotted versus actual sigma values (y axis), right, for the ABL apparatus for all materials studied. Dark blue region is the 95% confidence interval. Light blue region is the 95% prediction interval.

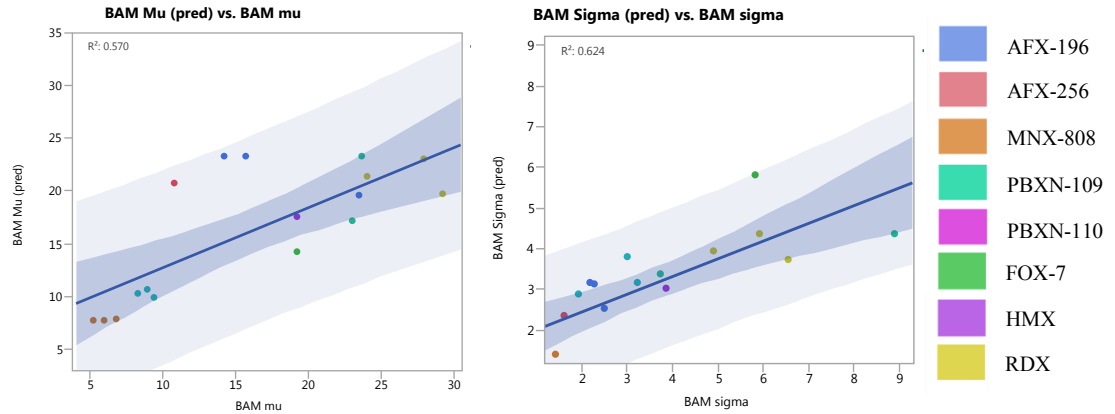


Figure 18. Predicted (pred) mu values (x axis) plotted versus actual mu values (y axis), left, and predicted (pred) sigma values (x axis) plotted versus actual sigma values (y axis), right, for the BAM apparatus for all materials studied. Dark blue region is the 95% confidence interval. Light blue region is the 95% prediction interval.

The prediction of ABL values from the BAM data is significantly more accurate than the prediction of BAM values from the ABL data. Using Equations 2, 3, 6 and 7 along with experimental data from the ABL apparatus, BAM μ is predicted with 57% accuracy and σ with 62% accuracy. Using Equations 2, 3, 4 and 5 along with experimental data from the ABL apparatus, BAM values are predicted with 89% accuracy for μ and 83% accuracy for σ . These derived expressions allow for a basic understanding of where to expect historical BAM values to now fall on the ABL apparatus but does not allow accurate prediction of BAM values while transitioning to the ABL apparatus. There remains significant work to be done to obtain a more accurate and generally applicable correlation.

5. CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

Herein is described an experimental methodology which results in a statistical correlation between the BAM Friction and ABL Sliding Friction apparatuses. The correlation has been demonstrated across a variety of materials, including single component explosive powders, and polymer or wax composite explosive formulations. The correlation was found to be significantly stronger in the prediction of BAM values from ABL data than the converse. The observations in this study are based solely on the sensitivity of the energetic materials, and do not take into account any of the variation in ability to initiate due to mixture properties, or any interactions between the test apparatus and the energetic material. Additionally, the study focused on secondary explosive materials and does not extend to propellants, pyrotechnics, primary explosives, etc. Any measureable characteristics of the initiation methods of the test apparatus (such as roughness of the interface) have not been explored as factors of the experiment and are classified as one of two levels in a single variable (categorical factor): BAM or ABL friction apparatus. It is likely that additional data will improve parameter estimates and the ability to predict energetic sensitivity from one friction apparatus to another.

5.2 Future Work

The research presented herein represents an initial study into the development of a correlation between the BAM and ABL friction apparatuses across a broad range of materials. There is a significant amount of work remaining to obtain a solid correlation that works both ways (converting ABL into BAM data and vice versa). To further improve the correlation and ensure its generality, future studies should consider increasing the number of replicate runs for each sample, introducing lot-to-lot variation and including additional materials of interest (raw ingredients, melt-castable, polyurethane based and experimental formulations). The sample preparation for the melt-castable explosives, including grinding method and particle size effects, should be explored. Finally, other variables should be explored (including temperature, humidity, initiation effects, mixture properties and instrument specific variables) to further strengthen the correlation.

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APPENDIX

Individual Probit Regression Curves – Actual vs. Predicted

LIST OF FIGURES

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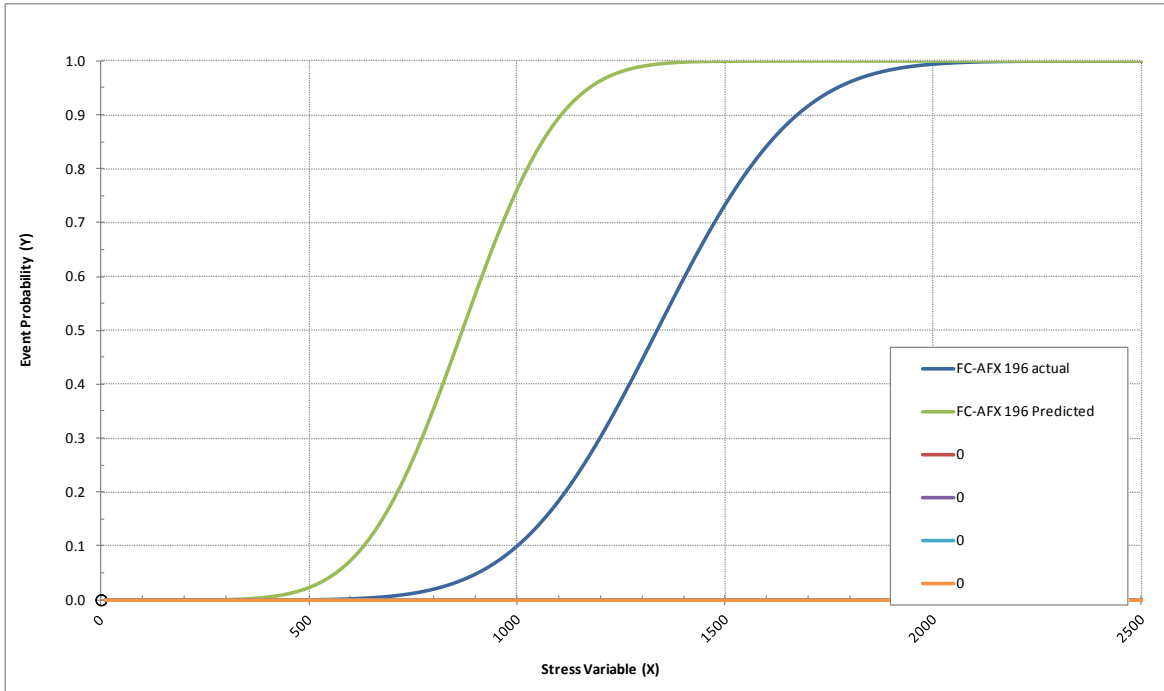


Figure A-1. Probit Regression Curve for AFX-196 sample. Actual experimental data in blue and prediction in green.

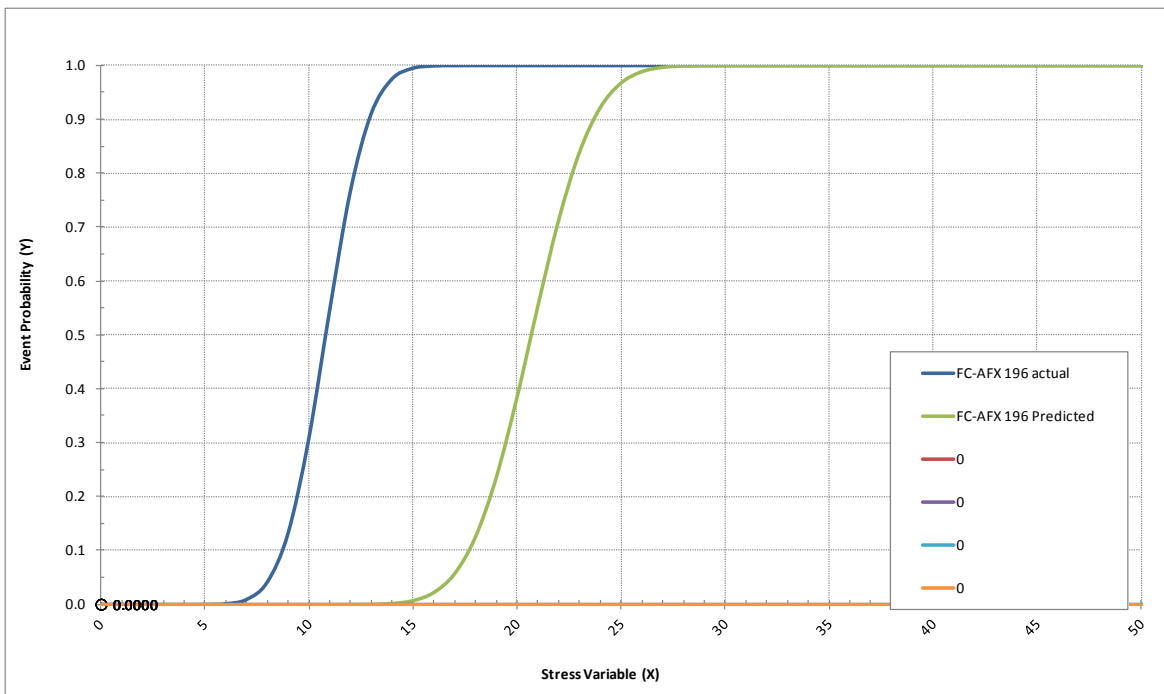


Figure A-2. Probit Regression Curve for AFX-196 sample. Actual experimental data in blue and prediction in green.

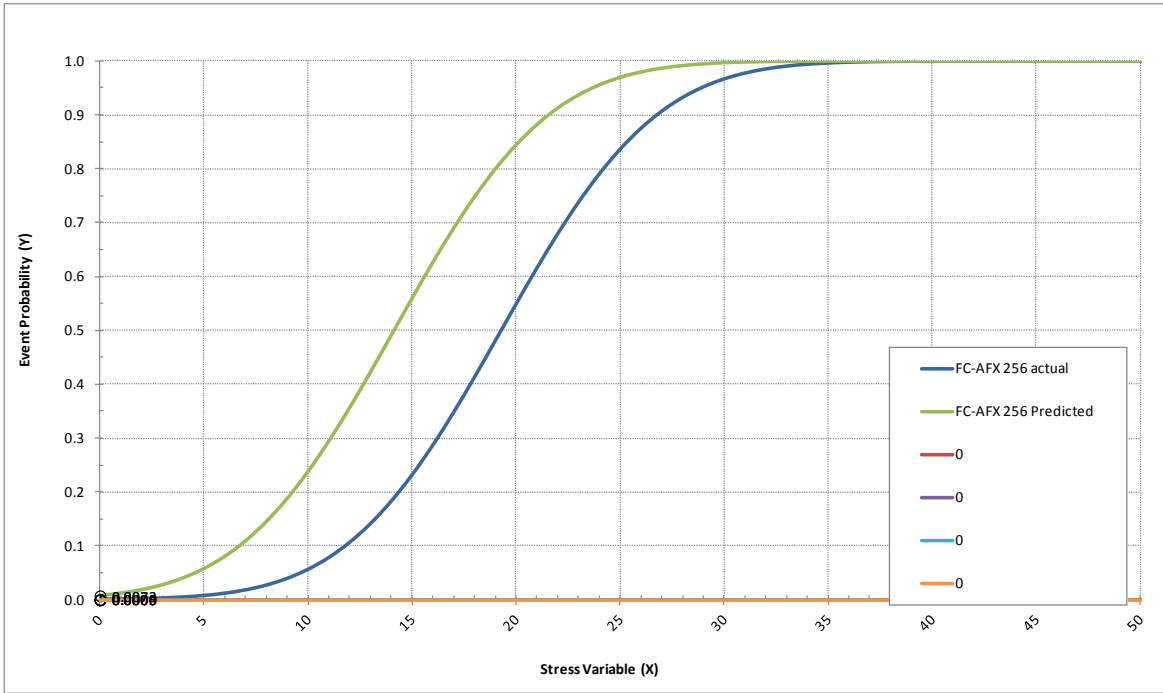


Figure A-3. Probit Regression Curve for AFX-256 sample. Actual experimental data in blue and prediction in green.

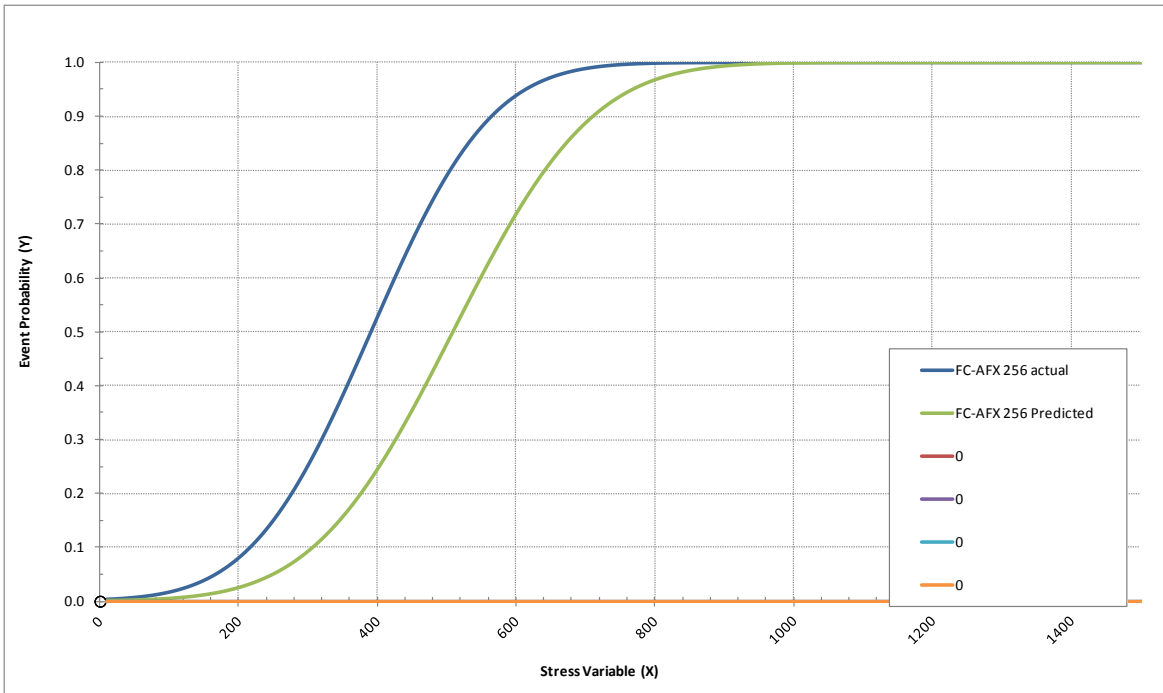


Figure A-4. Probit Regression Curve for AFX-256 sample. Actual experimental data in blue and prediction in green.

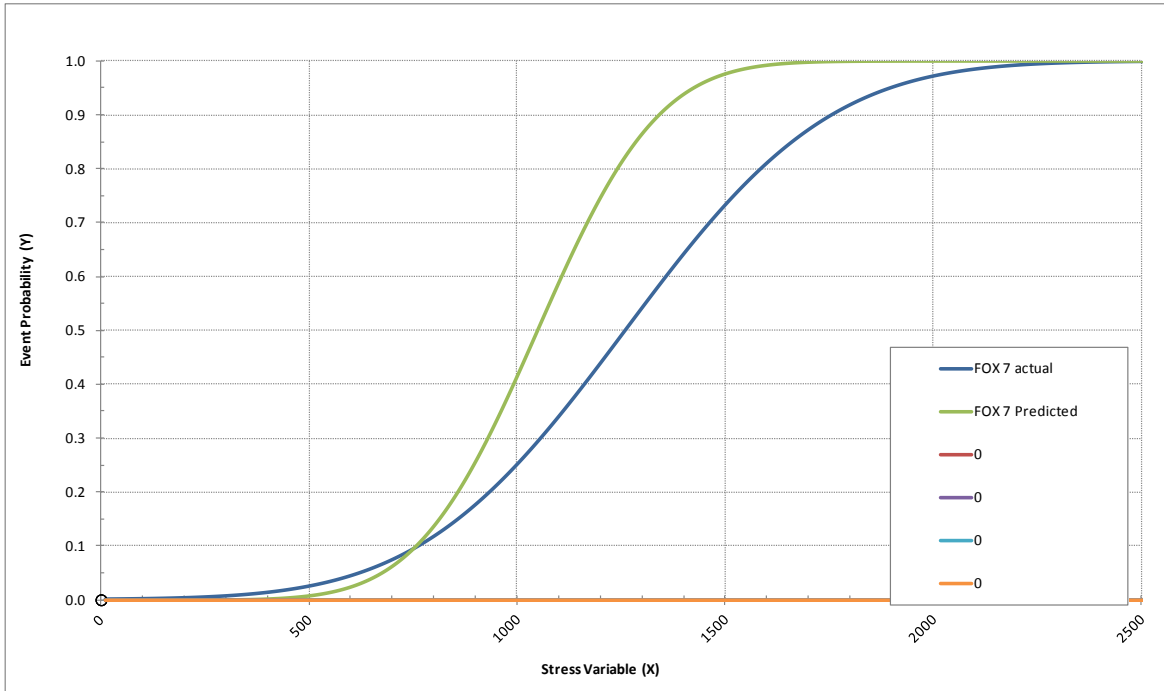


Figure A-5. Probit Regression Curve for FOX-7 sample. Actual experimental data in blue and prediction in green.

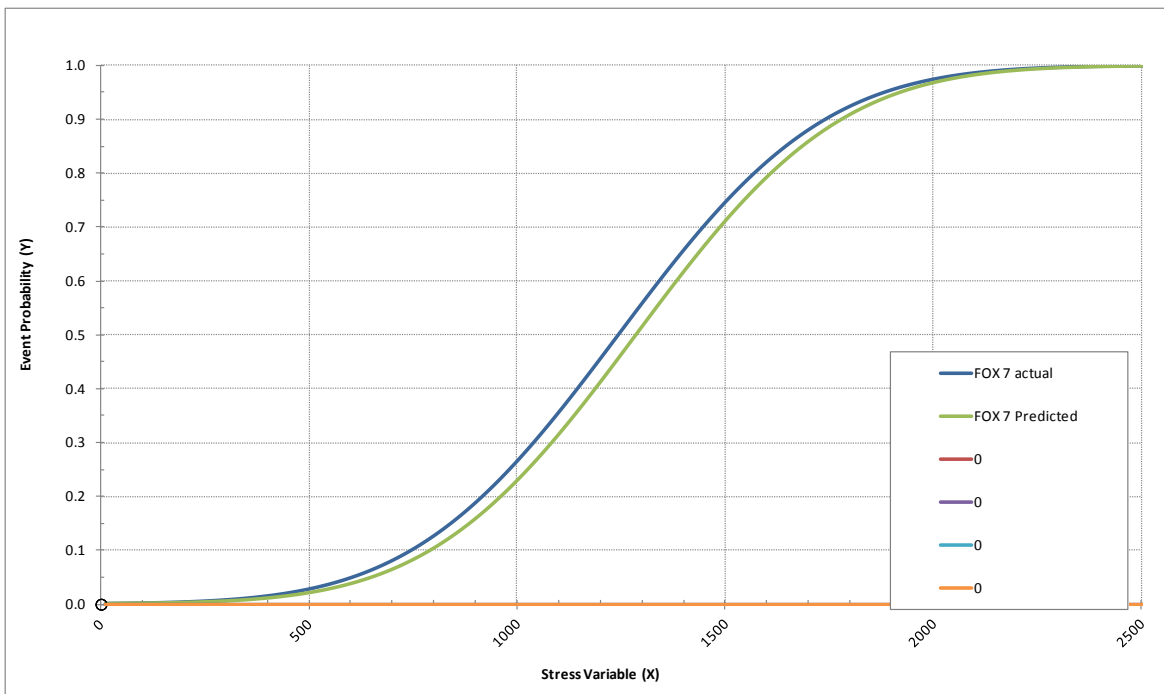


Figure A-6. Probit Regression Curve for FOX-7 sample. Actual experimental data in blue and prediction in green.

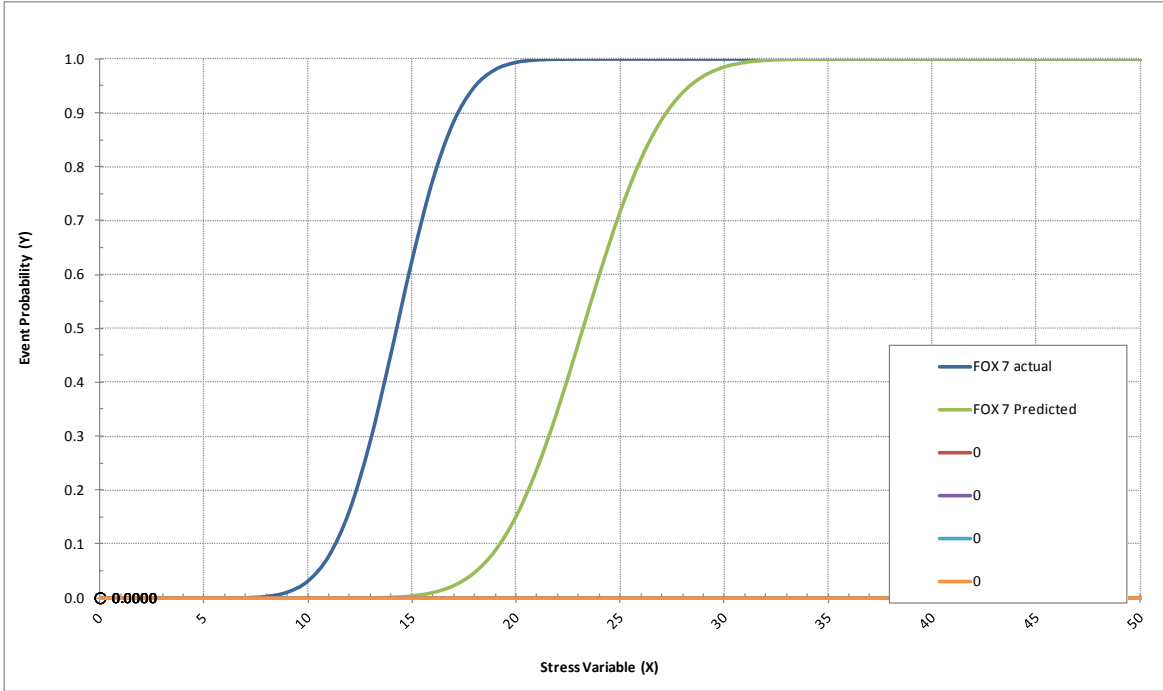


Figure A-7. Probit Regression Curve for FOX-7 sample. Actual experimental data in blue and prediction in green.

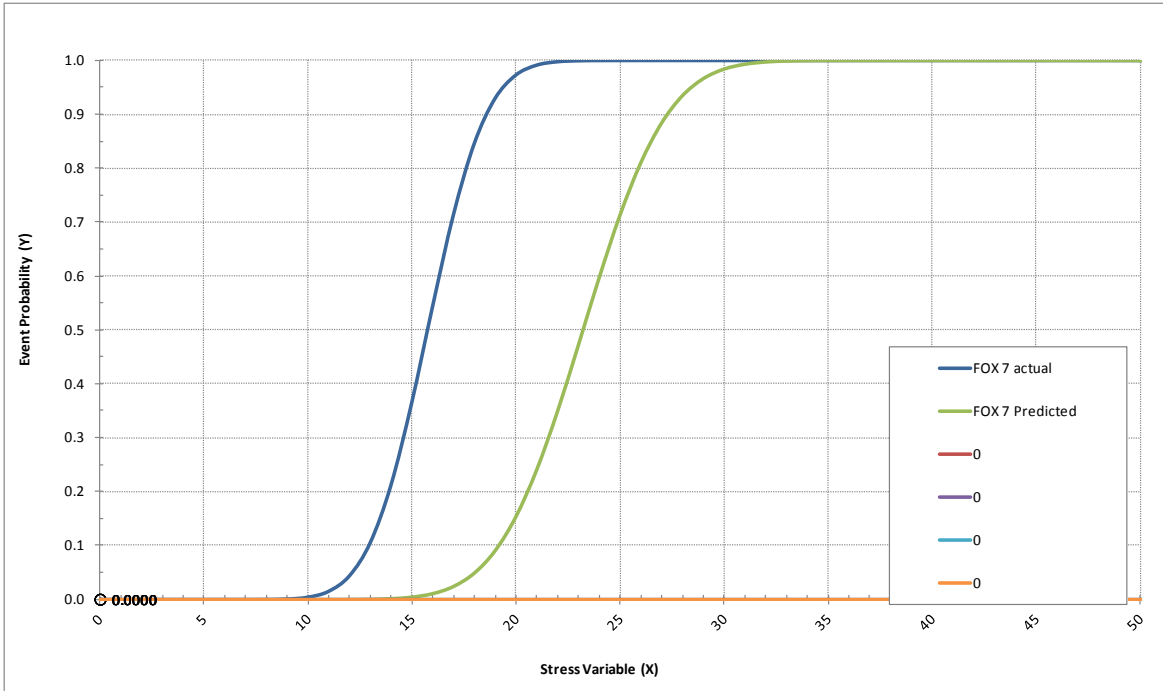


Figure A-8. Probit Regression Curve for FOX-7 sample. Actual experimental data in blue and prediction in green.

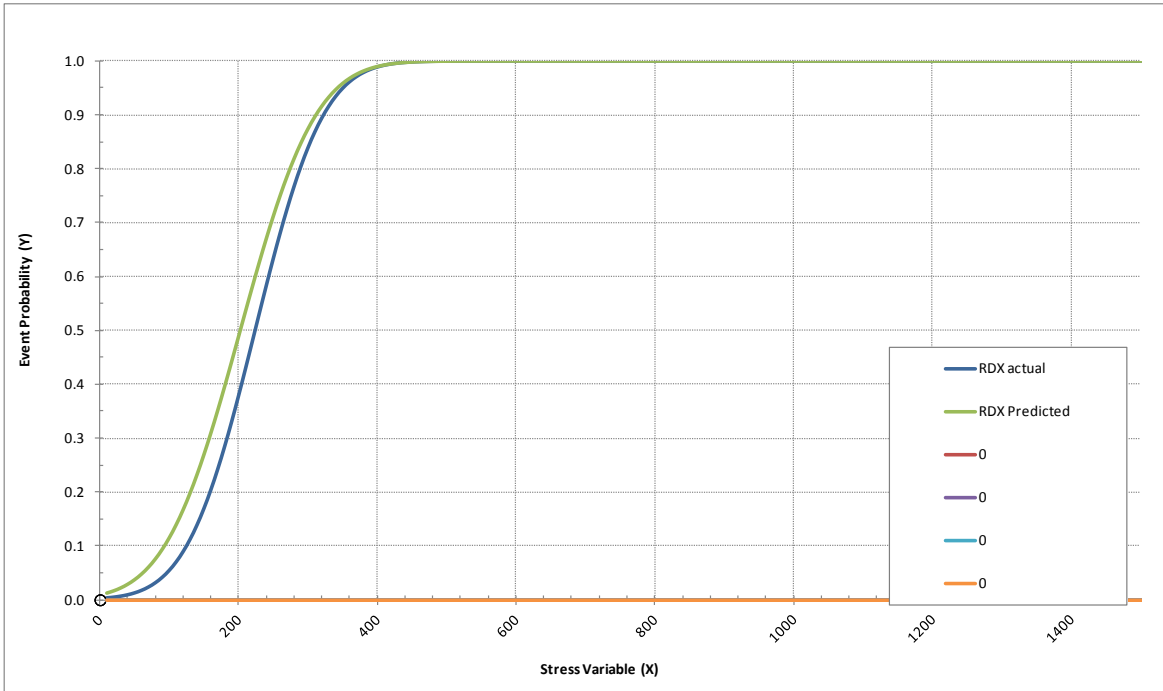


Figure A-9. Probit Regression Curve for RDX sample. Actual experimental data in blue and prediction in green.

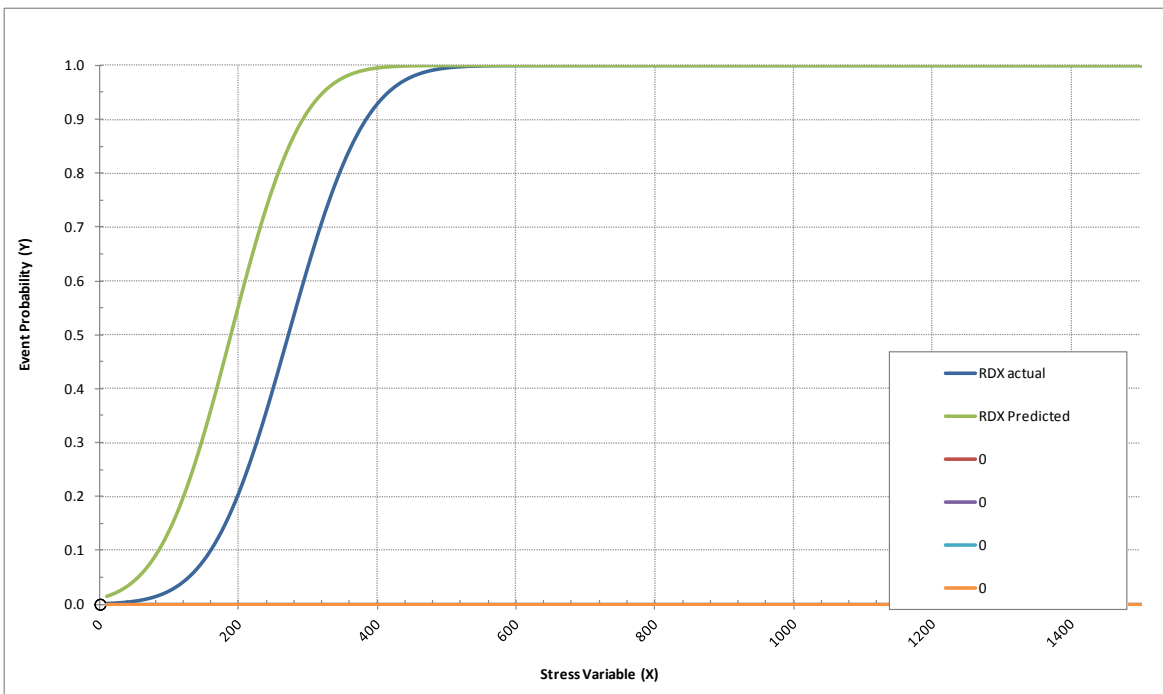


Figure A-10. Probit Regression Curve for RDX sample. Actual experimental data in blue and prediction in green.

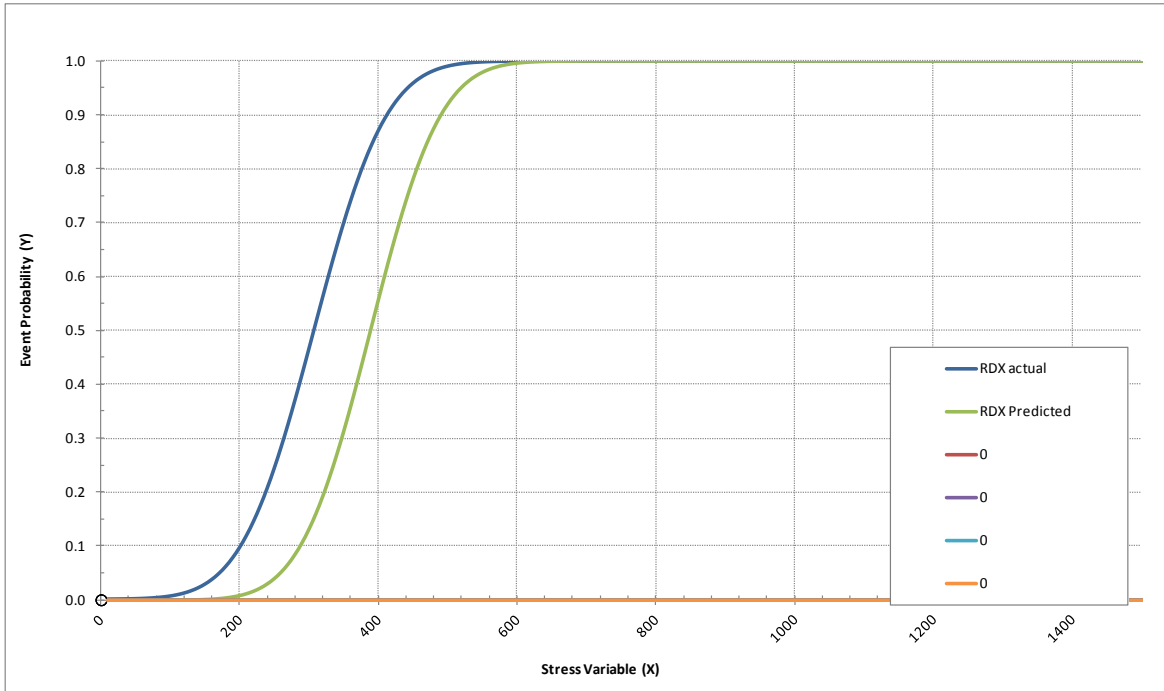


Figure A-11. Probit Regression Curve for RDX sample. Actual experimental data in blue and prediction in green.

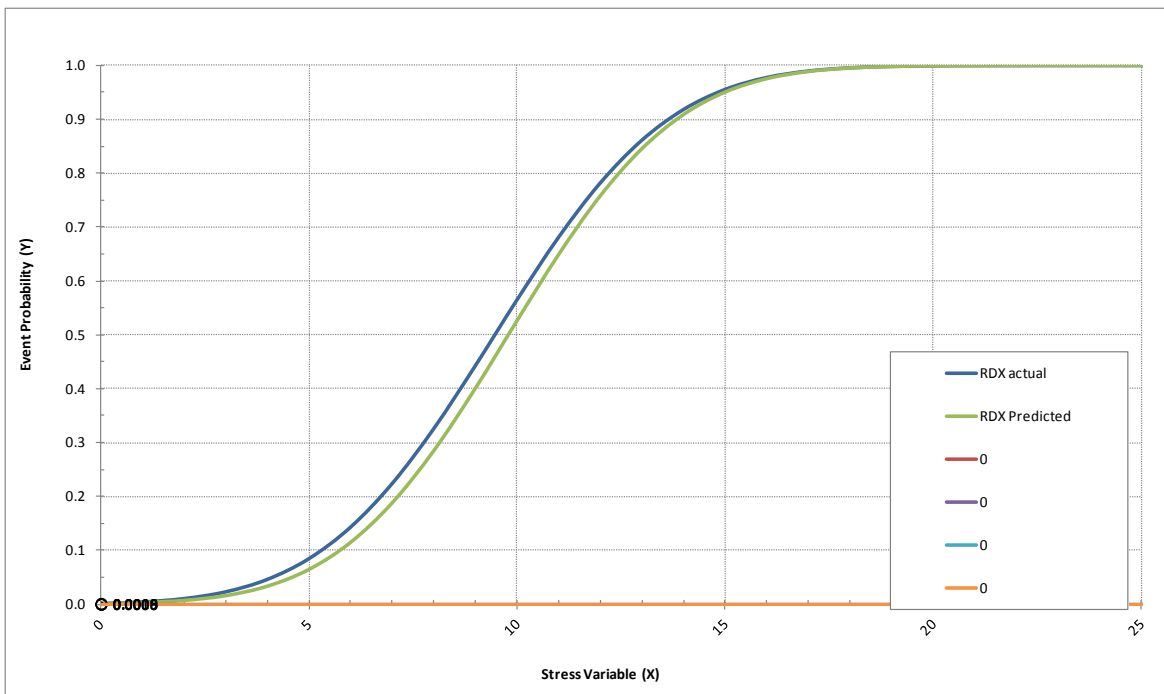


Figure A-12. Probit Regression Curve for RDX sample. Actual experimental data in blue and prediction in green.

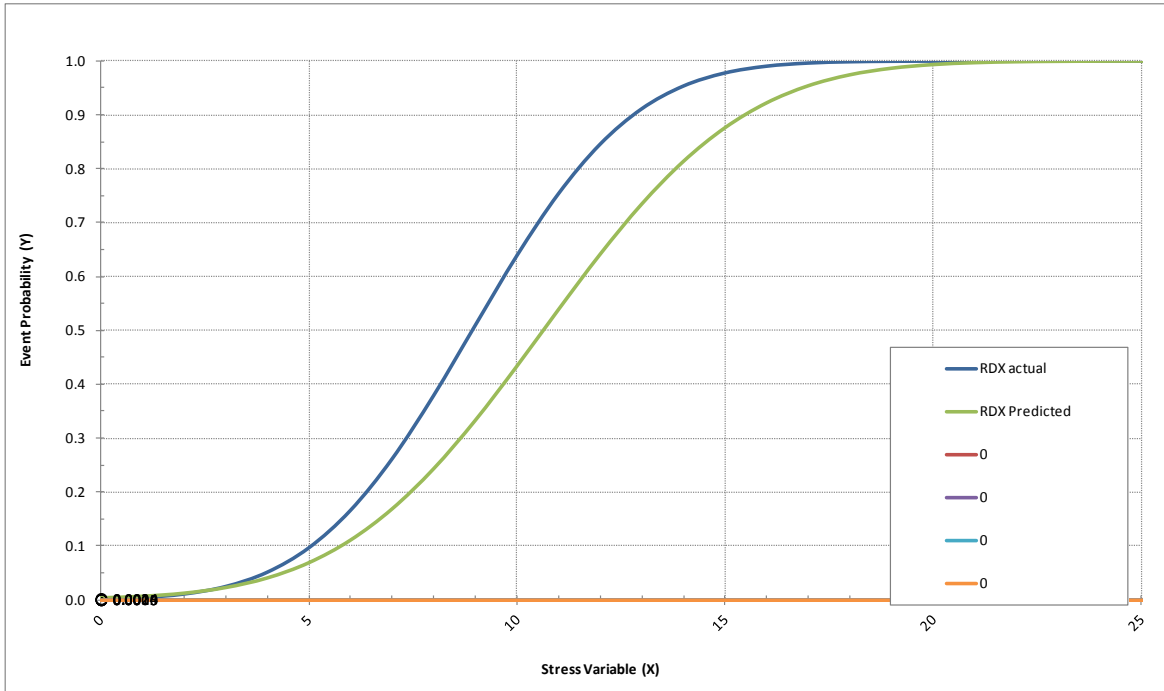


Figure A-13. Probit Regression Curve for RDX sample. Actual experimental data in blue and prediction in green.

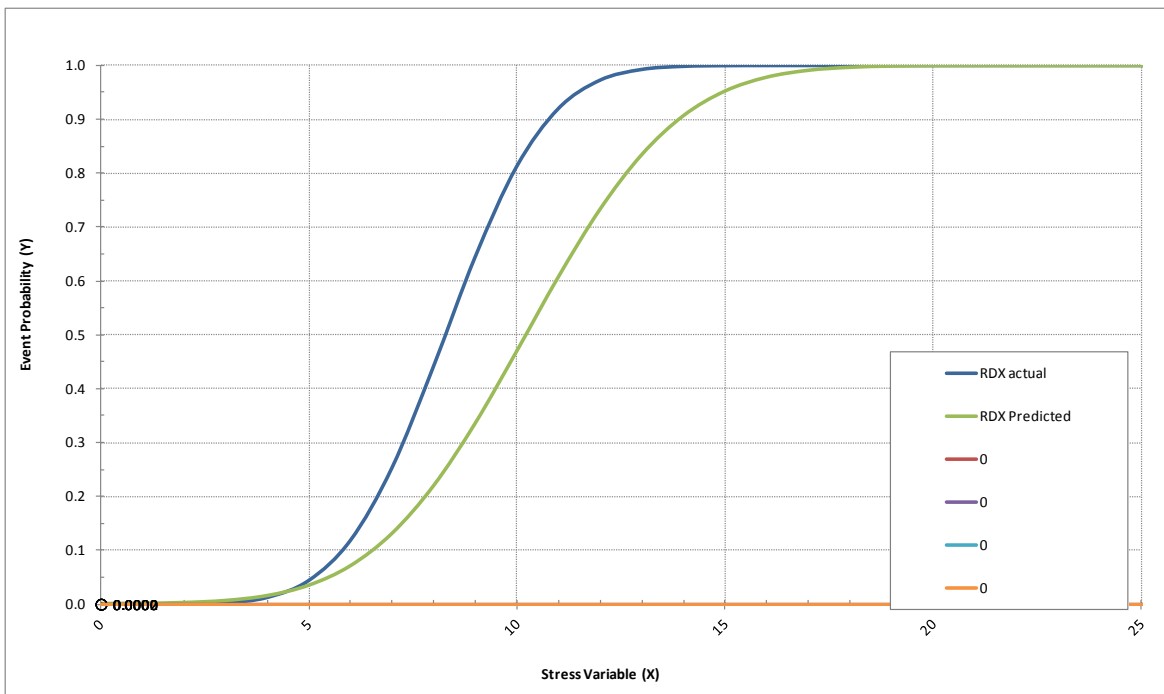


Figure A-14. Probit Regression Curve for RDX sample. Actual experimental data in blue and prediction in green.

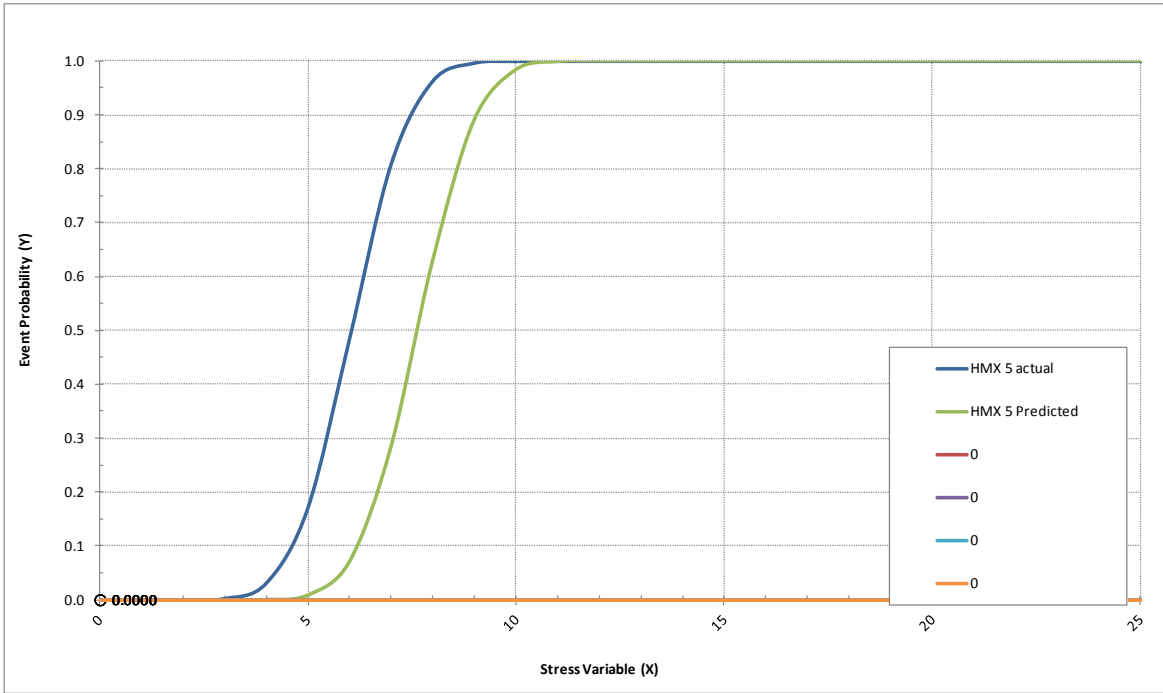


Figure A-15. Probit Regression Curve for HMX sample. Actual experimental data in blue and prediction in green.

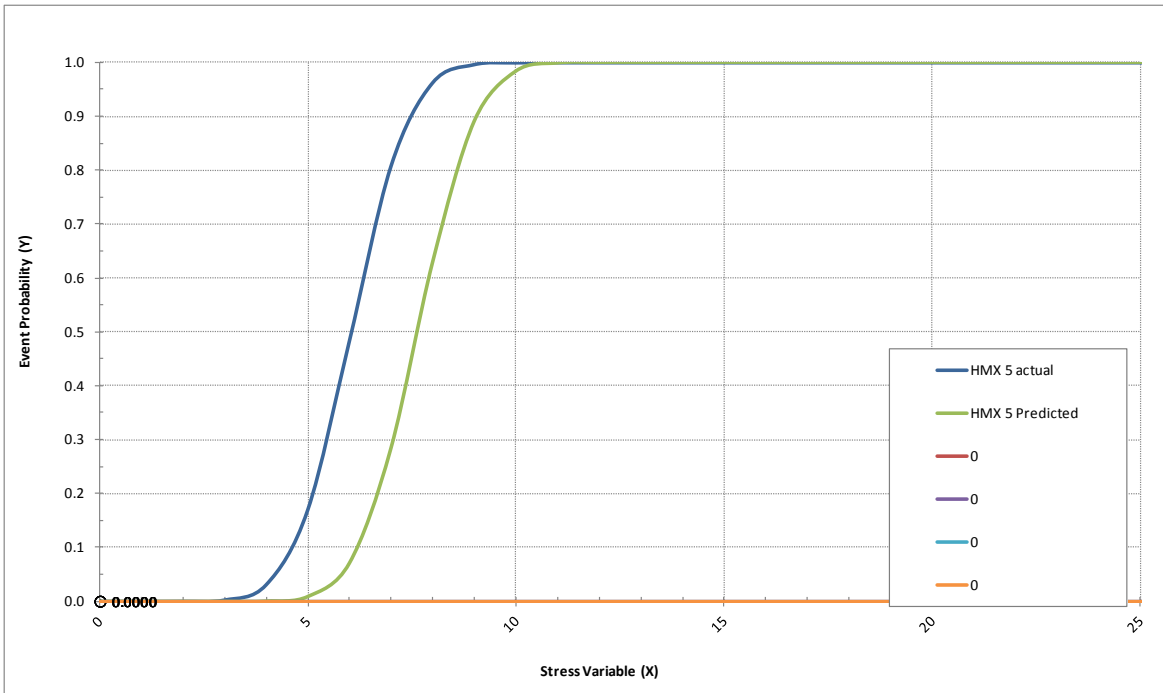


Figure A-16. Probit Regression Curve for HMX sample. Actual experimental data in blue and prediction in green.

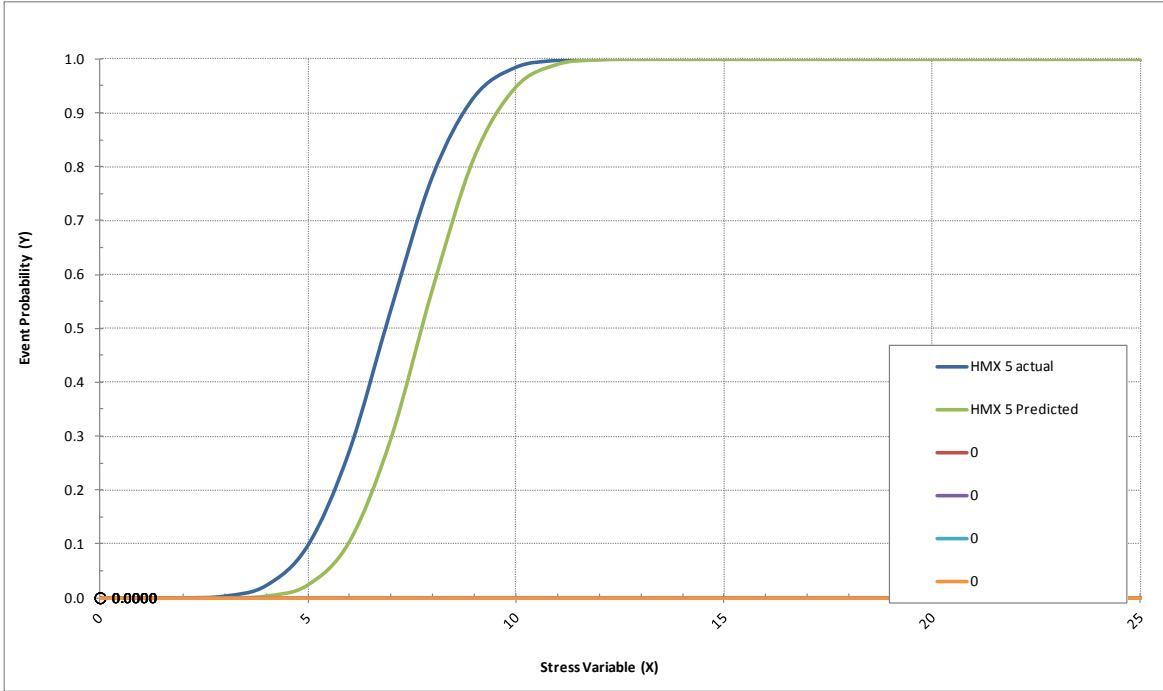


Figure A-17. Probit Regression Curve for HMX sample. Actual experimental data in blue and prediction in green.

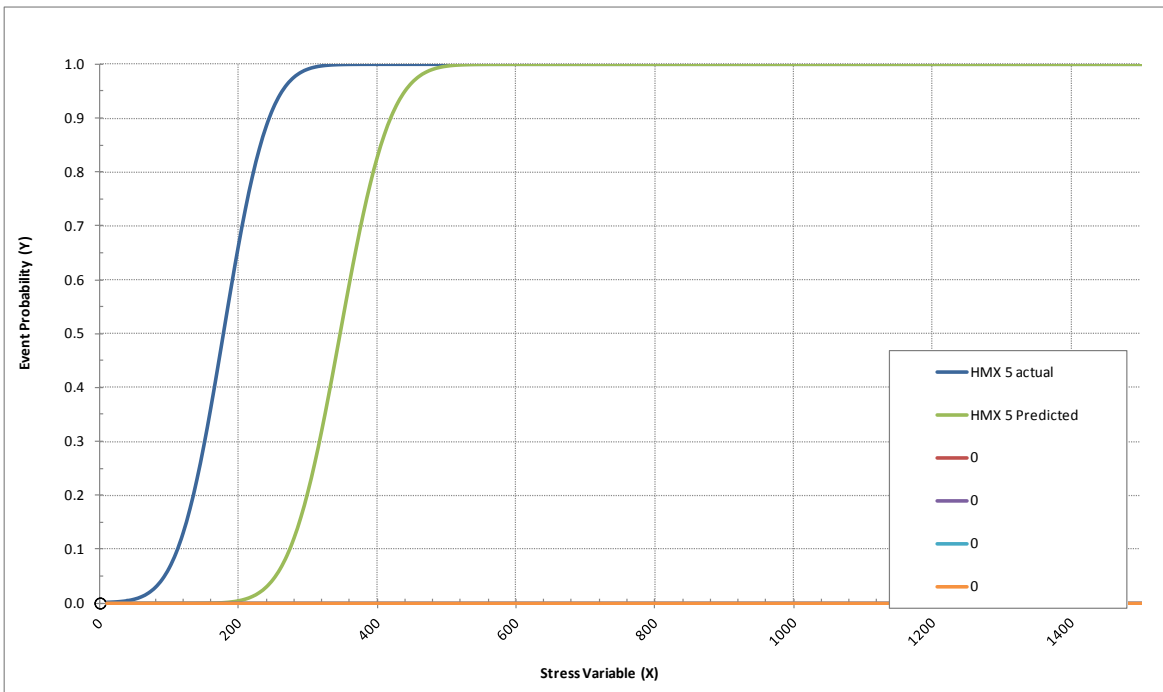


Figure A-18. Probit Regression Curve for HMX sample. Actual experimental data in blue and prediction in green.

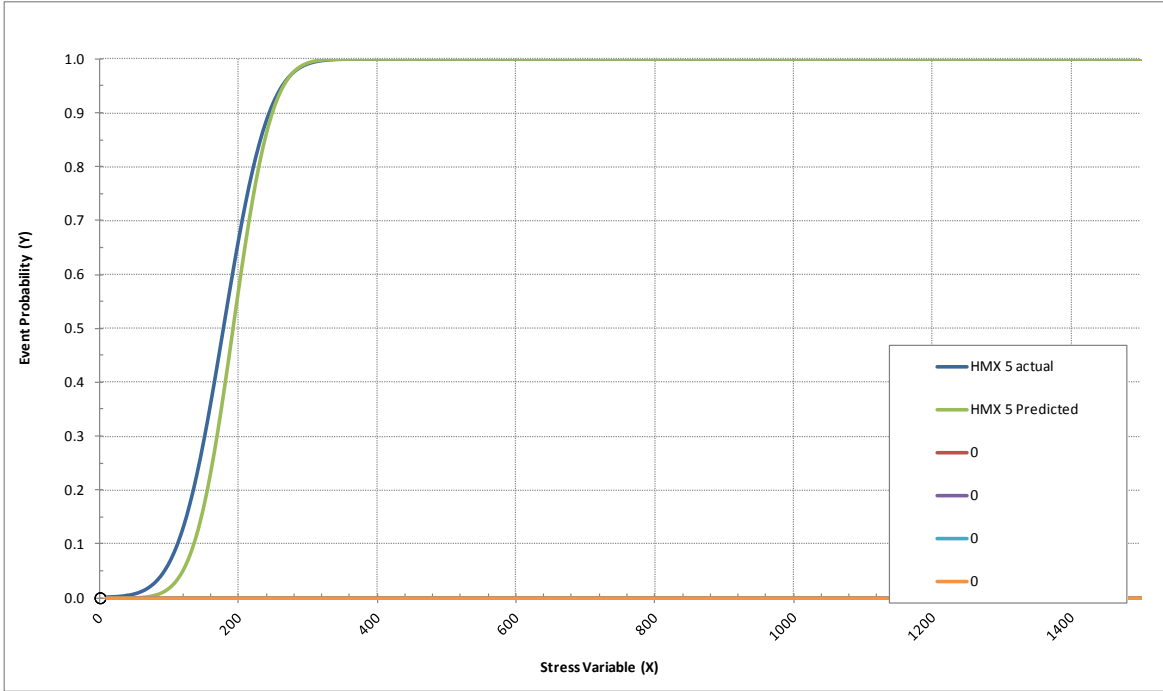


Figure A-19. Probit Regression Curve for HMX sample. Actual experimental data in blue and prediction in green.

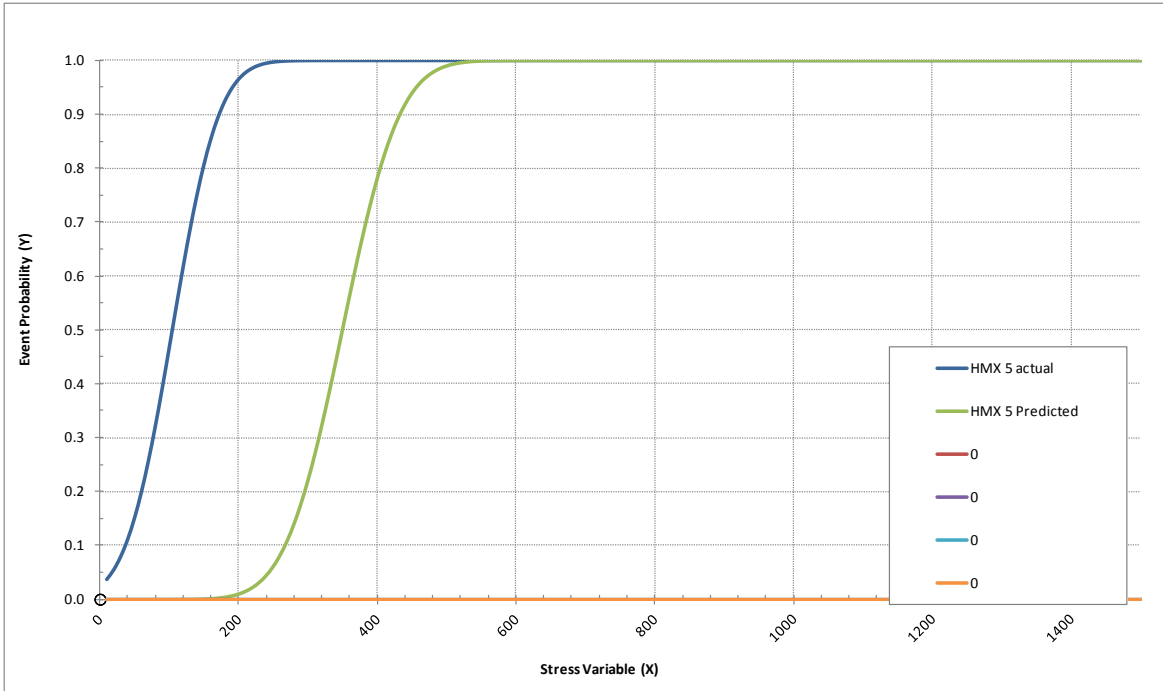


Figure A-20. Probit Regression Curve for HMX sample. Actual experimental data in blue and prediction in green.

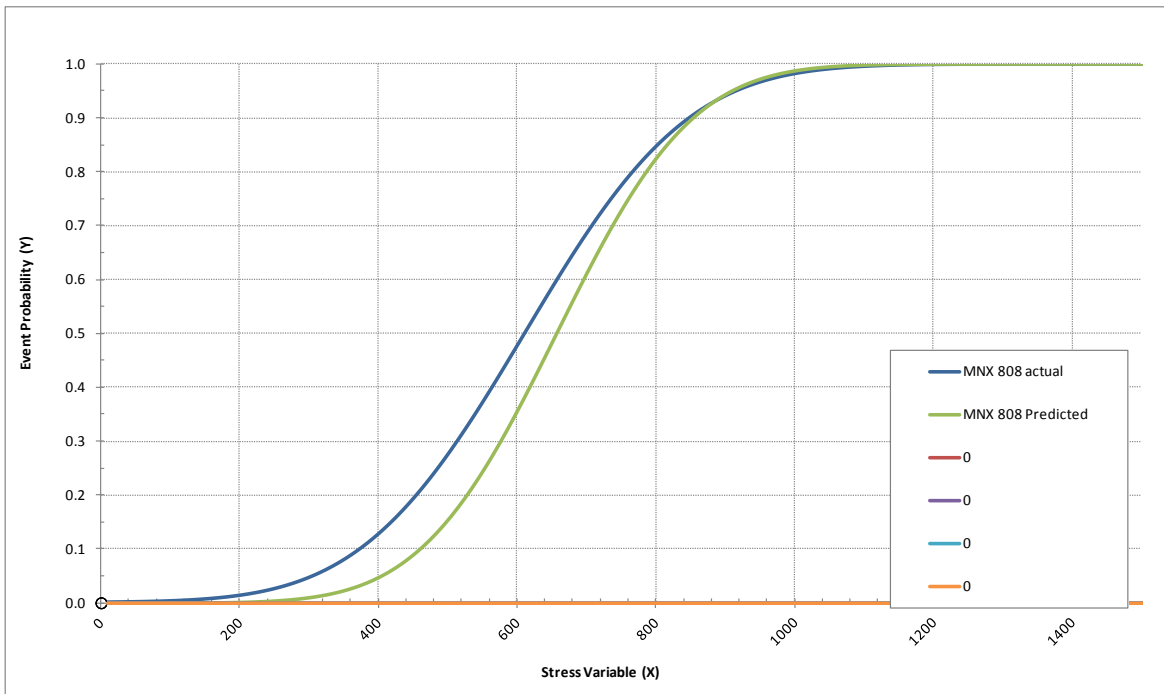


Figure A-21. Probit Regression Curve for MNX-808 sample. Actual experimental data in blue and prediction in green.

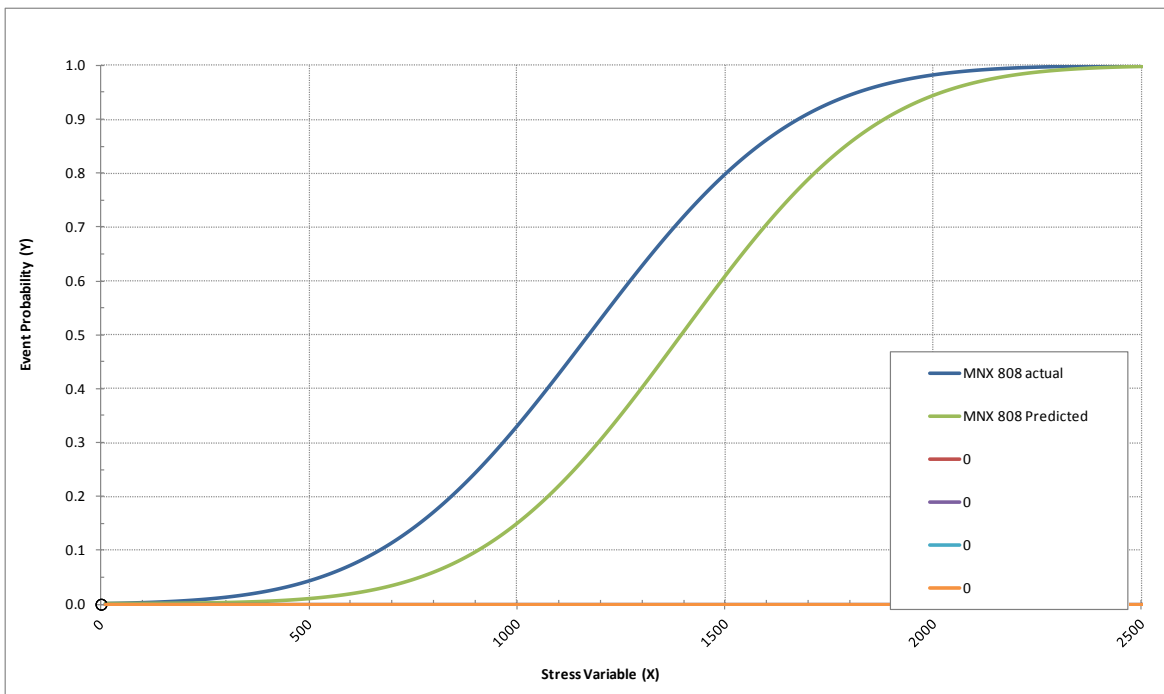


Figure A-22. Probit Regression Curve for MNX-808 sample. Actual experimental data in blue and prediction in green.

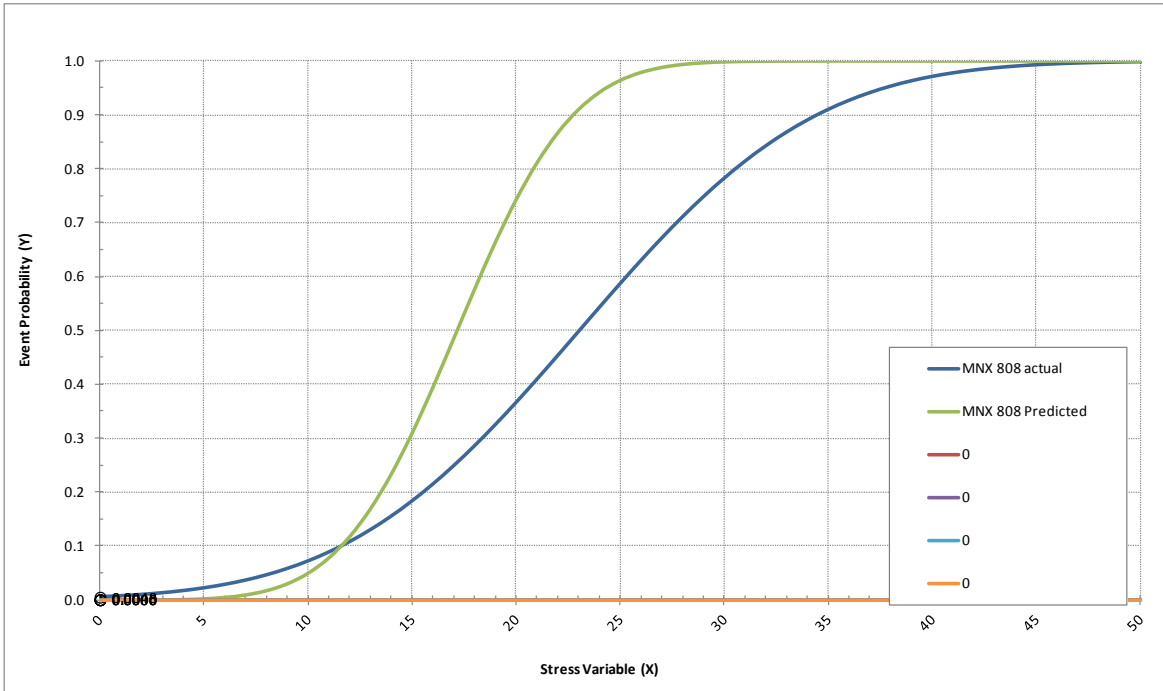


Figure A-23. Probit Regression Curve for MNX-808 sample. Actual experimental data in blue and prediction in green.

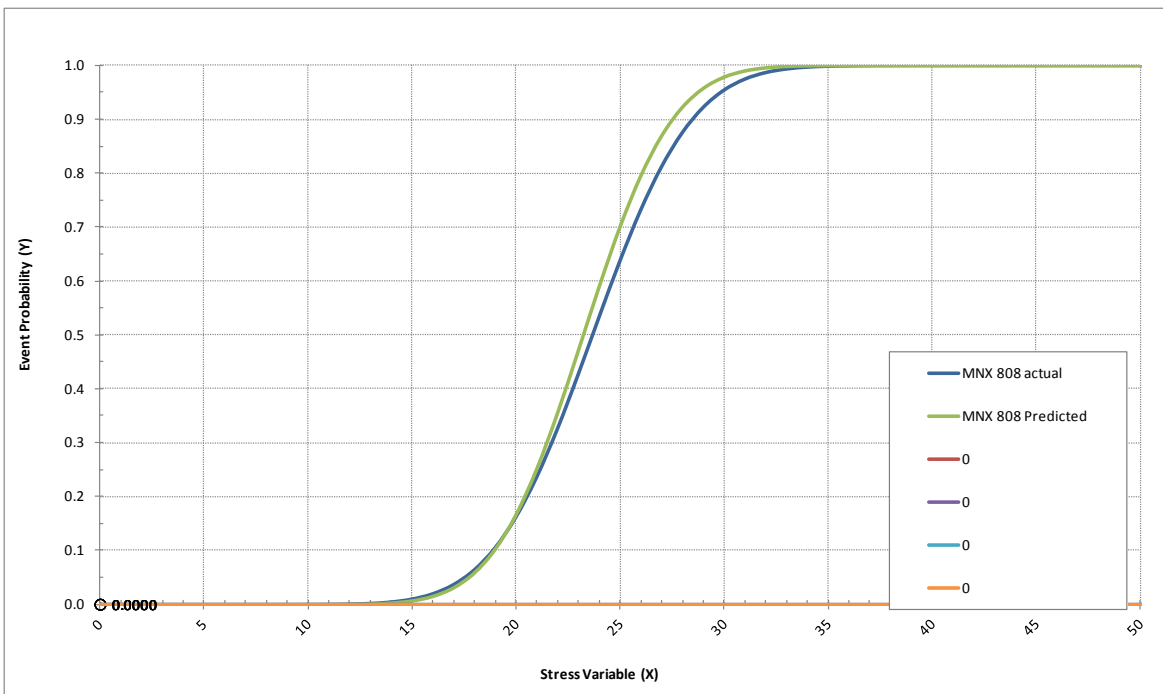


Figure A-24. Probit Regression Curve for MNX-808 sample. Actual experimental data in blue and prediction in green.

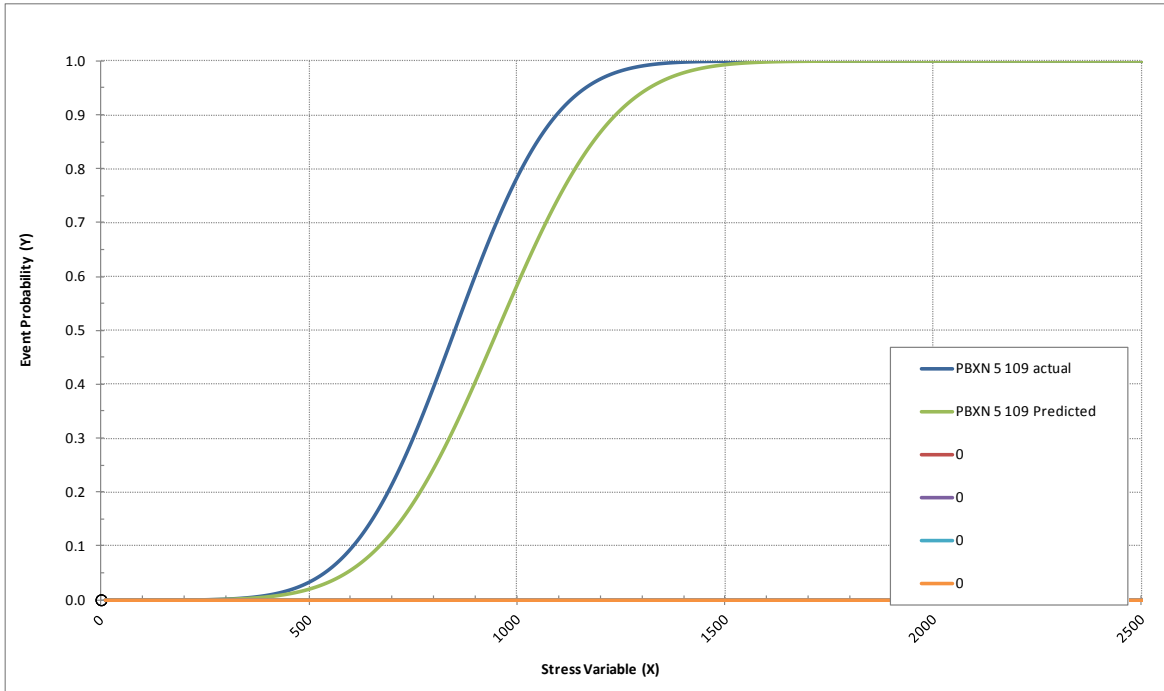


Figure A-25. Probit Regression Curve for PBXN-109 sample. Actual experimental data in blue and prediction in green.

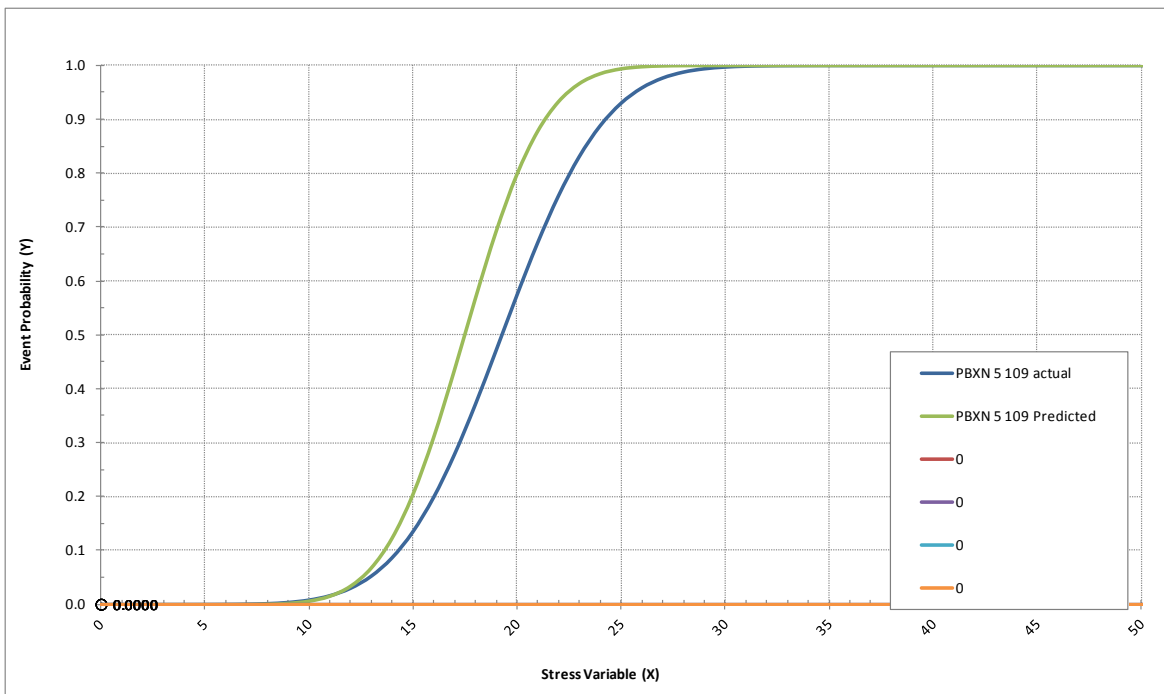


Figure A-26. Probit Regression Curve for PBXN-109 sample. Actual experimental data in blue and prediction in green.

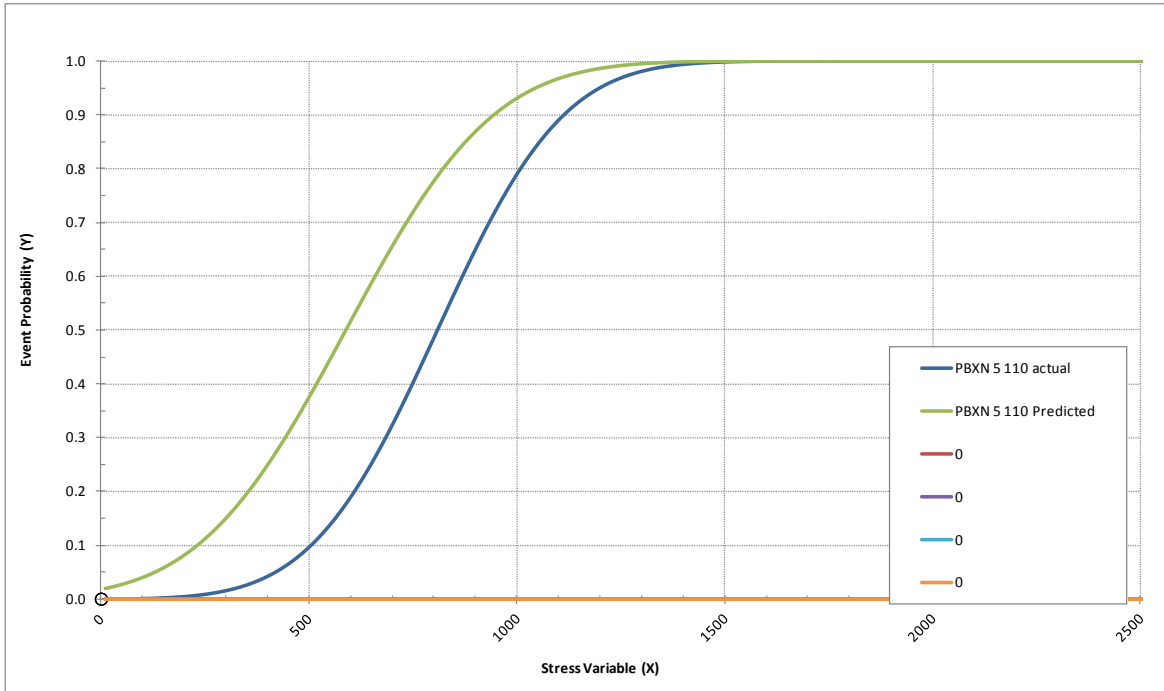


Figure A-27. Probit Regression Curve for PBXN-110 sample. Actual experimental data in blue and prediction in green.

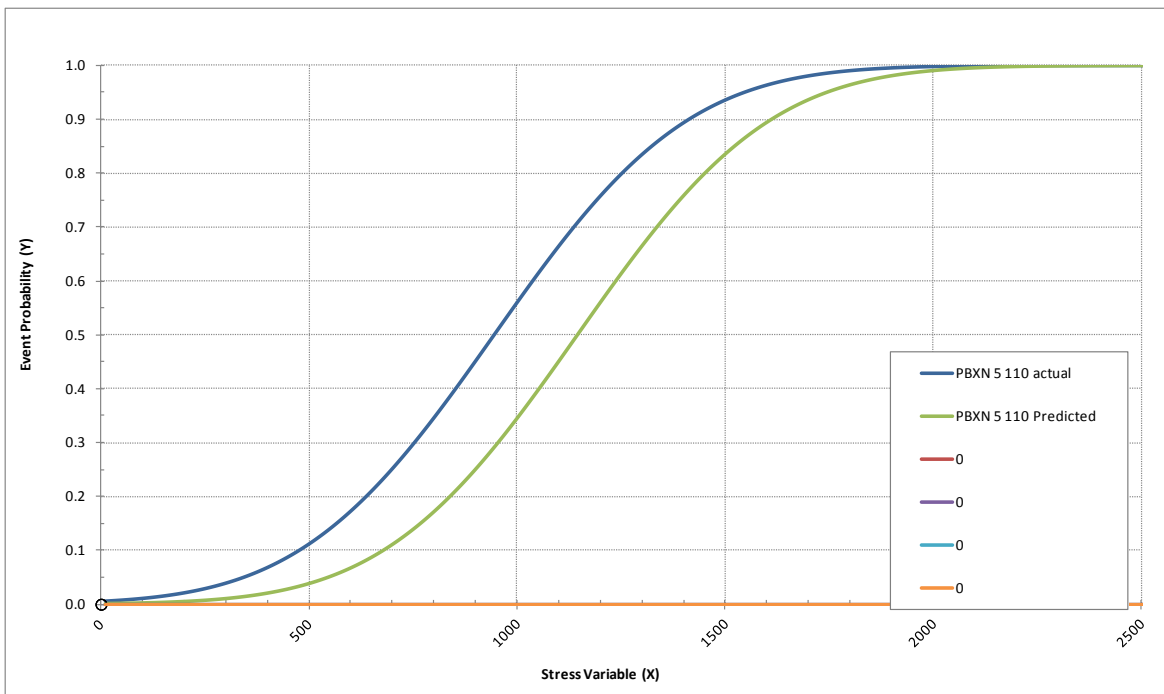


Figure A-28. Probit Regression Curve for PBXN-110 sample. Actual experimental data in blue and prediction in green.

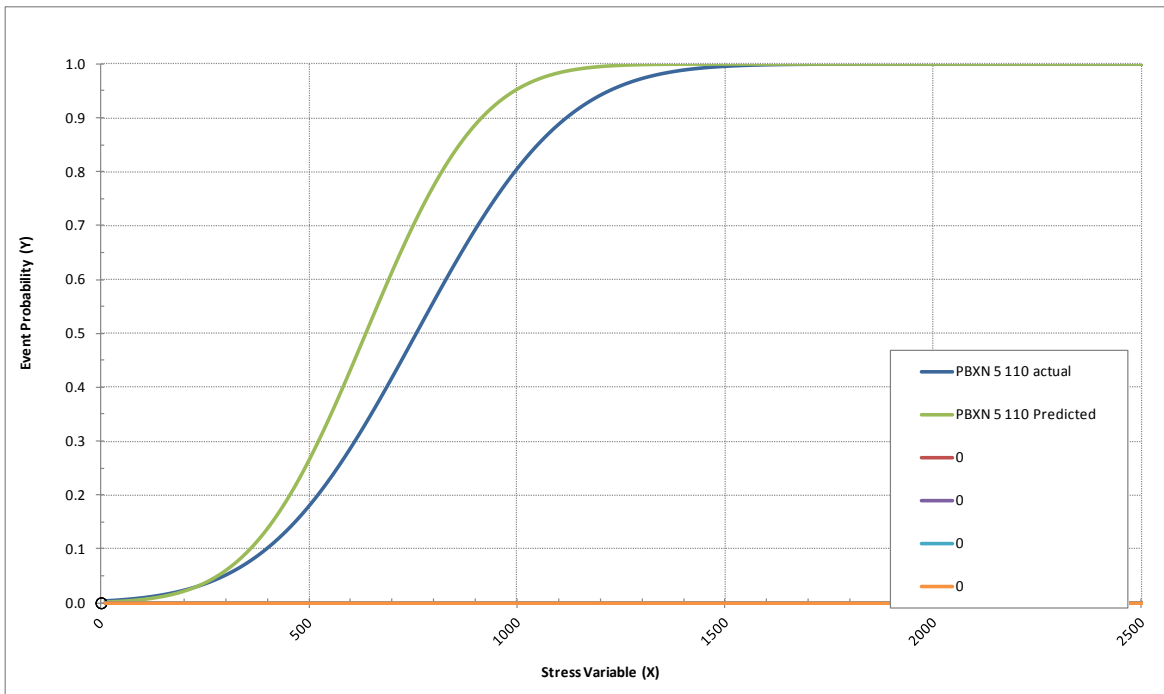


Figure A-29. Probit Regression Curve for PBXN-110 sample. Actual experimental data in blue and prediction in green.

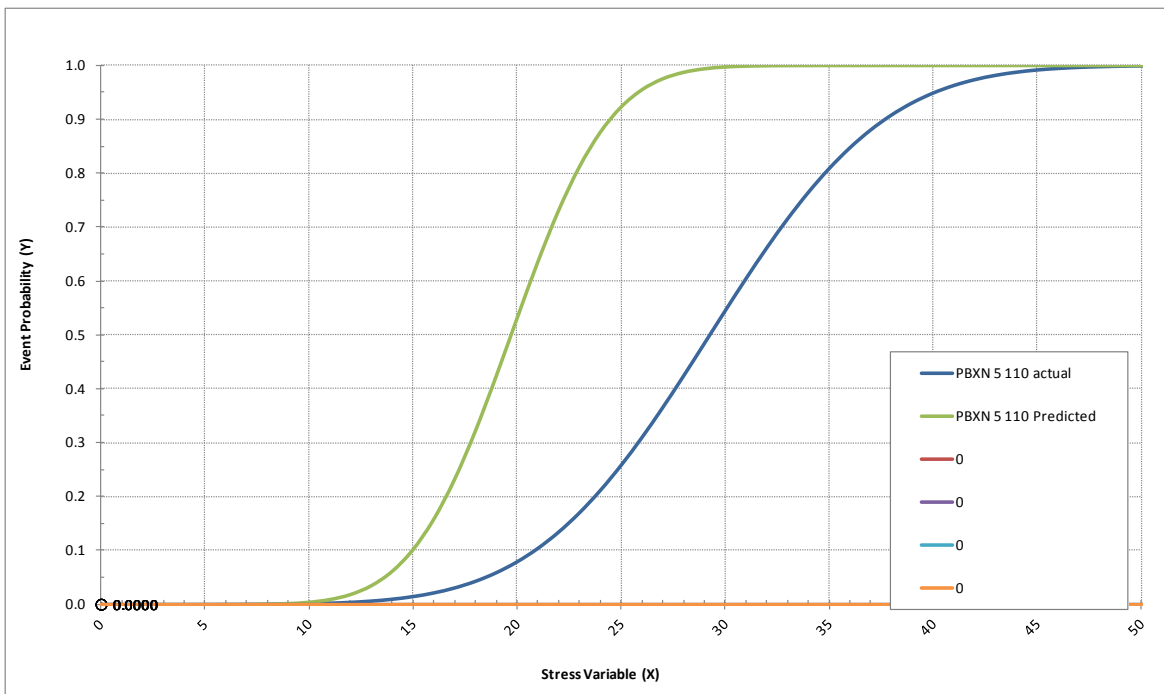


Figure A-30. Probit Regression Curve for PBXN-110 sample. Actual experimental data in blue and prediction in green.

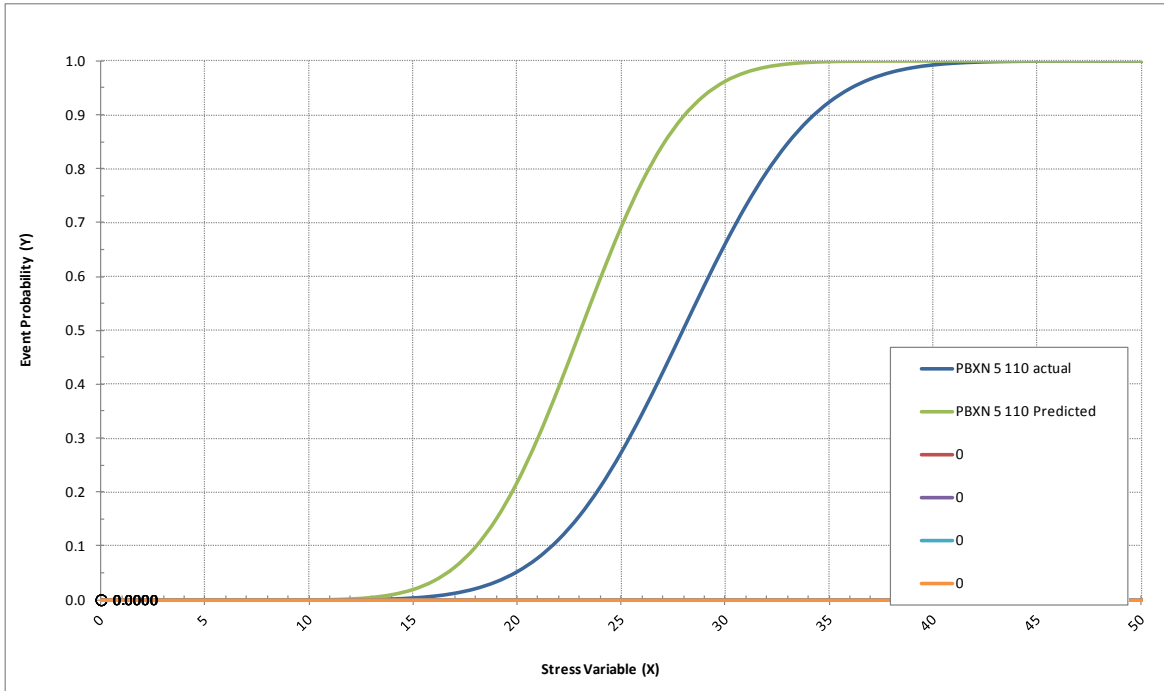


Figure A-31. Probit Regression Curve for PBXN-110 sample. Actual experimental data in blue and prediction in green.

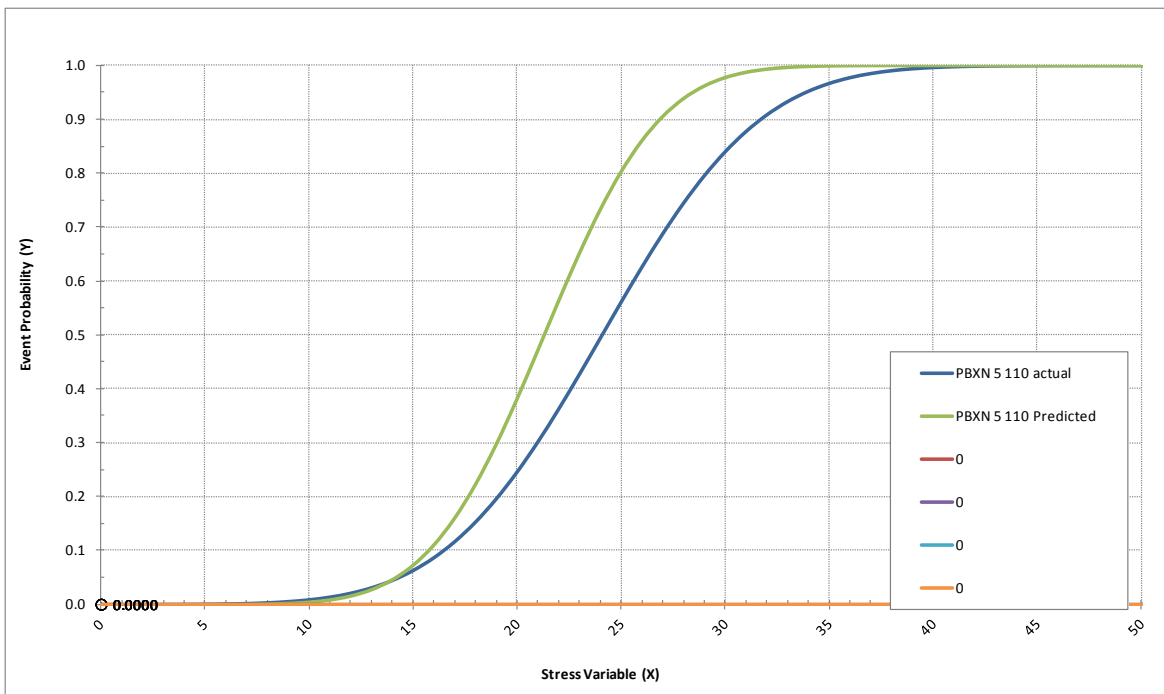


Figure A-32. Probit Regression Curve for PBXN-110 sample. Actual experimental data in blue and prediction in green.

Raw Data

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0													0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0							0	0					0	0
11.2							0	0					0	0
10.8							0	0					0	0
9.6							0						0	0
8.4	0	0	0	0	0								0	0
8.0	0	0	0	0									0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up							
	1	2	3	4	5	6	1	2	3	4	5	6		
1995														
1585										0				
1260	0	1												
1000	0	0	0	0	0									
800	0	0	0	0	0									
660														
560														
420														
370														
320														
240														
180														
130														
100														
50														

Sample max 196
 Date 12 May 2014
 Temp 11.9
 RH 16%

Overview

Down	1 No-fire search
	2 No-fire locati
	3 No-fire confir
Up	4 All-fire search
	5 All-fire locati
	6 All-fire confir
	7 Mixed-result

Figure A-33. Raw data sheet for AFX-196

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
36.0														0	0
32.4														0	0
28.8														0	0
25.2														0	0
24.0														0	0
21.6														0	0
19.2														0	0
18.0														0	0
16.8														0	0
16.0														0	0
14.4	o	o					o	o	o	o	o			0	0
12.8	o	o	o				o			o				0	0
12.0	o	o	o	o	o									0	0
11.2	o	o	o	o	o									0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4														0	0
6.0														0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

Mostly burn marks on plate
a few sound, no visible stuff

psi	Down						Up								
	1	2	3	4	5	6	1	2	3	4	5	6			
1995															
1585	o														
1260															
1000								o							
800	o	o	o												
660	o	o	o	o	o										
560	o	o	o	o	o										
420															
370															
320															
240															
180															
130															
100															
50															

Sample AFX 196
Date 6 May 2014
Temp 19.0
RH 42

↑ Smoke or smell →

Overview

Down	1 No-fire search
Down	2 No-fire locati
Down	3 No-fire confir
Down	4 All-fire search
Down	5 All-fire locati
Down	6 All-fire confir
Down	7 Mixed-result
Up	

Figure A-34. Raw data sheet for AFX-196

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
36.0														0	0
32.4														0	0
28.8														0	0
25.2														0	0
24.0	1-ack													0	0
21.6	1						m	h	s	m	m			0	0
19.2	0	1s					m	h	m	m	s			0	0
18.0	0	m					m	m	0					0	0
16.8	m						0							0	0
16.0	1m						0							0	0
14.4	1s						0							0	0
12.8	1s						0							0	0
12.0	0	0	0	0	0									0	0
11.2	0	0	0	0	0									0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4														0	0
6.0														0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

BAM

psi	Down						Up						Sum	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	
800	0	0	0	0	0									0
660	0	0	0	0	0									0
560														0
420														0
370														0
320														0
240														0
180														0
130														0
100														0
50														0

Sample Arx 196
 Date 20 Feb 21
 Temp 17.8
 RH 52%

- Overview
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

Down

1995 1ack
 1585 1ack
 1260 1ack
 1000 0 1ack

11111
 11111
 0

Note: All on OPar! / Smoke

Figure A-35. Raw data sheet for AFX-196

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
36.0														0	0
32.4														0	0
28.8							1	1	1	1	1	1		0	0
25.2	0						1	1	1	1	1	1		0	0
24.0	0	0					1	1	1	0	0			0	0
21.6	0	0					1	1	0	0	0			0	0
19.2	0	0	1				1	0						0	0
18.0	0	1	1				0							0	0
16.8	1						1	1	0					0	0
16.0	0	1												0	0
14.4	0	0	0	0	0									0	0
12.8	0	0	0	0	0									0	0
12.0														0	0
11.2														0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4														0	0
6.0														0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

BAM

psi	Down						Up						Sum	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	
800	10													0
660	10						10	10	10	10	10			0
560	10						10	10	10	10	10			0
420	0	10					0							0
370	10						0							0
320	0	10					0							0
240	0	10					0							0
180	0	0	0	0	0									0
130	0	0	0	0	0									0
100														0
50														0

Sample AFX 256
 Date 26 Feb 2011
 Temp 12.8
 RH 52%

- Overview
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

Down

1995 10F
 1585 0 10F
 1260 10
 1000 1F

Figure A-36. Raw data sheet for AFX-256

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0													0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

"Go's" are kindly brown burr
 streaks on plate
 rarely sand.

psi	Down						Up							
	1	2	3	4	5	6	1	2	3	4	5	6		
1995														
1585														
1260														
1000														
800														
660														
560														
420														
370														
320														
240														
180														
130														
100														
50														

Sample 1047 Fno
 Date 9 May 2014
 Temp 14c
 RH 45

Overview

Down	1 No-fire searc
Down	2 No-fire locati
Down	3 No-fire confi
Down	4 All-fire searc
Down	5 All-fire locati
Down	6 All-fire confir
Down	7 Mixed-result

Figure A-37. Raw data sheet for FOX-7

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0	0	0	0	1	1								0	0
21.6	0	0	0	0	0	1	0						0	0
19.2	0	0	0	1	0								0	0
18.0	0	0	1	1	0								0	0
16.8	0	0	0	0	0								0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up						Sum
	1	2	3	4	5	6	1	2	3	4	5	6	Go
800													0
660													0
560													0
420													0
370													0
320													0
240													0
180													0
130													0
100													0
50													0

Sample FOX 7 Fire
 Date 11 Feb 201
 Temp 17 C
 RH 60

- Overview
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

1900	No-go	90
	5	2
1500	4	1
1200		
1995		11

Figure A-38. Raw data sheet for FOX-7

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0	0	0	1	1	1								0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0	0	0											0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up						Sum
	1	2	3	4	5	6	1	2	3	4	5	6	Go
800	0	0	0	0									0
660													0
560													0
420													0
370													0
320													0
240													0
180													0
130													0
100													0
50													0

1000 0 0 0 0

Sample FOX 7
 Date 10 FEB 14
 Temp 15C
 RH 68%

- Overview
- | |
|------|
| Down |
| Up |
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

Figure A-39. Raw data sheet for FOX-7

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
36.0														0	0
32.4														0	0
28.8														0	0
25.2														0	0
24.0														0	0
21.6														0	0
19.2														0	0
18.0							0							0	0
16.8	0	1						0		0				0	0
16.0	0	0	1					0						0	0
14.4	0	0	0	1						0				0	0
12.8	0	0	0	0	0									0	0
12.0	0	0	0	0	0									0	0
11.2														0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4														0	0
6.0														0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

Also, marks = pops at behavior-though still rare

psi	Down						Up					
	1	2	3	4	5	6	1	2	3	4	5	6
1995												
1585							0					
1260							0	0				
1000							0					
800	0	0	0	0	0							
660	0	0	0	0	0							
560												
420												
370												
320												
240												
180												
130												
100												
50												

Sample FOX 7 Fibre foot 1871
 Date 6 May 2014
 Temp 19.5
 RH 72%

- Overview
- | | |
|------|-------------------|
| Down | 1 No-fire search |
| Down | 2 No-fire locati |
| Down | 3 No-fire confi |
| Down | 4 All-fire search |
| Down | 5 All-fire locati |
| Down | 6 All-fire confir |
| Down | 7 Mixed-result |

Visual "goes"
 A few "pops"

Figure A-40. Raw data sheet for FOX-7

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0													0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4							1	1	1	1	1		0	0
12.8							1	0	1	1	1	1	0	0
12.0							0	0					0	0
11.2							0	0					0	0
10.8							0	0					0	0
9.6	0	1					0	0					0	0
8.4	0	1					1	0	1	0			0	0
8.0	0	1					1	0					0	0
7.2	1	1					0						0	0
6.4	1	1					0						0	0
6.0	0	0	0	0	0	0	0						0	0
5.6	0	0	0	0	0	0	0						0	0
5.4	0	0	0	0	0	0	0						0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up						Sum
	1	2	3	4	5	6	1	2	3	4	5	6	Go
800													0
660													0
560							1	1	1	1	1	1	0
420							1	1	1	1	1	1	0
370							0						0
320	1						0	1	1	0			0
240	1						0						0
180	0	0	1				0						0
130	0	0	0	0	0	0	0						0
100	0	0	0	0	0	0	0						0
50													0

Sample FOX II Standard → cont. # 1929
 Date 5 May 2014
 Temp 21C
 RH 12%

- Overview
- | |
|------|
| Down |
| Up |
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

Figure A-41. Raw data sheet for RDX Class V

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
36.0														0	0
32.4														0	0
28.8														0	0
25.2														0	0
24.0														0	0
21.6														0	0
19.2														0	0
18.0														0	0
16.8														0	0
16.0														0	0
14.4														0	0
12.8														0	0
12.0	0	1					0	0						0	0
11.2	1						0	0						0	0
10.8							0	0						0	0
9.6							0	0						0	0
8.4	1						0	0						0	0
8.0	1						0	0						0	0
7.2	1						0	0						0	0
6.4	0	0	0	0	0									0	0
6.0	0	0	0	0	0									0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

BAM

psi	Down						Up								
	1	2	3	4	5	6	1	2	3	4	5	6			
1995															
1585															
1260															
1000															
800															
660															
560															
420															
370															
320	1								0						
240	0	0	0	0	0		0	0	0	0					
180	0	0	0	0	0										
130	0	0	0	0	0										
100	0	0	0	0	0										
50	0	0	0	0	0										

Sample RDX 17 5th cat 1429 Overview

Date 8 May 2014

Temp 19

RH 45

Down

- 1 No-fire search
- 2 No-fire locati
- 3 No-fire confi
- 4 All-fire search
- 5 All-fire locati
- 6 All-fire confir
- 7 Mixed-result

Figure A-42. Raw data sheet for RDX Class V

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0													0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2							1	1	1	1	1		0	0
10.8							1	1	1	1	1		0	0
9.6							1	0					0	0
8.4	0	0	1				0						0	0
8.0							0						0	0
7.2							1	0					0	0
6.4	0	0	0	0	0		1	0					0	0
6.0	0	0	0	0	1		0						0	0
5.6	0	0	0	0	0								0	0
5.4	0	0	0	0	0								0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up						Sum	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	
800														0
660														0
560							1	1	1	1	1	1		0
420							1	1	1	1	1	1		0
370							1	0						0
320							0							0
240							0							0
180	0	0	0	0	0									0
130	0	0	0	0	0									0
100														0
50														0

Sample: 53-V
 Date: 6 Feb 2014
 Temp: 19.4C 22% RH
 RH: 22%

- Overview
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

Figure A-43. Raw data sheet for RDX Class V

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
	36.0														0
32.4														0	0
28.8														0	0
25.2														0	0
24.0														0	0
21.6														0	0
19.2														0	0
18.0														0	0
16.8														0	0
16.0														0	0
14.4														0	0
12.8														0	0
12.0														0	0
11.2														0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4	0	1					0							0	0
6.0	0	1					0	0						0	0
5.6	0	1					0	0						0	0
5.4	0	1					0	0						0	0
4.8	0	0	0	0	0	0	0							0	0
4.2	0	0	0	0	0	0	0							0	0
4.0	0	0	0	0	0	0	0							0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

BAM

psi	Down						Up						Sum	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	
	800													
660														0
560														0
420														0
370														0
320														0
240														0
180														0
130														0
100														0
50														0

Sample HMX V (21F 167)
 Date 8 May 2014
 Temp 19
 RH 42

Overview

Down	1 No-fire search
	2 No-fire location
	3 No-fire confirmation
Up	4 All-fire search
	5 All-fire location
	6 All-fire confirmation
	7 Mixed-results check

Figure A-44. Raw data sheet for HMX Class V

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0													0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0	1												0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8	1						1	1	1	1	1		0	0
9.6	0	0	0	1									0	0
8.4	1						1	1	1	1	1		0	0
8.0	1						1	1	1	1	1		0	0
7.2	0	0	1				0						0	0
6.4	1						0						0	0
6.0	1						0						0	0
5.6	0	0	0	0	0								0	0
5.4	1												0	0
4.8	0	0	0	0	0								0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up						Sum
	1	2	3	4	5	6	1	2	3	4	5	6	Go
800	1												0
660	1												0
560	1												0
420	1												0
370	1												0
320	1						1	1	1	1			0
240	1						1	0			1		0
180	0	1					1	1	1	1	1		0
130	0	1					1	1	0				0
100	1						1	1	0				0
50	0	0	0	0	0								0

25 0 0 0 0 0

Sample HMX-S BAE (FINE PARTICLE SIZE)
 Date 11 FEB 14
 Temp 17 °C
 RH 60%

- Overview
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

Figure A-45. Raw data sheet for HMX Class V

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0													0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up						Sum
	1	2	3	4	5	6	1	2	3	4	5	6	Go
800													0
660													0
560													0
420													0
370													0
320													0
240													0
180													0
130													0
100													0
50													0

ABL

25

Sample HMX-V Cat 1673
 Date 5 May 2014
 Temp 9/
 RH 72

Overview

- | | | |
|------|---|-----------------------|
| Down | 1 | No-fire search |
| | 2 | No-fire location |
| Up | 3 | No-fire confirmation |
| | 4 | All-fire search |
| | 5 | All-fire location |
| | 6 | All-fire confirmation |
| | 7 | Mixed-results check |

Figure A-46. Raw data sheet for HMX Class V

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0							1	1	0	1	1	1	0	0
32.4							1	1	0	1	1	1	0	0
28.8							0						0	0
25.2								1	0				0	0
24.0							0	1	0				0	0
21.6							0						0	0
19.2							0						0	0
18.0							0						0	0
16.8							0						0	0
16.0							0						0	0
14.4	0	0	0	0	0	0							0	0
12.8	0	0	0	0	0	0							0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up							
	1	2	3	4	5	6	1	2	3	4	5	6		
1995														
1585														
1260							1	1	1	1	1	1	1	1
1000	1						1	0	1	1	1	1	1	1
800	1						1	0						
660	1						0	0						
560	1						0	0						
420	1						0							
370	0	0	0	0	0	0	1							
320	0	0	0	0	0	0	1							
240														
180														
130														
100														
50														

Sample BAM POB
Date 12 May 19
Temp 18.8
RH 46

Overview

Down	1	No-fire search
Down	2	No-fire locati
Down	3	No-fire confir
Down	4	All-fire search
Down	5	All-fire locati
Down	6	All-fire confir
Down	7	Mixed-result

Cut from Peak
*1000ms cut strip!

Figure A-47. Raw data sheet for MNX-808

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0													0	0
32.4													0	0
28.8													0	0
25.2													0	0
24.0													0	0
21.6													0	0
19.2													0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up							
	1	2	3	4	5	6	1	2	3	4	5	6		
1995														
1585														
1260														
1000														
800														
660														
560														
420														
370														
320														
240														
180														
130														
100														
50														

Sample MINY 808
Date 7 May 2011
Temp 19c
RH 48%

Cut from Puck

Down	Overview
1	No-fire searc
2	No-fire locati
3	No-fire confi
4	All-fire searc
5	All-fire locati
6	All-fire confir
7	Mixed-result

Figure A-48. Raw data sheet for MNX-808

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
36.0														0	0
32.4							/	/	/	/	/			0	0
28.8							/	/	/	/	/			0	0
25.2	/						/	/	/	0				0	0
24.0	0	0	0	0	0									0	0
21.6	0	0	0	0	0									0	0
19.2	0	0	0	0	0									0	0
18.0	0	0	0	0	0									0	0
16.8	0	0	0	0	0									0	0
16.0														0	0
14.4														0	0
12.8														0	0
12.0														0	0
11.2														0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4														0	0
6.0														0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

BAM

psi	Down						Up						Sum	
	1	2	3	4	5	6	1	2	3	4	5	6		Go
800	0	0	0	0	0									0
660	0	0	0	0	0									0
560	0	0	0	0	0									0
420														0
370														0
320														0
240														0
180														0
130														0
100														0
50														0

Sample MX 808
 Date 15 Feb 14
 Temp 16.4 C
 RH 31%

- Overview
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

	Down	Up
1000	0/1	
1260	1	1/0
1585		1/0
1995		1/1/1/1

* - ON SOME OF THE MIXES, IT'S POSSIBLE THAT THE FRICTION TEST IS NOT GETTING THE EXPLOSIVE, ONLY THE BINDING AGENT

Figure A-49. Raw data sheet for MNX-808

kg	Down						Up						Summary		
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go	
36.0														0	0
32.4														0	0
28.8														0	0
25.2							1	1	1	1	1			0	0
24.0	1						1	1	1	1	1			0	0
21.6	0	0	0	1										0	0
19.2	0	0	1											0	0
18.0	0	1												0	0
16.8	0													0	0
16.0	0	0	0	1										0	0
14.4	0	0	0	0	1									0	0
12.8	0	0	0	0	0	0								0	0
12.0	0	0	0	0	0									0	0
11.2														0	0
10.8														0	0
9.6														0	0
8.4														0	0
8.0														0	0
7.2														0	0
6.4														0	0
6.0														0	0
5.6														0	0
5.4														0	0
4.8														0	0
4.2														0	0
4.0														0	0
3.6														0	0
3.2														0	0
3.0														0	0
2.8														0	0
2.4														0	0
2.0														0	0

BAM

psi	Down						Up						Sum	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	
800	0	0	1											0
660	1													0
560	0	0	0	0	0									0
420	0	0	0	0	0									0
370														0
320														0
240														0
180														0
130														0
100														0
50														0

Sample PBXN 5 109
 Date 13 FEB 14
 Temp 16.4C
 RH 31%

- Overview
- 1 No-fire search
 - 2 No-fire location
 - 3 No-fire confirmation
 - 4 All-fire search
 - 5 All-fire location
 - 6 All-fire confirmation
 - 7 Mixed-results check

	Down	Up
1000	1	0
1260	1	1/1/1
1585	1	1/1/1
1995		

Figure A-50. Raw data sheet for PBXN-109

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0							1	1	0	0	1	1	0	0
32.4							1	1	1	1	1		0	0
28.8							0						0	0
25.2							0						0	0
24.0	1						0	0					0	0
21.6	0	0	0	0	0	1							0	0
19.2	0	0	0	0	0	1							0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up							
	1	2	3	4	5	6	1	2	3	4	5	6		
1995														
1585														
1260	1													
1000	1													
800	1													
660	0	1												
560	0	0	0	0	0									
420	0	0	0	1										
370	0	0	0	0	0									
320	0	0	0	0	0									
240														
180														
130														
100														
50														

Sample PBX 110
Date 13 May 14
Temp 18.8
RH 46%

Down	Up
1	No-fire search
2	No-fire locati
3	No-fire confi
4	All-fire search
5	All-fire locati
6	All-fire confir
7	Mixed-result

Figure A-51. Raw Data sheet for PBXN-110

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0							/	/	/	/	/	/	0	0
32.4							0						0	0
28.8							0						0	0
25.2							0						0	0
24.0	0	0	0	0			1	0					0	0
21.6	0	0	0	0	0								0	0
19.2	0	0	0	0	0								0	0
18.0													0	0
16.8													0	0
16.0													0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

psi	Down						Up					
	1	2	3	4	5	6	1	2	3	4	5	6
1995	/						/	/	/	/	/	
1585	/						/	/	/	/	/	
1260	/						/	0				
1000	/						0					
800	0	0	0	1			0					
660	0	0	1				0					
560	0	0	1				1	0				
420	0	0	0	0	0							
370	0	0	0	0	0							
320												
240												
180												
130												
100												
50												

Sample PBX-110
Date 7 May 2014
Temp 19.0
RH 48%

Overview
Down
Up

- 1 No-fire search
- 2 No-fire locati
- 3 No-fire confi
- 4 All-fire search
- 5 All-fire locati
- 6 All-fire confir
- 7 Mixed-result

Figure A-52. Raw data sheet for PBXN-110

kg	Down						Up						Summary	
	1	2	3	4	5	6	1	2	3	4	5	6	Go	No-Go
36.0							/	/	/	/	/		0	0
32.4							/	/	/	/	/		0	0
28.8							/	/	/	0			0	0
25.2							0						0	0
24.0	0	1					1	1	0				0	0
21.6	0	0	0	1			0						0	0
19.2	0	1					1	0					0	0
18.0	0	0	0	1									0	0
16.8	0	0	0	0	0								0	0
16.0	0	0	0	0	0								0	0
14.4													0	0
12.8													0	0
12.0													0	0
11.2													0	0
10.8													0	0
9.6													0	0
8.4													0	0
8.0													0	0
7.2													0	0
6.4													0	0
6.0													0	0
5.6													0	0
5.4													0	0
4.8													0	0
4.2													0	0
4.0													0	0
3.6													0	0
3.2													0	0
3.0													0	0
2.8													0	0
2.4													0	0
2.0													0	0

BAM

.010 - .040 Sample Thickness X .5" Long X .5" Long

psi	Down						Up						Sum
	1	2	3	4	5	6	1	2	3	4	5	6	Go
800	0	0	1										0
660	0	1											0
560	1												0
420	0	0	0	0	0								0
370	0	0	0	0	0								0
320													0
240													0
180													0
130													0
100													0
50													0

Sample PBXN 5 110
 Date 12 FEB
 Temp 17
 RH 46

- Overview
- | | |
|------|-------------------------|
| Down | 1 No-fire search |
| | 2 No-fire location |
| | 3 No-fire confirmation |
| Up | 4 All-fire search |
| | 5 All-fire location |
| | 6 All-fire confirmation |
| | 7 Mixed-results check |

1000	1	Down
1266	1	Up
1585	01	1111
1915		1111

* - WE WERE GETTING NO-GO UNTIL CRAIG SLICED SAMPLES TO REDUCE THICKNESS IT IS POSSIBLE THIS 1585 WAS AN UNLIT SAMPLE.

Figure A-53. Raw data sheet for PBXN-110

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