Simplified Target Sizing Model for Visual Sample Plan (VSP) – Redacted Version

Methodology for Munition Specific Fragmentation Distances
for use in VSP based on TP-16 Methodology

STATISTICAL VERIFICATION AND REMEDIATION SAMPLING METHODS (200837)

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1 INTRODUCTION

The Department of Defense (DoD) is currently performing many remedial investigations (RI) to identify locations where concentrated regions of munitions of explosive concern (MEC) and unexploded ordnance (UXO) may be present, estimate potential remediation efforts and costs, and support land transfer decisions and no further remediation on some areas. Through the SERDP and ESTCP programs, DoD has supported the development of statistical design modules that assist with UXO remediation within Visual Sample Plan (VSP), a statistical support software program developed by Pacific Northwest National Laboratory.

This technical paper documents the methods used by the Visual Sample Plan (VSP) software to define the conservative radius used to establish the size of a munition specific impact area. As the use of VSP has increased within the Department of Defense (DoD) environmental restoration community the need to standardize the dimensions of the impact areas of interest has increased. These conservative radii values will provide a stronger technical basis and ease the future implementation of VSP in DoD assessments. The majority of this document summarizes the work to implement a simple interface in VSP that allows the user to pick the target area radius using a few features of the munition of interest and its respective diameter. This functionality is primarily for VSP users that cannot get access to the complete list of munition specific VSP fragmentation distances available in the appendices of the restricted version of this document. The restricted version of this document can be obtained from the U.S. Army Corps of Engineers Engineering and Support Center, Huntsville, Environmental and Munitions Center of Expertise.

When designing transect surveys for the detection and remediation of unexploded ordnance (UXO), the high anomly density areas are used as an indicator for regions with potential UXO. Detection of these high fragment density areas is accomplished using geophysical sensors to locate metallic anomalies on or underneath the earth's surface. After the data have been collected, the spatial density of these anomalies must be interpreted in order to make an inference on the location of potential target areas. Transect surveys that are appropriately spaced to ensure a high probability of traversing and detecting target areas of concern are usually performed. The spacing between transects is a function of several parameters, some of which depend on the munition of concern.

A primary consideration for transect survey design is the expected size and shape of a target area of concern, which requires knowledge about the expected fragmentation dispersion pattern for the particular munition of interest and its use on the site. Historically, site managers and munitions experts have been required to provide their best estimate of the size and shape of the high density fragmentation area (target area) that would result from using a particular munition on that site. These best estimates came from educated guesses or from examining firing tables and lethal or safety circle estimates. Visual Sample Plan (VSP) was then used to derive the transect survey design given this user input.

An earlier ESTCP sponsored project (0507) conducted by Huntsville Army Corps of Engineers, explored an engineering simulated model approach for deriving expected target area sizes and shapes given munitions use. This project derived preliminary estimates but was never fully completed.

To better assist with transect survey design in VSP, we have derived an approach for determining the expected target area radius for various munitions. We have used the data and general techniques put forth in Department of Defense Explosive Safety Board Technical Paper No.16. This report outlines how we derived the conservative radius values that will be implemented in VSP and summarizes the VSP fragment distances for all the munitions' data provided to PNNL.

1.1 Wide Area Assessment

The document "ESTCP Pilot Project Wide Area Assessment for Munitions Response" documents the full wide area assessment (WAA) demonstration completed in 2008 (Andrews and Nelson 2008). In addition, Pacific Northwest National Laboratory (PNNL) has published multiple technical papers on the applications of VSP to this problem[1]. Statistical sampling methods and tools were developed for several phases of the characterization and decision-making process including optimal sampling designs for the detection, delineation and anomaly density estimation of impact areas. These optimal sampling design procedures were implemented in VSP and demonstrated during the larger ESTCP WAA pilot study.

1.2 Visual Sample Plan

VSP is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results to support confident decision-making. VSP couples site, building, and sample location visualization capabilities with optimal sampling design and statistical analysis strategies. VSP, available for free at vsp.pnnl.gov, is currently focused on design and analysis for the following applications.

- Environmental Characterization and Remediation
- Environmental Monitoring and Stewardship
- Response and Recovery of Chemical/Biological/Radiation Terrorist Event
- Footprint Reduction and Remediation of Unexploded Ordnance (UXO) Sites
- Sampling of Soils, Buildings, Groundwater, Sediment, Surface Water, Subsurface Layers.

1.3 Transect Spacing for Target Area Identification

The VSP software has a module focused on determining the required spacing between geophysical transects to confidently detect a specified target area of interest. Before a VSP user can begin optimizing a transect design, he/she must define the size of the target area of interest. A target area represents the area within which the geophysical anomaly density is expected to be significantly elevated above background/clutter. Figure 1 shows the first tab of the "Transect Spacing Needed to Locate a UXO Target Area" VSP dialog. The lower half of the dialog has the target area size and dimension inputs used to define the target area of interest. The interface itself is simple to use and intuitive as to what the inputs represent; however, the process of identifying a munition of interest from the conceptual site model and determining the appropriate size of a target area for that munition is not easy. Additionally, the target area dimension is the most influential of all the inputs necessary to complete a transect design. There have been a number of approaches considered to derive this input including accounting for probable errors of impact around a target, frag dispersion modeling, hazard safety circles, elicitation of expert opinion, and using historical spatial frag dispersion observed on similar sites with similar munitions. None of these were standardized so the inputs of these parameters varied significantly from project to project. This report addresses this issue and presents a standardized approach for determining the expected target area size and shape for various munitions.

[1] http://serdp.org/Program-Areas/Munitions-Response/Support-Tools/MR-200325

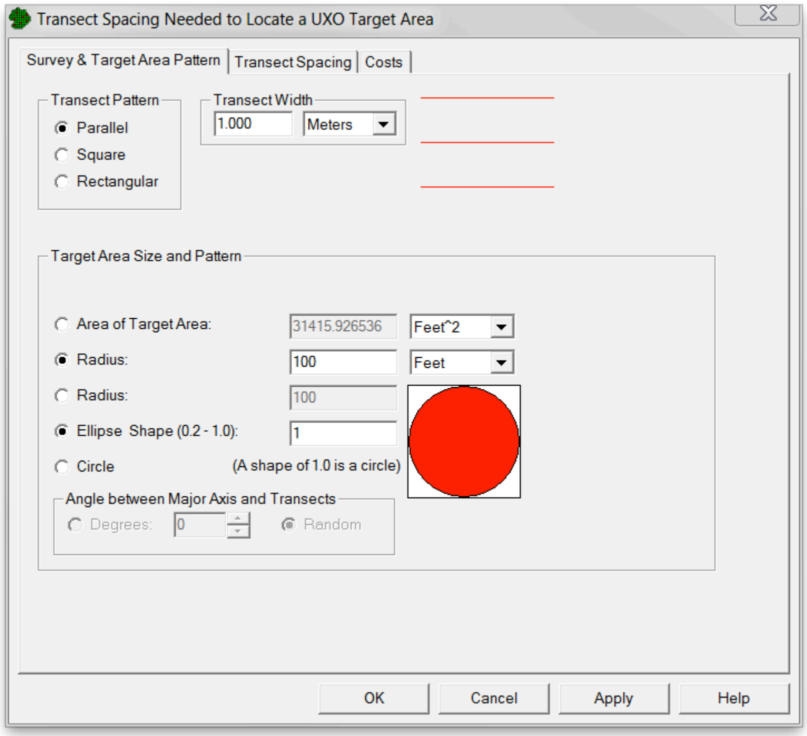

Figure 1 -- VSP 6.0 Dialog for the target area input options for target area dimensions

1.4 Technical Paper 16 and Munitions Safety Development

The Department of Defense Explosive Safety Board (DDESB) was established to "provide objective advice to the Secretary of Defense and Service Secretaries on matters concerning explosives safety…"[2]. As a part of this mission, technical paper (TP) 16 was developed to provide Department of Defense Explosives Safety Board (DDESB) approved methodologies for calculating the characteristics of primary fragments from munitions explosions. It includes methodologies for calculating: primary fragment mass and velocity, maximum fragment range, hazardous fragment distance, effects of detonating stacks of items, effects of detonating buried items, and penetration information[3]. It is updated on a semi-regular basis with the planned release of the 4th revision.

This document is the primary source for the information related to the fragment dispersion from many of the munitions used on historical ranges. As such, VSP users often rely on it as a basis for the assumed target area size based on the specified munition of interest. However, this dependence is difficult as the document is restricted on the DDESB website and the final results put forth in the document are not specifically for the purposes needed by VSP users. We will use the foundations put forth in TP-16 to derive results used for VSP.

2 Technical Basis for VSP Target Area Radii

This section documents the simplified approach developed for use in VSP. This approach provides the basis for the default options to be used in a future VSP 6.X version. In an effort to simplify the process

[2] http://www.ddesb.pentagon.mil/
[3] http://www.ddesb.pentagon.mil/techpapers.html

and be conservative, we have based the approach entirely on the munition specific fragmentation distances and have ignored the implications of the range and deflection probable errors (discussed below) that were considered in the original research.

2.1 Background on Target Radii Development

Figure 2 depicts the process originally proposed for defining the dimension of the target area of interest. This process begins with knowing the distance of fire that then drives the probable errors (range and deflection, see FM 3-22.91 Chapter 2). These probable errors identify the rectangular area where munitions are expected to impact when appropriately fired at the desired target. The fragment dispersion is then combined with the impact footprint to create the ellipse shown at the bottom right of Figure 2.

An example of a firing table with the range and deflection probable errors shown is provided in Figure 3. The range probable errors are the larger of the two (in meters) and differ from 4 meters to 37 meters. The distance and angle at which the projectile is fired is the primary factor defining the errors. However, these tables are munition specific and are affected by the weapon firing the projectile as well.

There will be some cases where knowledge of the specific probable errors is reliable enough that they could be leveraged to increase the assumed target area dimension and thus reduce survey costs. However, we have assumed that knowledge of the shortest firing range of interest will be limited along with the other pertinent information necessary to use such tables informatively. By ignoring these probable errors, we are defining a smaller target area of interest which builds some conservatism into our eventual efforts to determine transect spacing.

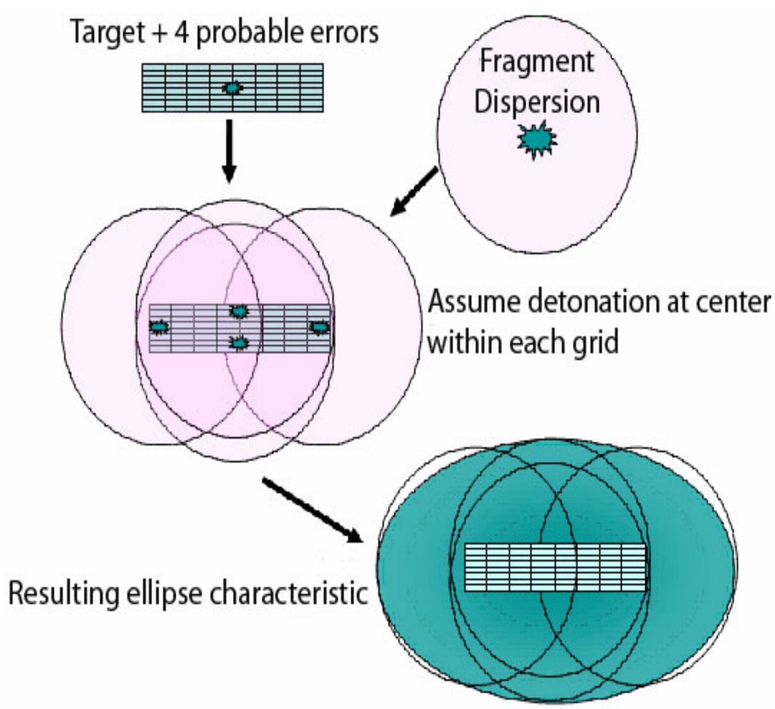

Figure 2 – Diagram of how target area dimensions could be defined using probable errors and fragment dispersion.

CHARGE 4G				TABLE G SUPPLEMENTARY DATA						FT 155-AM-2 PROJ, HE, M107 FUZE, PD, M577		
1	2	3	4	5	6	7	8	9	10	11	12	13
RANGE	ELEV	PROBABLE ERRORS					ANGLE OF FALL	COT ANGLE OF FALL	TML VEL	MO	COMP SITE FOR ANGLE OF SITE	
				FUZE M564								
		R	D	HB	TB	RB					+1 MIL SITE	-1 MIL SITE
M	MIL	M	M	M	SEC	M	MIL		M/S	M	MIL	MIL
0	0.0	4	0				0		316	0	0.000	0.000
500	25.4	4	0				26	39.4	308	0	0.001	0.000
1000	51.7	5	1	1	0.06	18	53	19.1	301	13	0.002	-0.002
1500	78.9	7	1	2	0.07	19	83	12.3	296	30	0.005	-0.005
2000	107.0	8	1	2	0.07	21	113	9.0	290	54	0.010	-0.010
2500	136.2	9	2	3	0.08	22	146	6.9	285	87	0.017	-0.016
3000	166.6	11	2	4	0.08	23	180	5.6	280	129	0.026	-0.024
3500	198.4	12	2	5	0.09	25	217	4.6	276	181	0.038	-0.035
4000	231.7	14	3	7	0.09	26	256	3.9	272	244	0.054	-0.049
4500	267.0	16	3	8	0.10	27	297	3.3	268	319	0.075	-0.068
5000	304.5	18	4	10	0.11	29	341	2.9	265	410	0.103	-0.093
5500	344.9	20	4	12	0.11	30	389	2.5	262	517	0.142	-0.125
6000	389.0	23	5	14	0.12	32	441	2.2	259	647	0.199	-0.171
6500	438.3	25	5	17	0.13	33	500	1.9	257	804	0.287	-0.238
7000	495.5	28	6	20	0.14	35	566	1.6	255	1002	0.445	-0.347
7500	566.7	31	7	24	0.15	37	647	1.4	254	1269	0.831	-0.553
8000	677.4	34	8	32	0.17	39	768	1.1	255	1714		-1.191
******	******	******	******	******	******	******	******	******	******	******	******	******
8000	886.8	37	9	46	0.19	38	977	0.7	260	2597		2.216
7500	996.2	35	10	53	0.21	35	1078	0.6	263	3042	-1.849	1.576
7000	1066.3	32	10	57	0.21	32	1142	0.5	265	3309	-1.461	1.367
6500	1122.1	30	9	60	0.22	30	1193	0.4	267	3508	-1.301	1.255
6000	1169.8	27	9	63	0.22	27	1238	0.4	268	3665	-1.208	1.183
5500	1211.6	24	9	65	0.22	24	1279	0.3	269	3793	-1.146	1.131
5000	1248.5	21	8	67	0.23	21	1317	0.3	269	3897	-1.101	1.092
4500	1280.7		8	69	0.23	18	1355	0.2	269	3980	-1.066	1.061

Figure 7-16. Table G.

Figure 3 – Example of Firing Table information where columns 3 and 4 show the range and deflection errors for different firing distances.

2.2 Simplifying the Target Sizing Approach

As with any modeling routine there are trade-offs between usability and exactness. Specifically, the inputs are intuitive and the user has access to the necessary values to use while the model is reasonably matched to reality. Every modeling project has to deal with the realities of these trade-offs. The original target-sizing project leaned more heavily towards exactness at the expense of usability (Versar, 2007). We have established a method that results in a set of standardized conservative assumptions regarding angle of impact of the munition, firing distance, firing orientation, and probable errors that have allowed for a more useable approach.

2.3 Munition Fragmentation Modeling

Technical paper (TP) 16 provides Department of Defense Explosives Safety Board (DDESB) approved methodologies for calculating the characteristics of primary fragments. It includes methodologies for calculating maximum fragment distances[4]. This paper methodically documents the mathematical engineering models used to represent the fragment dispersion of over 200 different items, which range from grenades to mortars to 2,000 lb bombs. One of the primary uses of the paper was to provide safety distances to explosive ordnance disposal (UXO) technicians. With this use in mind the developers of TP-16 defined 'conservative' as making sure the fragmentation distance was not underestimated. We will use the same engineering models for fragmentation distance (TP-16 process), but will alter some of the inputs and data analysis for the specific needs of VSP target area development.

2.4 VSP Fragmentation Modeling for Target Area Radii

As shown in Figure 1, the default target area dimensions are generally defined using the radius of a circular area. We have assumed that the fragment distance estimates from the TP-16 process would represent the radius of the target area of interest as the fragments could be thrown any direction at the distance specified. In making this assumption we recognize the simplification we have imposed and discuss some of these specific simplifications below.

The fragments from one explosion are used to model the entire target area. Unlike previous target-sizing work we are not requiring duration of use as an input to drive the target area density and size. In addition, we recognize that the fragment dispersions modeled in TP-16 are for one explosion. As explained in Section 2.2, we have made the simplifying 'conservative' assumption that the range and deflection probable errors are not included in the target area size definition. Without including the probable errors, we have assumed the fragment dispersion of one item is sufficient to mark the footprint of the assumed target area for VSP use.

Target area shape is not circular. There are many cases, if not most, where the target area is not circular. The previous work under the target-sizing project proposed that many target areas would have more of an oval or cone shape. Often specific firing targets are close enough to each other, especially with smaller munitions, that the impact area would be a much more elongated oval. We have assumed that the circular footprint as a result of firing at one target is the smallest the area that could exist based on the identified munition of interest and therefore would drive the transect design. The VSP user is still left with the option to override the conservative radius if they have specific information about the shape and orientation of the target area.

Each munition has unique characteristics and therefore a unique fragment radius that should be used to drive the target area dimension. TP-16 is a restricted document due to some of the sensitivities

[4] http://www.ddesb.pentagon.mil/techpapers.html

of having munition specific information. In order for VSP to use the research from TP-16, we honored those restrictions as well. Based on our interaction with the TP-16 authors the simplest method to avoid munition specific information while still providing enough detail for VSP users was to fit a statistical model to the relationship between the munition diameter and the fragmentation distance to the pertinent munitions modeled in TP-16. Additionally, this simplifying step helps when the specific model of munition is unknown. For example, in TP-16 there are multiple 81 mm projectiles listed that each have a different fragmentation distance and some munitions are not listed as well. Appendix B of the PNNL technical report does have the VSP fragmentation distance for all munitions provided to PNNL. While these values are not included in VSP, they can be obtained from the Army Corps of Engineers for project use.

2.5 Diameter / Fragmentation Distance Relationship

There are many factors that control the distance of fragment dispersion from a munition. The primary inputs that are used in the TP-16 process include

- Casing material,
- Explosive type,
- Explosive weight, and
- Ordnance purpose (practice bomb, high explosive munitions, bombs, mortars, chemical, etc.).

These characteristics would be the general elements that describe the differences in fragmentation distances for two munitions of the same diameter. In general the diameter is strongly correlated with the explosive weight and the casing material is related to the ordnance purpose. With the exception of practice bombs all the modeled munitions will have fragment dispersion. We have used the munition diameter as the user defined input that will drive the target area radius based on the fragmentation distance. To partially address the casing material and ordnance purpose we have derived separate diameter-fragmentation distance statistical models for aerial munitions (bombs) standard surface-fired rounds, and chemical surface-fired rounds.

3 Data Analysis and Modeling of VSP Fragmentation Distances

As explained previously, we used the same engineering model/software as documented in TP-16. As the maximum fragmentation distance reported in TP-16 are too large for the design needs in VSP and the hazardous distances shown are too small, the fragmentation distance of the objects of 95^{th} percentile weight were selected to establish a "VSP fragmentation distance". Figure 4 shows the relative decrease in the VSP fragmentation distance as compared to the maximum fragmentation distance using the TP-16 process. The points are colored by munition type and labeled in the figure.

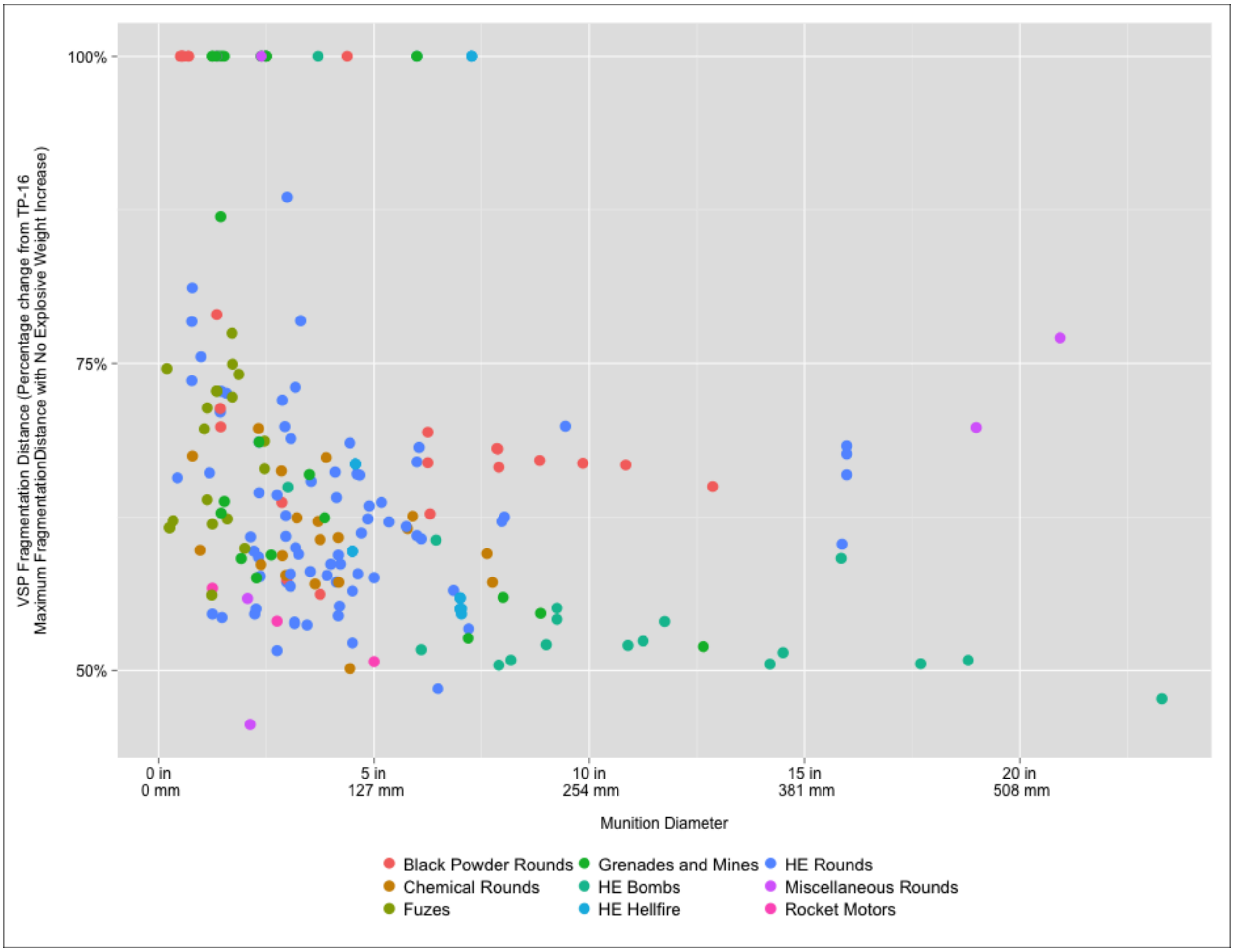

Figure 4 – Scatterplot of the percentage decrease in fragmentation distance observed using the VSP fragmentation distance as compared to the maximum fragmentation distance (no 20% explosive weight increase).

As can be seen from the previous figure, we were provided with munition models for 9 different munitions types for a total of approximately 200 munitions. TP-16 categorizes some of the munitions based on their modeled relationship. The data that were provided by the TP-16 authors have four different modeling categories – not labeled, Extremely Heavy Case, Non-Robust, and Robust (Figure 5 shows these data).

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Figure 5 – Scatterplots of the different munitions types and their relationship between diameter and VSP fragmentation distance. The colors of the points represent the munitions modeling category assignment.

3.1 Munitions Used for Diameter/Fragmentation Relationship

The purpose of this work is to define a standard relationship that maps munition diameter to fragmentation distance, similar to the work done in TP-16, but for applications in VSP based transect designs. As such, a few of the munition types provided to us will be dropped from the diameter/fragmentation model analysis (aerial bombs will be modeled separately in 3.2.4). These types are listed below with a short justification.

- **Grenades and Mines** – It is not clear that these items make sense in the diameter to fragmentation relationship and will be dropped (VSP can still be used for target areas resulting from these munitions but the target area size of interest will not be determined within VSP).
- **Rocket Motors** – There are only three listed and any study looking for rocket motors would probably not be trying to find target areas. If rockets were a driver for target area dimension definition, the fragmentation from the rocket itself would be much larger.
- **Fuzes** – These can exist in a remedial investigation study. However, their fragmentation distance is very small and the fragmentation from the munition would be much larger. It is also not clear that diameter would be a common way to identify them in a generic fashion.
- **HE Hellfire** – There are relatively few items, but those that are available from TP-16 show no relationship between diameter and fragmentation distance.
- **Aerial bombs --** From the scatter plot it should be clear that aerial high explosive bombs (HE bombs in Figure 5) have larger munition diameters relative to the other rounds and the linear relationship between diameter and fragmentation distance is not very strong. As such, bomb specific analyses will be done separately from the ground fired munitions.

The following two figures show the final set of data that will be used to create a model between diameter and fragmentation distance. Almost all the Chemical rounds are extremely heavy cased and there are few heavy cased items in the other munitions types.

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Figure 6 – The four munition types that are used to build the munition diameter relationship to fragmentation distance. Note that a munition's robustness does not appear to differentiate its modeled relationship between diameter and fragmentation distance within a munition type.

For the cases shown above, it is not clear that using the munition robustness provides any significant benefit to explaining the diameter/fragmentation relationship that munition type doesn't already address (we should note that the non-categorized munitions do show less variability). As such, we will group all munitions together and ignore robustness in the modeling process. Figure 7 shows the 126 remaining munitions in one frame and highlights that the chemical rounds (green dots) should be fit separately from the non-chemical rounds as they tend to have a much shorter fragmentation rate for similar diameter non-chemical rounds.

As there are few munitions with diameters above 400 mm, the modeling in this area will be very imprecise and can affect the relationship along the rest of the space inappropriately. Thus, we have dropped these from the generic relationship modeling. This will limit the modeling to munitions with a diameter less than 350 mm.

A summary of the six dropped munitions is listed in Table 1. Note that the torpedo and naval mine are the two extreme purple dots observed on the right and would not be generally searched for under the current uses of VSP.

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Figure 7 – Final set of munitions data used for modeling (excluding circled points above 400 mm).

Table 1 – Summary of the 6 dropped munitions that had diameters over 400 mm.

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3.2 Modeling the Relationship between Munition Diameter and Fragmentation Distance

TP-16 and the scientists developing that work have proposed using different order polynomials for modeling the relationship between the munition diameter and fragmentation distance. PNNL recommends using LOESS methods for modeling the relationship. We will present the results from both methods and then compare them after each is presented. For the comparison of each method we will be fitting the statistical model assuming a multiplicative error structure (i.e. modeling the relationship between munition diameter and the ln(Fragmentation Distance)). However, many more modeling assumptions were evaluated. We describe all of the comparisons in the following section and Appendix A.

3.2.1 Nth Order Polynomial Linear Model Evaluation

TP-16 proposes fitting both a third order and fifth order polynomial to model the relationship. They also propose fitting the relationship with both the dependent and independent variables in the natural log space. Specifically, their equations are

- $ln(fragment\ distance) = A + B\times ln(diameter) + C\times \ln(diameter)^2 + D\times \ln(diameter)^3$
- $\ln(fragment\ distance) = A + B\times \ln(diameter) + C\times \ln(diameter)^2 + D\times \ln(diameter)^3 + E\times \ln(diameter)^4 + F\times \ln(diameter)^5$

We have also fit the 2nd order polynomial model as well for the case where both variables are modeled in the natural log space.

- $ln(fragment\ distance) = A + B\times ln(diameter) + C\times \ln(diameter)^2$

There are additional options beyond fitting the linear relationship in the $\ln(fragment\ distance) \sim \ln(diameter)$ space. We also looked at six additional fits resulting from the three nth order polynomial options previously proposed while fitting in the following two spaces.

- $\ln(fragment\ distance)\ {\sim}diameter$
- $fragment\ distance{\sim}diameter$

The plots of these nine fits and the linear model output are shown in Appendix C. From the results in Appendix C, we recommend using the ln(distance)~diameter 3rd order model for comparison against the loess modeling for the following reasons;

- The *distance~diameter* assumption space assumes an additive error model which we do not believe -- especially for munitions below 100 mm in diameter.
- The ln(*distance)~ln(diameter)* overfits the low diameter munitions.
- The ln(*distance*)~*diameter* is simpler and more intuitive model space (We should note that we will propose some adjustments at the boundary results when using this space).

Figure 8 shows the three model spaces and the best fitting n^{th} order polynomial. From this figure, we highlight that the reasonableness of the 3^{rd} order polynomial ln(*distance*)~*diameter* model. We are primarily concerned with good lower bound estimates at the lower diameters. The lower bounds on the other two models are too wide in in this area.

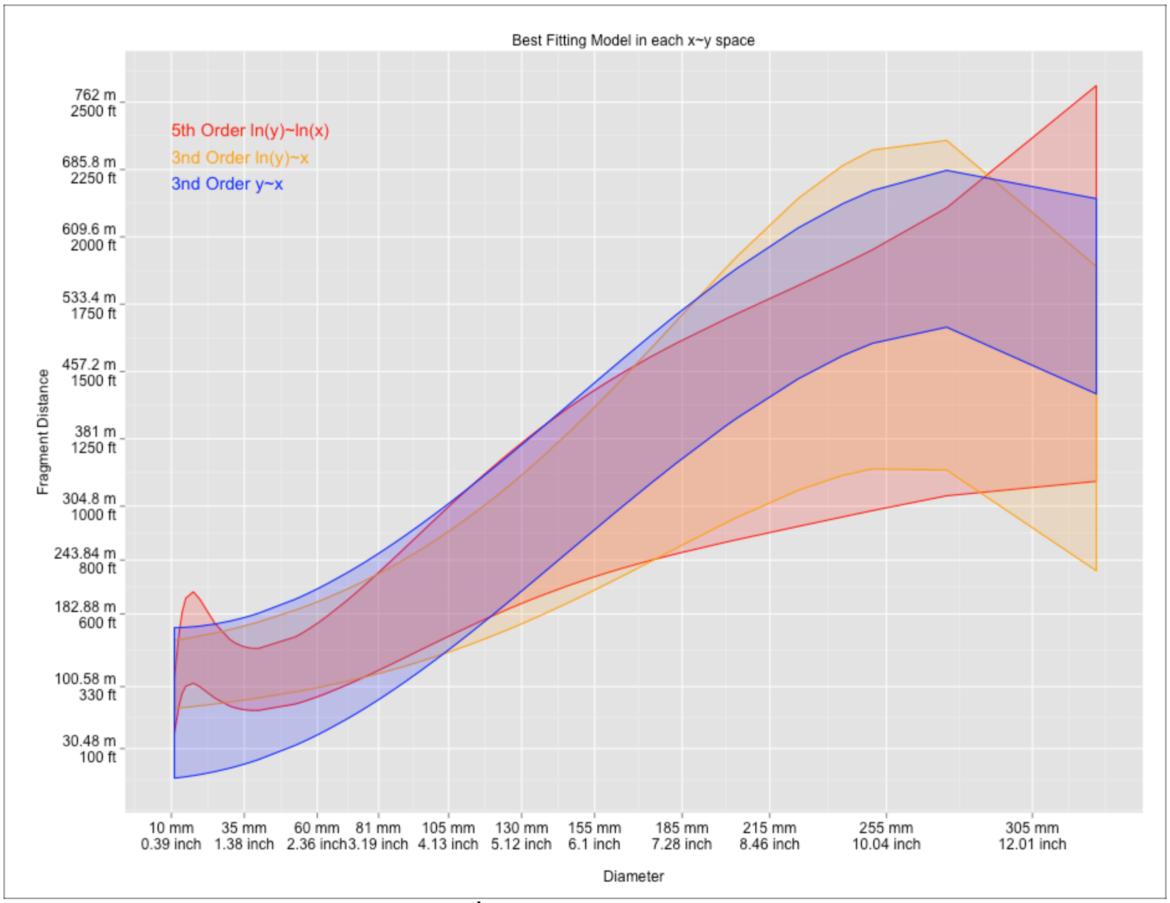

Figure 8 -- Model comparison of the best n^{th} order polynomial fit in each y~x space. Where y = fragmentation distance and x = munition diameter. The shaded area on each model is the region from the mean fit line to the lower bound of the prediction interval.

3.2.2 Loess Modeling

We propose using Loess regression to model the relationship between munition diameter and fragment distance. These methods are well suited for the problem at hand and are accepted and well established within statistical modeling[5]. A major difference between Loess and parametric modeling is the lack of final parametric equation that can be reported. However, there is a final model available from a Loess fit

[5] http://www.itl.nist.gov/div898/handbook/pmd/section1/pmd144.htm

that provides a similar ability to estimate uncertainty and the associated prediction intervals. Loess is a fairly straight forward, computationally intense, extension of least squares regression (Jacoby 2000). Figure 9 shows the fit of the loess model compared to the other three models shown in Figure 8 – the purple band shows the Loess fit. We note the lower bound performance across the entire range of diameters. The Loess model performs better (i.e. tighter) for lower diameters and approaches the tightness of the y-x model in the upper diameters. While there is some slight upward tendency at the lower diameters, the loess model does not overfit as well. Figure 10 is an additional diagnostic to the reliability of the Loess model. In this case the fit is reasonable as the residuals are distributed randomly about zero. The Loess model was fit with a 0.75 span with M-estimator local weighting using a locally quadratic fit[6].

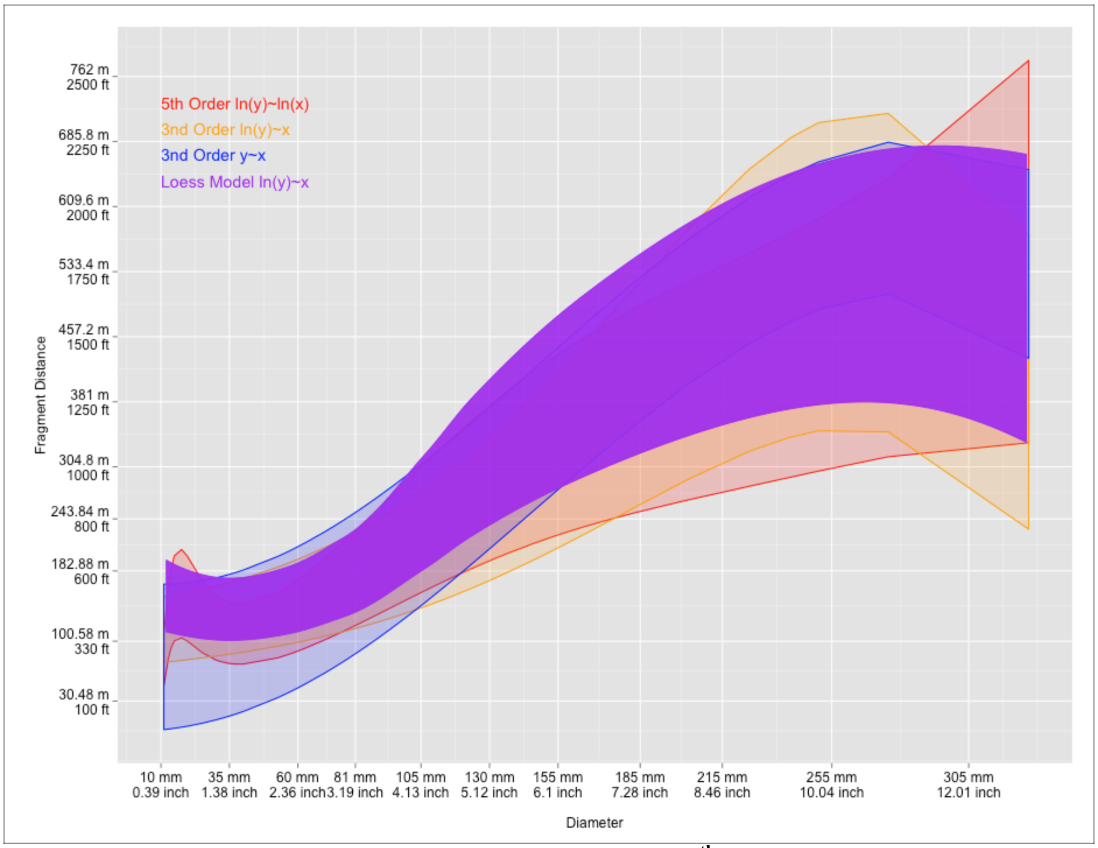

Figure 9 – Loess model (dark purple) compared three of the nth order polynomial models shown in Figure 8.

[6] http://stat.ethz.ch/R-manual/R-patched/library/stats/html/loess.html

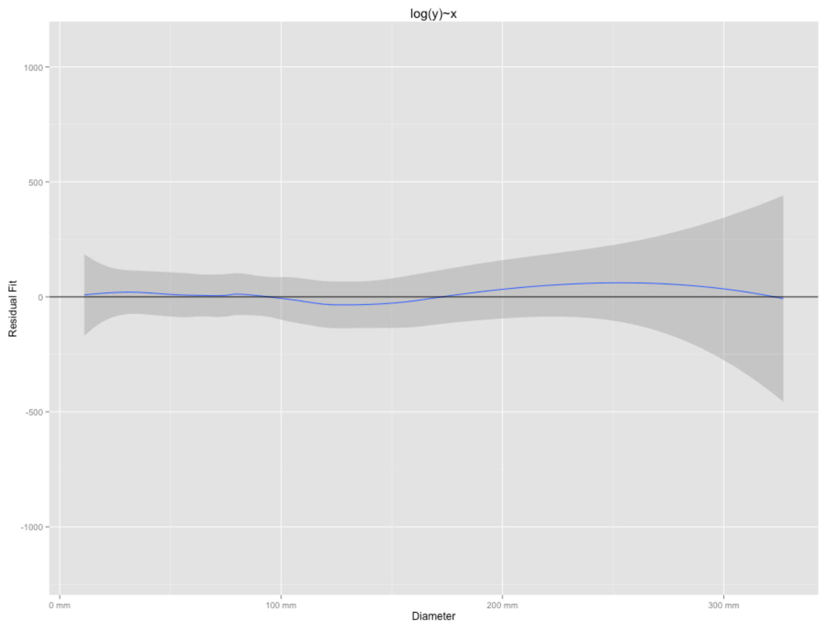

Figure 10 – Residual plot with a Loess fit through the residuals. This plot is used to diagnose the fit of the model to the data. In this case the fit is reasonable as the residuals are distributed randomly about zero.

Figure 11 shows the final high explosive (non-chemical) ground fired rounds lower prediction interval bound proposed for use in VSP. As compared to Figure 9, the tails of the lower bound are fixed. For the small diameter munitions the lower bound was constrained such that smaller rounds could not have a larger fragmentation distance. Similarly, the larger diameter rounds were constrained such that the larger diameter rounds could not have a smaller fragmentation distance.

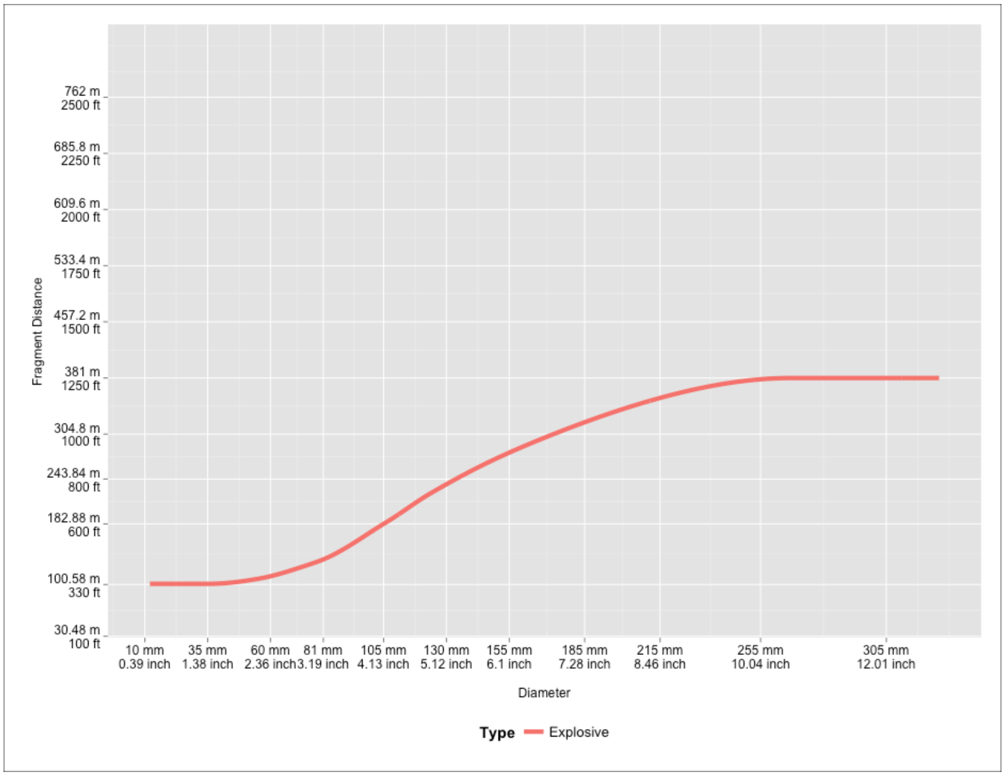

Figure 11 – Final adjusted Loess lower bound prediction interval of the relationship between munition diameter and fragmentation distance.

3.2.3 Defining the Lower Prediction bound for Chemical Rounds

Figure 12 shows the lower prediction interval bound for the chemical rounds (green) and the non-chemical rounds (red). The chemical rounds were fit with the same Loess assumptions explained in Section 3.2.2 to derive the green lower bound. We note that there are a limited number of chemical munitions available to model the relationship between diameter and distance. This limited data introduces more uncertainty and may possibly inflate the lower bounds (clearly observable in the tails).

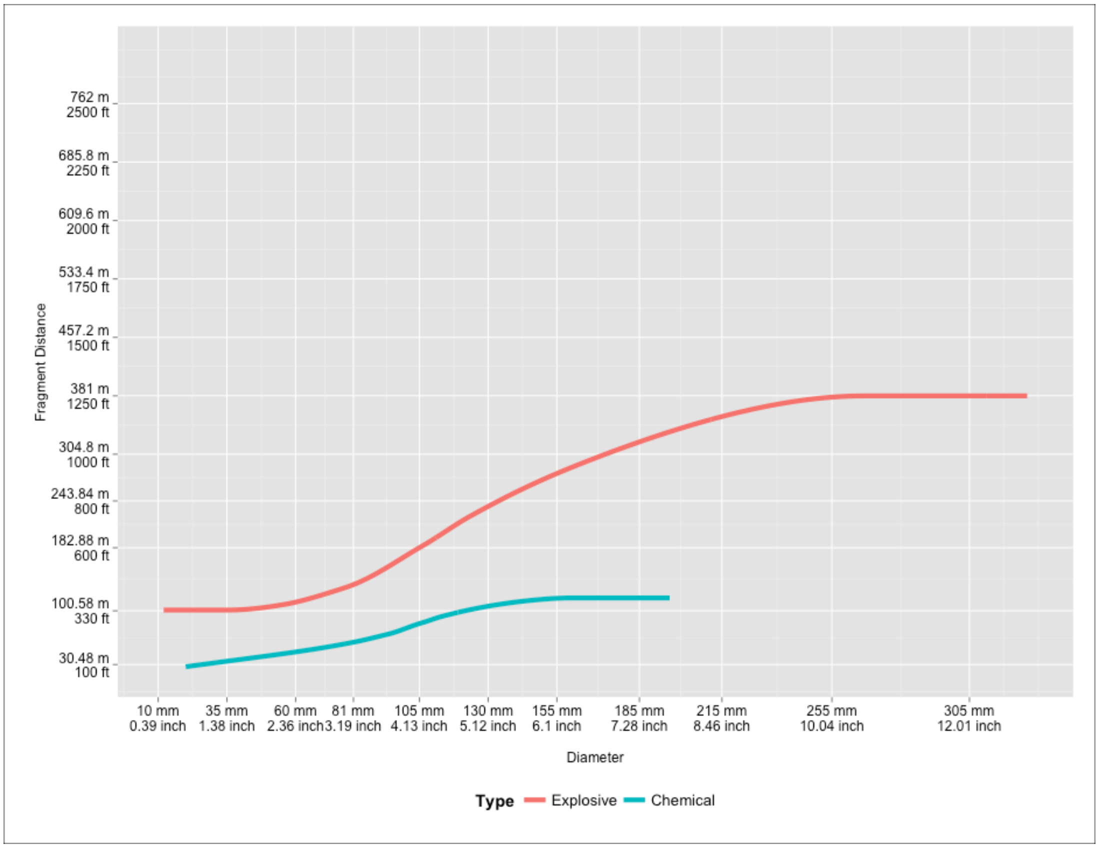

Figure 12 – Lower prediction interval bound for the chemical rounds (green) and the non-chemical rounds (red). The chemical rounds were fit with the same Loess assumptions explained in Section3.2.2.

3.2.4 Defining the Lower Bounds for Aerial Bombs

There are only 19 aerial bombs available in TP-16 for use in modeling a standardized relationship between diameter and fragmentation distance. Ignoring the limited number of points for model fitting, the following figure shows that the relationship between diameter and fragmentation distance is weak (R^2 of 0.1). When separating the bombs into two groups of above or below 100 lbs the linear relationship is even weaker. As shown in Figure 13 by the two dashed lines, we propose using the minimum fragmentation distance for the bombs in each group – 714 ft (218 m) for bombs that are 100 lbs or smaller and 1427 ft (435 m) for bombs that are larger than 100 lbs.

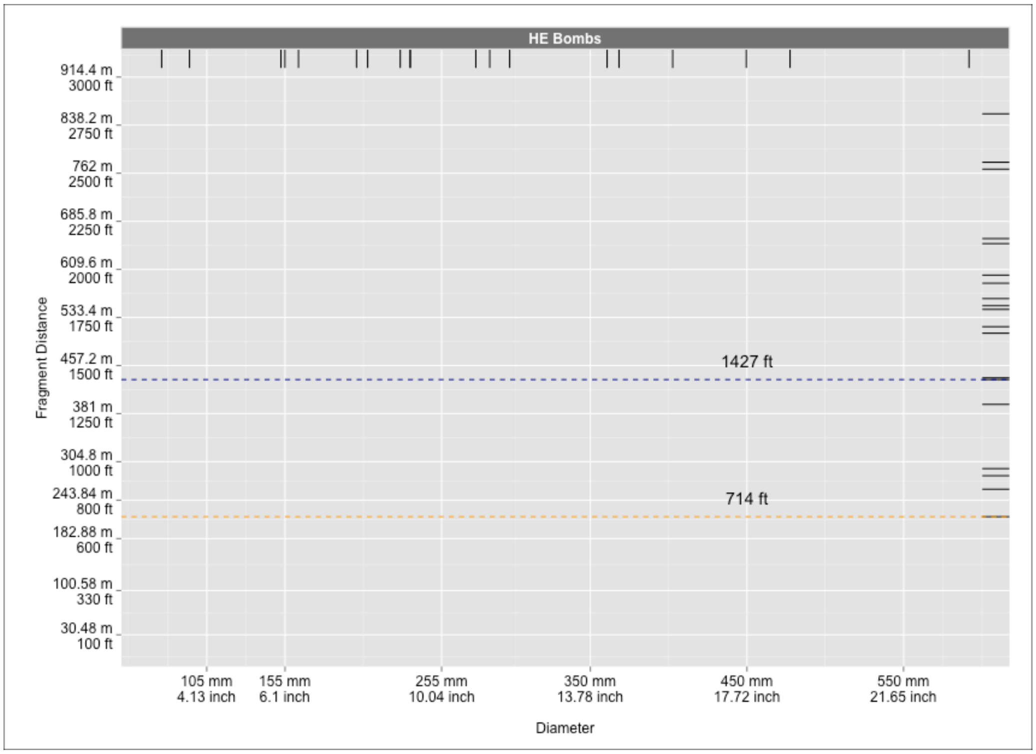

Figure 13 – Scatter plot of the aerial bombs. The dashed lines show the VSP target area radii to be used for transect design.

3.3 Comparison of Final Results to VSP Camp Beale Demonstration Designs

Hathaway (2008) documents the transect design used at the Camp Beale demonstration. This site was the final wide area demonstration site as a part of the larger ESTCP led demonstration. At this site VSP was used to develop the three separate transect designs based on specific munitions of interest. Table 2 shows the comparison of the generalized target area radii, developed in this section, compared to the target area radii used during the Camp Beale demonstration. While not drastically different, the generalized target area radii are all slightly larger than those assumed during the Camp Beale demonstration. The Camp Beale radii were picked based on TP-16 with an added degree of conservatism. While not necessary, the generalized target area radii proposed for use in future releases of VSP line up quite well to those used at Camp Beale.

Table 2 – Comparison of the Camp Beale results to the proposed radius assumptions documented in this report.

Munition	Camp Beale Demonstration Assumed Radius	Generalized Default Radius for VSP
100 lb Bomb (191 mm)	700 feet	714 feet
105 mm	600 feet	600 feet
81 mm	400 feet	442 feet

4 Implementation in VSP

Figure 14 depicts the target sizing options that will be implemented in the next release of VSP. The following list highlights the options on the transect design dialog and how they can be used for selecting a default target area size.

- **Manual / Munition selection:** If the user selects the radio button labeled "I want VSP to calculate the size/shape of the target area of concern" the various inputs and selections are displayed allowing automatic lookup of target radius based on munition features. If the user selects "I want to specify the size/shape of the target area of concern", all of these additional inputs and selections are hidden and the dialog reverts to the basic use as shown in Figure 1 above.
- **Surface Launched / Air Launched selection:** If the user selects "Surface Launched" then the various inputs and selections are displayed allowing automatic lookup of target radius based on munition size. If the use selects "Air Launched" then the "High Explosive / Chemical" selector is changed to "<= 100 lb" or "> 100 lb" selection. All other inputs and selections are hidden. The configuration is illustrated in Figure 14 and 15.
- **High Explosive / Chemical selection:** If the user selects "High Explosive" then the range of inputs on the slider is 12mm to 326mm (0.47" to 12.83") and the Target Area radius is looked up from the Target-HE table stored within VSP (see Appendix A). If the user selects Chemical then the range of inputs on the slider is 20mm to 196mm (0.79" to 7.72") and the Target Area radius is looked up from the table stored within VSP (see Appendix A).
- **<= 100 lb / > 100 lb selection:** If the user selects "<= 100 lb" then the Target Area radius is set to 714 feet (217.627 m). If the user selects "> 100 lb" then the Target Area radius is set to 1427 feet (434.95 m).
- **Slider selection:** Allows the user to select a munition size between the minimum and maximum. The selected munition size is shown in the text below the slider. The slider can be moved by the mouse or arrow keys once it is selected.
- **mm / inch selection:** If the user selects "mm" then the slider limits and munition size text are displayed in millimeters. If the user selects "inch" then the slider limits and munition size text are displayed in inches.

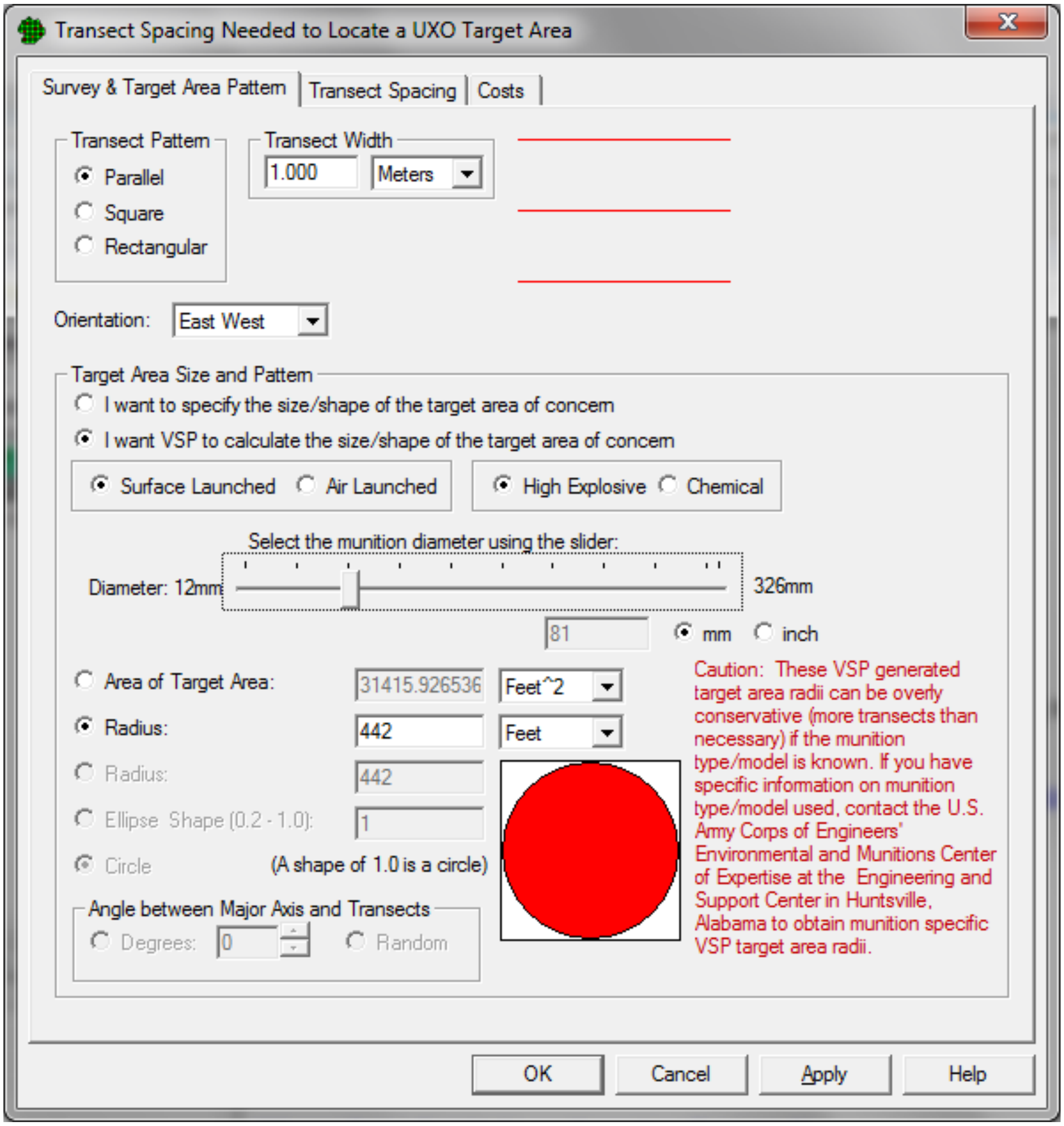

Figure 14 – Target area inputs with target sizing lookup enabled

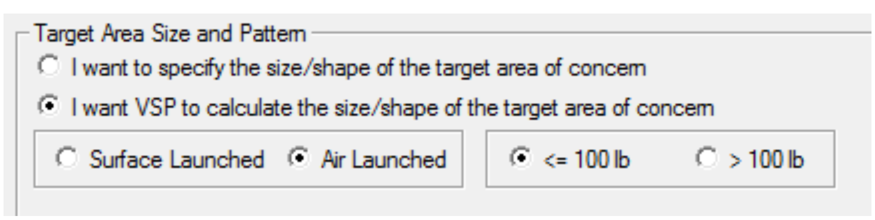

Figure 15 – Target area input for air-launched munitions

5 Conclusion

This report summarizes the work done by PNNL to incorporate a standardized approach to default target area radius selection. This report in its entirety will be made available from the U.S. Army Corps of Engineers Engineering and Support Center, Huntsville, Environmental and Munitions Center of Expertise. PNNL will not distribute the complete report with all data and appendices. A PNNL-distributable version is available with all tables in section 3, Figures 5-7, Appendix B, and Appendix C removed. We will include modified versions of Figures 8-13 that have all points removed. PNNL has obtained ESTCP and Army COE approval on the unrestricted report version. The information in the unrestricted report is used as the help file in VSP.

An appropriate target area radius is the primary driver in establishing a reliable transect spacing to traverse and detect areas of interest within previously used military ranges. TP-16 has been used heavily in the past for this objective. However, as its objectives were not to establish values for use in VSP, we have leveraged all the methods and data from TP-16 to create a “VSP” fragment distance. This work establishes a standardized framework that all projects can leverage for use in VSP transect designs.

6 Acknowledgements

The Army Corps of Engineers was key in getting these methods developed and implemented in VSP. Specifically Andrew Schwartz, Michelle Crull, and Susan Hamilton. Michelle and Susan provided us with the data from TP-16 to be able to make adjustments for VSP needs. This work would have been almost impossible without their support. With Versar corporation, Andy has shepherded the idea of standard target area definitions for almost a decade. His guidance and support on getting a tool that will work for all interested parties was invaluable. Lastly, Herb Nelson and ESTCP have funded this work and continue to push the necessary research to improve the usability of VSP in project specific applications.

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Appendix A – Table of VSP Generated Target Area Radii

The values listed below are the VSP generated target area radii based on the lower bounds of the fragmentation distance/ munitions diameter models and will be accessible to all VSP users through the module, report generator, and help files. Aerial bombs will be 714 ft (218 m) for bombs that are 100 lbs or smaller and 1427 ft (435 m) for bombs that are larger than 100 lbs.

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
0.47	12	333.24	101.57	Not Applicable	Not Applicable
0.51	13	333.24	101.57	Not Applicable	Not Applicable
0.55	14	333.24	101.57	Not Applicable	Not Applicable
0.59	15	333.24	101.57	Not Applicable	Not Applicable
0.63	16	333.24	101.57	Not Applicable	Not Applicable
0.67	17	333.24	101.57	Not Applicable	Not Applicable
0.71	18	333.24	101.57	Not Applicable	Not Applicable
0.75	19	333.24	101.57	Not Applicable	Not Applicable
0.79	20	333.24	101.57	90.72	27.65
0.83	21	333.24	101.57	92.31	28.14
0.87	22	333.24	101.57	93.9	28.62
0.91	23	333.24	101.57	95.49	29.1
0.94	24	333.24	101.57	97.07	29.59
0.98	25	333.24	101.57	98.65	30.07
1.02	26	333.24	101.57	100.23	30.55
1.06	27	333.24	101.57	101.81	31.03
1.1	28	333.24	101.57	103.38	31.51
1.14	29	333.24	101.57	104.95	31.99
1.18	30	333.24	101.57	106.52	32.47
1.22	31	333.24	101.57	108.08	32.94
1.26	32	333.24	101.57	109.64	33.42
1.3	33	333.24	101.57	111.2	33.89
1.34	34	333.24	101.57	112.76	34.37
1.38	35	333.24	101.57	114.31	34.84
1.42	36	333.29	101.59	115.86	35.31
1.46	37	333.48	101.64	117.41	35.79
1.5	38	333.8	101.74	118.96	36.26
1.54	39	334.26	101.88	120.51	36.73
1.57	40	334.84	102.06	122.05	37.2

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
1.61	41	335.54	102.27	123.6	37.67
1.65	42	336.36	102.52	125.15	38.14
1.69	43	337.29	102.81	126.7	38.62
1.73	44	338.33	103.12	128.25	39.09
1.77	45	339.47	103.47	129.8	39.56
1.81	46	340.71	103.85	131.36	40.04
1.85	47	342.05	104.26	132.92	40.52
1.89	48	343.48	104.69	134.49	40.99
1.93	49	344.99	105.15	136.06	41.47
1.97	50	346.59	105.64	137.65	41.95
2.01	51	348.26	106.15	139.23	42.44
2.05	52	350	106.68	140.83	42.93
2.09	53	351.82	107.23	142.44	43.41
2.13	54	353.69	107.81	144.05	43.91
2.17	55	355.63	108.4	145.68	44.4
2.2	56	357.61	109	147.32	44.9
2.24	57	359.71	109.64	148.98	45.41
2.28	58	361.99	110.33	150.65	45.92
2.32	59	364.45	111.09	152.33	46.43
2.36	60	367.08	111.89	154.03	46.95
2.4	61	369.85	112.73	155.75	47.47
2.44	62	372.76	113.62	157.5	48
2.48	63	375.8	114.54	159.26	48.54
2.52	64	378.94	115.5	161.04	49.09
2.56	65	382.18	116.49	162.85	49.64
2.6	66	385.5	117.5	164.68	50.19
2.64	67	388.9	118.54	166.53	50.76
2.68	68	392.37	119.59	168.41	51.33
2.72	69	395.89	120.67	170.31	51.91
2.76	70	399.47	121.76	172.24	52.5
2.8	71	403.09	122.86	174.19	53.09
2.83	72	406.75	123.98	176.17	53.7
2.87	73	410.44	125.1	178.18	54.31
2.91	74	414.12	126.23	180.24	54.94
2.95	75	417.81	127.35	182.33	55.57
2.99	76	421.52	128.48	184.46	56.22

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
3.03	77	425.3	129.63	186.64	56.89
3.07	78	429.18	130.82	188.84	57.56
3.11	79	433.22	132.05	191.08	58.24
3.15	80	437.47	133.34	193.35	58.93
3.19	81	441.98	134.72	195.64	59.63
3.23	82	446.78	136.18	197.97	60.34
3.27	83	451.85	137.72	200.4	61.08
3.31	84	457.17	139.35	202.94	61.86
3.35	85	462.74	141.04	205.57	62.66
3.39	86	468.54	142.81	208.27	63.48
3.43	87	474.55	144.64	211.05	64.33
3.46	88	480.76	146.54	213.88	65.19
3.5	89	487.15	148.48	216.76	66.07
3.54	90	493.72	150.48	219.66	66.95
3.58	91	500.43	152.53	222.58	67.84
3.62	92	507.27	154.62	225.5	68.73
3.66	93	514.23	156.74	228.41	69.62
3.7	94	521.29	158.89	231.3	70.5
3.74	95	528.43	161.07	234.43	71.45
3.78	96	535.63	163.26	237.99	72.54
3.82	97	542.88	165.47	241.91	73.74
3.86	98	550.16	167.69	246.09	75.01
3.9	99	557.44	169.91	250.42	76.33
3.94	100	564.71	172.12	254.81	77.67
3.98	101	571.95	174.33	259.2	79
4.02	102	579.14	176.52	263.5	80.31
4.06	103	586.27	178.69	267.66	81.58
4.09	104	593.3	180.84	271.64	82.8
4.13	105	600.21	182.95	275.4	83.94
4.17	106	606.99	185.01	278.88	85
4.21	107	613.83	187.1	282.48	86.1
4.25	108	620.86	189.24	286.38	87.29
4.29	109	628.06	191.43	290.44	88.53
4.33	110	635.4	193.67	294.5	89.76
4.37	111	642.86	195.95	298.42	90.96
4.41	112	650.42	198.25	302.09	92.08

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
4.45	113	658.05	200.57	305.38	93.08
4.49	114	665.71	202.91	308.49	94.03
4.53	115	673.39	205.25	311.54	94.96
4.57	116	681.06	207.59	314.53	95.87
4.61	117	688.68	209.91	317.46	96.76
4.65	118	696.23	212.21	320.33	97.64
4.69	119	703.67	214.48	323.14	98.49
4.72	120	710.99	216.71	325.88	99.33
4.76	121	718.14	218.89	328.56	100.14
4.8	122	725.09	221.01	331.17	100.94
4.84	123	731.82	223.06	333.73	101.72
4.88	124	738.34	225.04	336.21	102.48
4.92	125	744.81	227.02	338.63	103.21
4.96	126	751.25	228.98	340.99	103.93
5	127	757.65	230.93	343.28	104.63
5.04	128	764.03	232.87	345.5	105.31
5.08	129	770.36	234.81	347.66	105.97
5.12	130	776.65	236.72	349.76	106.61
5.16	131	782.91	238.63	351.79	107.23
5.2	132	789.12	240.52	353.76	107.83
5.24	133	795.29	242.4	355.67	108.41
5.28	134	801.41	244.27	357.52	108.97
5.31	135	807.48	246.12	359.31	109.52
5.35	136	813.5	247.95	361.04	110.04
5.39	137	819.47	249.77	362.71	110.55
5.43	138	825.39	251.58	364.32	111.05
5.47	139	831.26	253.37	365.88	111.52
5.51	140	837.07	255.14	367.39	111.98
5.55	141	842.82	256.89	368.84	112.42
5.59	142	848.52	258.63	370.24	112.85
5.63	143	854.17	260.35	371.58	113.26
5.67	144	859.76	262.05	372.88	113.65
5.71	145	865.29	263.74	374.12	114.03
5.75	146	870.77	265.41	375.32	114.4
5.79	147	876.19	267.06	376.47	114.75
5.83	148	881.56	268.7	377.56	115.08

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
5.87	149	886.87	270.32	378.61	115.4
5.91	150	892.13	271.92	379.61	115.71
5.94	151	897.33	273.51	380.54	115.99
5.98	152	902.49	275.08	381.4	116.25
6.02	153	907.59	276.63	382.17	116.48
6.06	154	912.65	278.17	382.86	116.69
6.1	155	917.66	279.7	383.46	116.88
6.14	156	922.62	281.21	383.97	117.03
6.18	157	927.54	282.71	384.39	117.16
6.22	158	932.41	284.2	384.71	117.26
6.26	159	937.25	285.67	384.93	117.33
6.3	160	942.05	287.14	385.06	117.37
6.34	161	946.81	288.59	385.08	117.37
6.38	162	951.54	290.03	385.08	117.37
6.42	163	956.24	291.46	385.08	117.37
6.46	164	960.9	292.88	385.08	117.37
6.5	165	965.53	294.29	385.08	117.37
6.54	166	970.14	295.7	385.08	117.37
6.57	167	974.73	297.1	385.08	117.37
6.61	168	979.28	298.49	385.08	117.37
6.65	169	983.82	299.87	385.08	117.37
6.69	170	988.33	301.24	385.08	117.37
6.73	171	992.81	302.61	385.08	117.37
6.77	172	997.27	303.97	385.08	117.37
6.81	173	1001.7	305.32	385.08	117.37
6.85	174	1006.11	306.66	385.08	117.37
6.89	175	1010.49	308	385.08	117.37
6.93	176	1014.84	309.32	385.08	117.37
6.97	177	1019.17	310.64	385.08	117.37
7.01	178	1023.47	311.95	385.08	117.37
7.05	179	1027.74	313.26	385.08	117.37
7.09	180	1031.99	314.55	385.08	117.37
7.13	181	1036.21	315.84	385.08	117.37
7.17	182	1040.4	317.11	385.08	117.37
7.2	183	1044.56	318.38	385.08	117.37
7.24	184	1048.7	319.64	385.08	117.37

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
7.28	185	1052.81	320.9	385.08	117.37
7.32	186	1056.88	322.14	385.08	117.37
7.36	187	1060.93	323.37	385.08	117.37
7.4	188	1064.95	324.6	385.08	117.37
7.44	189	1068.94	325.81	385.08	117.37
7.48	190	1072.9	327.02	385.08	117.37
7.52	191	1076.83	328.22	385.08	117.37
7.56	192	1080.72	329.4	385.08	117.37
7.6	193	1084.59	330.58	385.08	117.37
7.64	194	1088.43	331.75	385.08	117.37
7.68	195	1092.23	332.91	385.08	117.37
7.72	196	1096	334.06	385.08	117.37
7.76	197	1099.74	335.2	Not Applicable	Not Applicable
7.8	198	1103.45	336.33	Not Applicable	Not Applicable
7.83	199	1107.12	337.45	Not Applicable	Not Applicable
7.87	200	1110.76	338.56	Not Applicable	Not Applicable
7.91	201	1114.37	339.66	Not Applicable	Not Applicable
7.95	202	1117.94	340.75	Not Applicable	Not Applicable
7.99	203	1121.48	341.83	Not Applicable	Not Applicable
8.03	204	1124.98	342.89	Not Applicable	Not Applicable
8.07	205	1128.45	343.95	Not Applicable	Not Applicable
8.11	206	1131.88	345	Not Applicable	Not Applicable
8.15	207	1135.27	346.03	Not Applicable	Not Applicable
8.19	208	1138.63	347.05	Not Applicable	Not Applicable
8.23	209	1141.95	348.07	Not Applicable	Not Applicable
8.27	210	1145.23	349.07	Not Applicable	Not Applicable
8.31	211	1148.48	350.06	Not Applicable	Not Applicable
8.35	212	1151.68	351.03	Not Applicable	Not Applicable
8.39	213	1154.85	352	Not Applicable	Not Applicable
8.43	214	1157.97	352.95	Not Applicable	Not Applicable
8.46	215	1161.06	353.89	Not Applicable	Not Applicable
8.5	216	1164.1	354.82	Not Applicable	Not Applicable
8.54	217	1167.1	355.73	Not Applicable	Not Applicable
8.58	218	1170.06	356.64	Not Applicable	Not Applicable
8.62	219	1172.98	357.52	Not Applicable	Not Applicable
8.66	220	1175.86	358.4	Not Applicable	Not Applicable

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
8.7	221	1178.69	359.26	Not Applicable	Not Applicable
8.74	222	1181.47	360.11	Not Applicable	Not Applicable
8.78	223	1184.22	360.95	Not Applicable	Not Applicable
8.82	224	1186.91	361.77	Not Applicable	Not Applicable
8.86	225	1189.56	362.58	Not Applicable	Not Applicable
8.9	226	1192.17	363.37	Not Applicable	Not Applicable
8.94	227	1194.72	364.15	Not Applicable	Not Applicable
8.98	228	1197.23	364.92	Not Applicable	Not Applicable
9.02	229	1199.69	365.66	Not Applicable	Not Applicable
9.06	230	1202.1	366.4	Not Applicable	Not Applicable
9.09	231	1204.46	367.12	Not Applicable	Not Applicable
9.13	232	1206.76	367.82	Not Applicable	Not Applicable
9.17	233	1209.02	368.51	Not Applicable	Not Applicable
9.21	234	1211.23	369.18	Not Applicable	Not Applicable
9.25	235	1213.38	369.84	Not Applicable	Not Applicable
9.29	236	1215.48	370.48	Not Applicable	Not Applicable
9.33	237	1217.52	371.1	Not Applicable	Not Applicable
9.37	238	1219.51	371.71	Not Applicable	Not Applicable
9.41	239	1221.44	372.3	Not Applicable	Not Applicable
9.45	240	1223.32	372.87	Not Applicable	Not Applicable
9.49	241	1225.13	373.42	Not Applicable	Not Applicable
9.53	242	1226.9	373.96	Not Applicable	Not Applicable
9.57	243	1228.6	374.48	Not Applicable	Not Applicable
9.61	244	1230.24	374.98	Not Applicable	Not Applicable
9.65	245	1231.82	375.46	Not Applicable	Not Applicable
9.69	246	1233.34	375.92	Not Applicable	Not Applicable
9.72	247	1234.8	376.37	Not Applicable	Not Applicable
9.76	248	1236.19	376.79	Not Applicable	Not Applicable
9.8	249	1237.52	377.2	Not Applicable	Not Applicable
9.84	250	1238.79	377.58	Not Applicable	Not Applicable
9.88	251	1239.99	377.95	Not Applicable	Not Applicable
9.92	252	1241.12	378.29	Not Applicable	Not Applicable
9.96	253	1242.19	378.62	Not Applicable	Not Applicable
10	254	1243.19	378.92	Not Applicable	Not Applicable
10.04	255	1244.12	379.21	Not Applicable	Not Applicable
10.08	256	1244.98	379.47	Not Applicable	Not Applicable

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
10.12	257	1245.77	379.71	Not Applicable	Not Applicable
10.16	258	1246.49	379.93	Not Applicable	Not Applicable
10.2	259	1247.14	380.13	Not Applicable	Not Applicable
10.24	260	1247.72	380.3	Not Applicable	Not Applicable
10.28	261	1248.22	380.46	Not Applicable	Not Applicable
10.31	262	1248.65	380.59	Not Applicable	Not Applicable
10.35	263	1249	380.69	Not Applicable	Not Applicable
10.39	264	1249.27	380.78	Not Applicable	Not Applicable
10.43	265	1249.47	380.84	Not Applicable	Not Applicable
10.47	266	1249.59	380.88	Not Applicable	Not Applicable
10.51	267	1249.63	380.89	Not Applicable	Not Applicable
10.55	268	1249.63	380.89	Not Applicable	Not Applicable
10.59	269	1249.63	380.89	Not Applicable	Not Applicable
10.63	270	1249.63	380.89	Not Applicable	Not Applicable
10.67	271	1249.63	380.89	Not Applicable	Not Applicable
10.71	272	1249.63	380.89	Not Applicable	Not Applicable
10.75	273	1249.63	380.89	Not Applicable	Not Applicable
10.79	274	1249.63	380.89	Not Applicable	Not Applicable
10.83	275	1249.63	380.89	Not Applicable	Not Applicable
10.87	276	1249.63	380.89	Not Applicable	Not Applicable
10.91	277	1249.63	380.89	Not Applicable	Not Applicable
10.94	278	1249.63	380.89	Not Applicable	Not Applicable
10.98	279	1249.63	380.89	Not Applicable	Not Applicable
11.02	280	1249.63	380.89	Not Applicable	Not Applicable
11.06	281	1249.63	380.89	Not Applicable	Not Applicable
11.1	282	1249.63	380.89	Not Applicable	Not Applicable
11.14	283	1249.63	380.89	Not Applicable	Not Applicable
11.18	284	1249.63	380.89	Not Applicable	Not Applicable
11.22	285	1249.63	380.89	Not Applicable	Not Applicable
11.26	286	1249.63	380.89	Not Applicable	Not Applicable
11.3	287	1249.63	380.89	Not Applicable	Not Applicable
11.34	288	1249.63	380.89	Not Applicable	Not Applicable
11.38	289	1249.63	380.89	Not Applicable	Not Applicable
11.42	290	1249.63	380.89	Not Applicable	Not Applicable
11.46	291	1249.63	380.89	Not Applicable	Not Applicable
11.5	292	1249.63	380.89	Not Applicable	Not Applicable

Round Diameter (in)	Round Diameter (mm)	High Explosive Rounds (ft)	High Explosive Rounds (m)	Chemical Rounds (ft)	Chemical Rounds (m)
11.54	293	1249.63	380.89	Not Applicable	Not Applicable
11.57	294	1249.63	380.89	Not Applicable	Not Applicable
11.61	295	1249.63	380.89	Not Applicable	Not Applicable
11.65	296	1249.63	380.89	Not Applicable	Not Applicable
11.69	297	1249.63	380.89	Not Applicable	Not Applicable
11.73	298	1249.63	380.89	Not Applicable	Not Applicable
11.77	299	1249.63	380.89	Not Applicable	Not Applicable
11.81	300	1249.63	380.89	Not Applicable	Not Applicable
11.85	301	1249.63	380.89	Not Applicable	Not Applicable
11.89	302	1249.63	380.89	Not Applicable	Not Applicable
11.93	303	1249.63	380.89	Not Applicable	Not Applicable
11.97	304	1249.63	380.89	Not Applicable	Not Applicable
12.01	305	1249.63	380.89	Not Applicable	Not Applicable
12.05	306	1249.63	380.89	Not Applicable	Not Applicable
12.09	307	1249.63	380.89	Not Applicable	Not Applicable
12.13	308	1249.63	380.89	Not Applicable	Not Applicable
12.17	309	1249.63	380.89	Not Applicable	Not Applicable
12.2	310	1249.63	380.89	Not Applicable	Not Applicable
12.24	311	1249.63	380.89	Not Applicable	Not Applicable
12.28	312	1249.63	380.89	Not Applicable	Not Applicable
12.32	313	1249.63	380.89	Not Applicable	Not Applicable
12.36	314	1249.63	380.89	Not Applicable	Not Applicable
12.4	315	1249.63	380.89	Not Applicable	Not Applicable
12.44	316	1249.63	380.89	Not Applicable	Not Applicable
12.48	317	1249.63	380.89	Not Applicable	Not Applicable
12.52	318	1249.63	380.89	Not Applicable	Not Applicable
12.56	319	1249.63	380.89	Not Applicable	Not Applicable
12.6	320	1249.63	380.89	Not Applicable	Not Applicable
12.64	321	1249.63	380.89	Not Applicable	Not Applicable
12.68	322	1249.63	380.89	Not Applicable	Not Applicable
12.72	323	1249.63	380.89	Not Applicable	Not Applicable
12.76	324	1249.63	380.89	Not Applicable	Not Applicable
12.8	325	1249.63	380.89	Not Applicable	Not Applicable
12.83	326	1249.63	380.89	Not Applicable	Not Applicable

Appendix B – VSP Fragment Distances

These values will not be available in VSP or distributed by PNNL. They will be available for the Army Corps of Engineers to supply to contractors in much the same fashion as TP-16 is distributed.

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Appendix C – Linear Model Output and Graphics

In following three figures, the blue line show the 5th order fit, the red line shows the 3rd order fit, and the green line shows the 2nd order fit. The shaded area on each model is the region from the mean fit line to the lower bound of the prediction interval.

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