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Damage Expectancy Uncertainties for Deeply Buried Targets

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13. ABSTRACT *(Maximum 200 words)* This targeting uncertainties methodology quantifies the effect of systematic errors on the targeting prediction measure damage expectancy. The methodology, developed specifically to support the SEPW Phase 2 Study, evaluates and ranks the effect of uncertainties for applications involving a single buried target and a single earth penetrating weapon. This methodology models the penetration of the EPW, the ground shock environment, and the probability of damage to the underground target. Potential error sources treated in the methodology are impact velocity, geology, depth of burst, target hardness, ground shock prediction model, ground shock depth-to-effect, weapon aiming accuracy, distance damage prediction model, and target depth, location and size.

The methodology makes minimal use of assumed distributions and Monte Carlo techniques; instead it uses three points to describe the inherent dispersion for all but one error source. The values are sorted and used to define a distribution for DE. In addition, an analysis of variance technique is used to calculate the relative contributions of each error source to the uncertainty in DE. The added benefit of ranking the error sources in terms of their contribution to the uncertainty in DE can provide insight into deeply buried targeting problems.

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CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement

MULTIPLY →	BY →	TO GET
TO GET ←	BY ←	DIVIDE

Angstrom	1.0 x E -10	Meter (m)
Atmosphere (normal)	1.013 250 x E +2	Kilo pascal (kPa)
Bar	1.0 x E +2	Kilo pascal (kPa)
British thermal unit	1.054 350 x E +3	Joule (J)
Calorie	4.184	Joule (J)
Cal / cm^2	4.184 x E -2	Mega joule / m^2 (MJ / m^2)
Curie	3.7 x E +1	Giga becquerel (GBq)
Degree (angle)	1.745 329 x E -2	Radian (rad)
Degree Fahrenheit	$t_k = (t^\circ + 459.67) / 1.8$	Degree kelvin (K)
Electron volt	1.602 190 x E -19	Joule (J)
Erg	1.0 x E -7	Joule (J)
Erg / second	1.0 x E -7	Watt (W)
Foot	3.048 x E-1	Meter (m)
Foot - pound - force	1.355 818	Joule (J)
Gallon (U.S. liquid)	3.785 412 x E-3	$Meter^3$ (m^3)
Inch	2.54 x E -2	Meter (m)
Jerk	1.0 x E +9	Joule (J)
Joule / kilogram	1.0	Gray (Gy)
Kiloton	4.183	Terajoule
Kip (1000 lbf)	4.448 222 x E +3	Newton (N)
Kip / $inch^2$ (ksi)	6.894 757 x E +3	Kilo pascal (kPa)
Micron	1.0 x E -6	Meter (m)
Mil	2.54 x E -5	Meter (m)
Mile (international)	1.609 344 x E +3	Meter (m)
Ounce	2.834 952 x E -2	Kilogram (kg)
Pound - force inch	1.129 848 x E -1	Newton - meter (N m)
Pound - force / inch	1.751 268 x E +2	Newton / meter (N / m)
Pound - force / $foot^2$	4.788 026 x E -2	Kilo pascal (kPa)
Pound - force / $inch^2$ (psi)	6.894 757	Kilo pascal (kPa)
Pound - mass / $foot^3$	1.601 846 x E +1	Kilogram / $meter^3$ (kg / m^3)
Rad (radiation dose absorbed)	1.0 x E -2	Gray
Roentgen	2.579 760 x E -4	Coulomb / kilogram (C / kg)
Shake	1.0 x E -8	Second (s)
Slug	1.459 390 x E +1	Kilogram (kg)
Torr (mm Hg, 0° C)	1.333 220 x E -1	Kilo pascal (kPa)

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74," American Society of Testing and Materials.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION 1
INTRODUCTION

Under the sponsorship of the Defense Nuclear Agency, a quantitative methodology was developed to treat identified errors affecting targeting predictions. Described herein is a derivative of that methodology specifically developed to support the SEPW Phase 2 Study.

This targeting uncertainties methodology quantifies the effect of systematic errors on damage expectancy, DE (a measure of effectiveness used by the JSTPS to quantify the probability of achieving at least the specified level of target damage). The methodology evaluates and ranks the effect of uncertainties for applications involving a single buried target and a single earth penetrating weapon. The methodology models the penetration of the EPW, the ground shock environment, and the probability of damage to the underground target. Potential error sources treated in the methodology are impact velocity, geology, depth of burst, target hardness, ground shock prediction model, ground shock depth-to-effect, weapon aiming accuracy, distance damage prediction model, and target depth, location and size.

The methodology makes minimal use of assumed distributions and Monte Carlo techniques; instead it uses three points to describe the inherent dispersion for all but one error source. DE is calculated for each combination of error source values. The values are sorted and used to define a distribution for DE. In addition, an analysis of variance technique is used to calculate the relative contributions of each error source to the uncertainty in DE. The added benefit of ranking the error sources in terms of their contribution to the uncertainty in DE can provide insight into deeply buried targeting problems.

The uncertainties methodology is PC-compatible, fast running, and provides results which compare favorably with more rigorous mathematical methods.

The methodology will be described in Section 2, followed by an example problem in Section 3. Section 4 provides a summary. Hardware requirements and runtime procedures are given in Section 5. Section 6 provides references.

SECTION 2
UNCERTAINTIES METHODOLOGY

The uncertainties methodology for deeply buried targets is a PC-based algorithm which, unlike a Monte Carlo based routine, makes minimal use of assumed distributions. Instead it uses three points to describe the inherent dispersion of all but one of the identified error sources. This allows infinite flexibility in describing the suspected error. The three points may be thought of as a nominal value and lower and upper bounds; mean plus or minus one, two, or three standard deviations; median and quartiles; or for best agreement with Monte Carlo methods, 5th, 50th, and 95th percentiles. Generally, all combinations of values for the error sources are propagated through the methodology, creating a distribution of outcomes and allowing for an analysis of variance (ANOVA) technique to calculate the relative contribution of each error source to the uncertainty in outcome. A more complete discussion of the 3-point concept and its use is given in two references (Ref. 1) and (Ref. 4).

Potential error sources treated in the methodology include EPW impact velocity, geology, depth of burst (DOB), target hardness, ground shock prediction model, ground shock depth-to-effect, target depth, target location, target size, weapon aiming accuracy, and distance damage prediction model. An overall view of the uncertainties methodology is given in Figure 1.

As shown, the uncertainties methodology is performed in two parts. The first part (DTEUA) analyzes the uncertainty in depth-to-effect (DTE), given uncertainties in EPW impact velocity, target site geology, target hardness, and the DUG1C ground shock model. Outputs to the DTE analysis include uncertainty in DTE, and relative contributions of each error source to the uncertainty in DTE. In addition, a value for PSP (probability of successful penetration) is calculated based on the number of Monte Carlo trials which exceeded recommended levels of axial loading, or in which the penetration was sufficiently shallow to incur a rebounding condition.

The second part of the uncertainties methodology is concerned with uncertainties which influence DE (and were not examined in the first part of the methodology). Error sources of interest include target size, target depth, CEP (weapon aiming accuracy), target location, slant range damage sigma, and DTE (which was calculated in the first part of the methodology). Values for these error sources are used as inputs to the DUGDE code along with the PSP value calculated in DTEUA. Outputs from the DE analysis include a best estimate for DE as well as one standard deviation-type uncertainty bounds for DE. Also calculated are the relative contributions for each of the error sources to the uncertainty in DE.

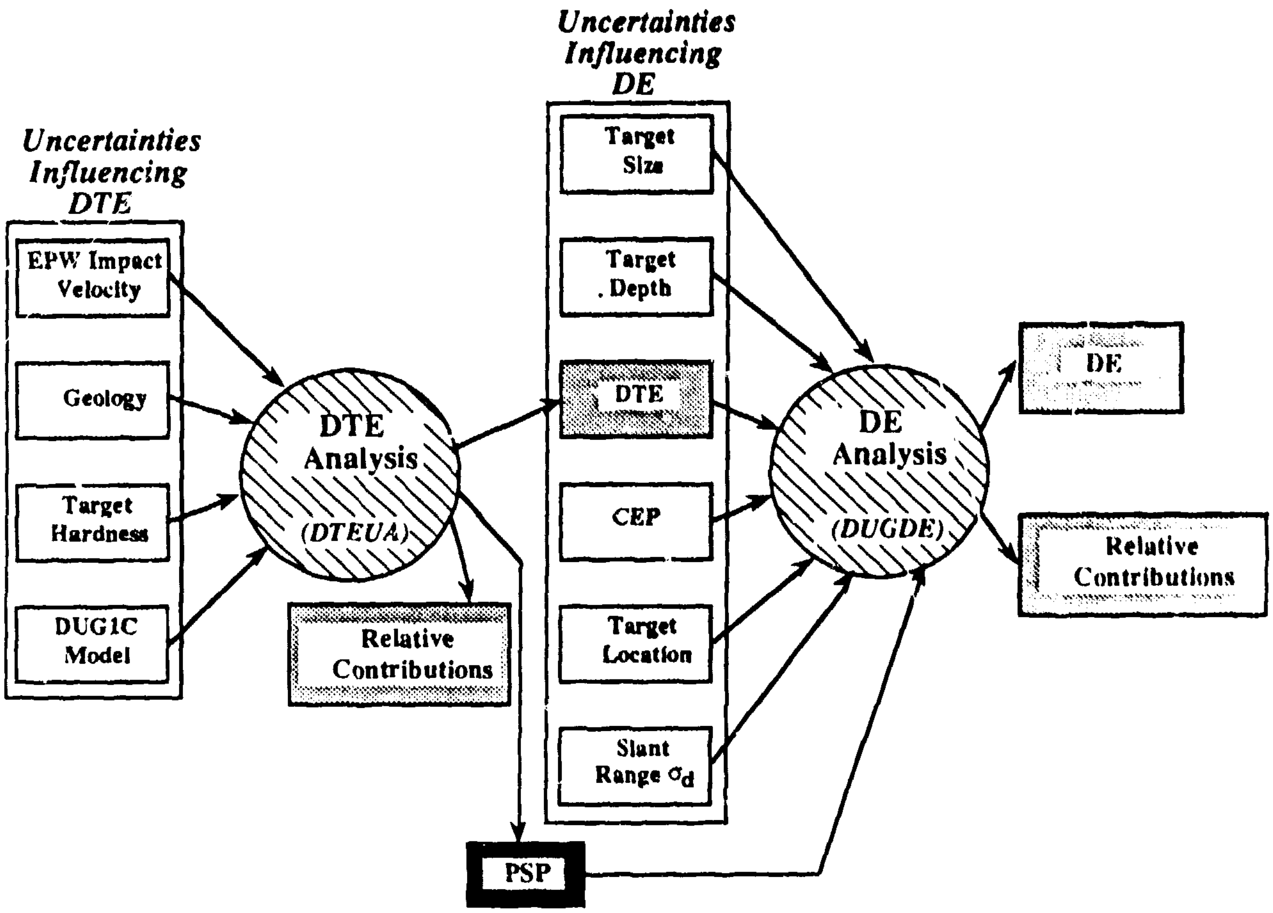

Figure 1. Overview of the uncertainties methodology for deeply buried targets.

2.1 DTE ANALYSIS.

This part of the methodology is concerned with the penetration of the EPW into the target site geology, propagation of the ground shock down toward the target, and the calculation of the depth-to-effect. A logic diagram of the DTE analysis is shown in Figure 2.

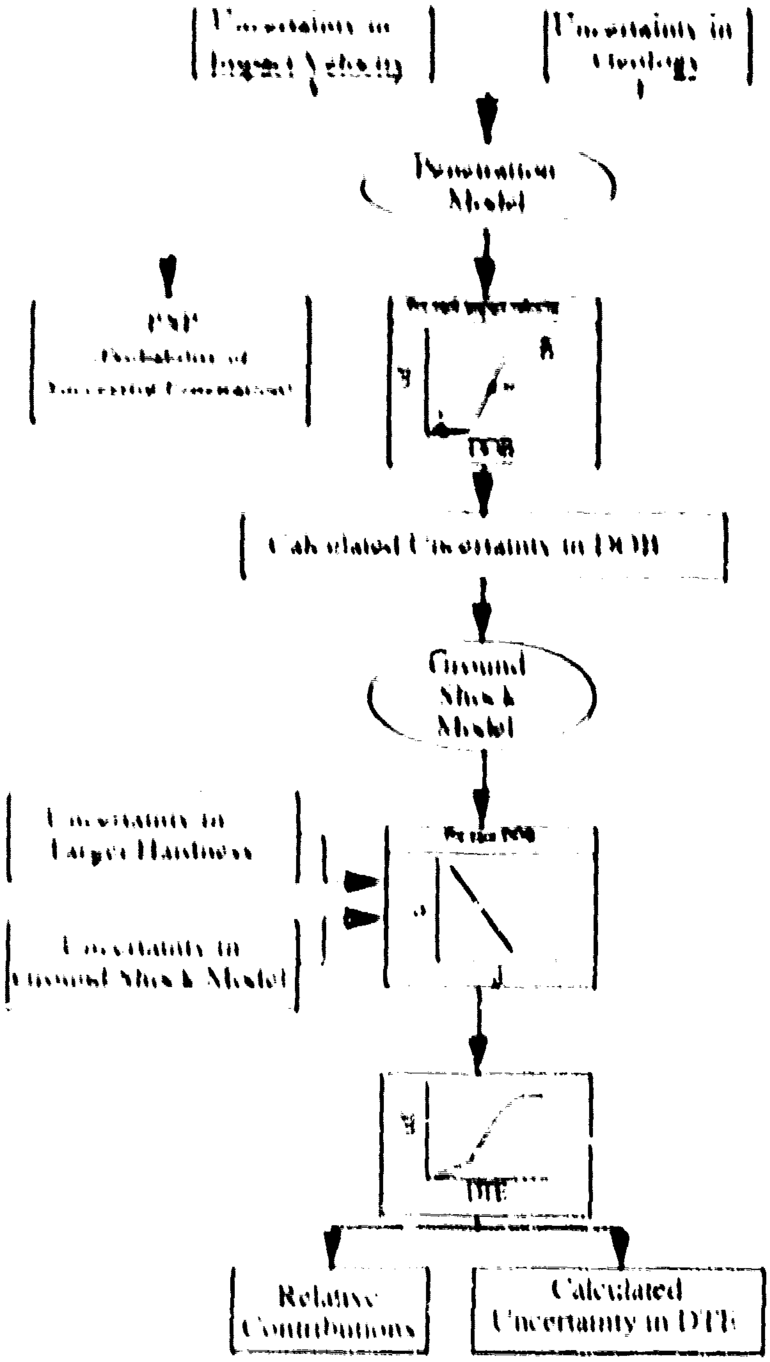

Figure 2 Flow chart for the DTE analysis.

The DTE analysis examines the effect of uncertainty in impact velocity, geology, target hardness, and ground shock model on DTE. Three points are used to define the dispersion in impact velocity, target hardness (defined in terms of peak stress), and confidence in ground shock model results.

However in order to assess the impact of uncertainty in geology on depth of penetration and thus DTE, a Monte Carlo technique is used. Uncertainty is assigned to each layer's thickness and penetrability. Given an impact velocity, a Monte Carlo sampling technique is used to sample each layer's thickness (assumed to be uniformly distributed) and penetrability (assumed to be normally distributed). Then the penetration equations are used to calculate the depth of penetration into the sampled geology and the maximum deceleration experienced by the penetrator.

These two steps (sample geology, calculate penetration) are repeated for a given number of trials in order to achieve a distribution of penetration depths, which represents the uncertainty in DOB due to the uncertainty in geology. From this distribution, the 5th, 50th, and 95th percentiles are read and saved as inputs for the ground shock model. In addition, the values calculated for depth of penetration and maximum deceleration for each trial are checked against rebounding and axial loading criteria to determine the probability of successful penetration (PSP). The value for PSP is used as input to the DE analysis.

The calculation of uncertainty in DOB due to uncertainty in geology is repeated for each impact velocity. Thus if both geology and impact velocity are assigned uncertainties, nine DOBs will be calculated.

Each DOB is used as an input to the ground shock model, which predicts the down-axis depth versus peak stress profiles. Values for depth to each target hardness are determined, as well as the uncertainty in those depths due to potential modeling errors. Since there are nine DOBs and nine depths (DTEs) read from the ground shock model output for each DOB, in all 81 (3^4) DTEs are calculated. These 81 DTE values are sorted to form a cumulative density function (cdf) for DTE.

Following discussion of the penetration and ground shock models, the calculation of the relative contributions of each of the four error sources will be discussed, as well as the conversion of the 81 calculated DTEs into the 3-point scheme for input into the DE analysis.

2.1.1 Penetration Model.

The model used to determine the depth of penetration of the EPW is based on the equations, definitions, and algorithms in two development reports by C.W. Young (Ref. 6, Ref. 7). The model, called PENDEPTH, is documented in its user's manual (Ref. 5). The model calculates the depth of penetration of an EPW through a layered geology. Generally, the penetrator's velocity exiting a layer is calculated, then applied as an impact velocity into the next layer. This is repeated for each layer until the penetrator stops.

Inputs to the model include those associated with both the weapon and the geology. Weapon inputs include impact angle and velocity; penetrator weight and diameter; nose shape, nose length, and performance coefficient. Geology inputs, for each layer, include a layer type (i.e., soil, rock, concrete, or frozen soil), a thickness, and a penetrability number (called the S-number). The harder a layer is, the lower its S-number will be, and in general the shallower the penetration depth.

PENDEPTH's output includes the path length and vertical component of the depth of penetration, as well as the layer in which the penetrator comes to rest. Additional outputs include the peak and average axial deceleration experienced by the penetrator in each layer, and the velocity as the penetrator enters each layer.

2.1.2 Ground Shock Model.

The values calculated for depth of penetration due to uncertainty in both impact velocity and geology are used as input to the ground shock model along with penetrator yield and geology information (e.g., layer thickness, air-filled voids, density, seismic and loading velocities, and attenuation exponent). The ground shock model is a DNA-approved engineering algorithm, called DUG1C, which predicts the down-axis (1D) depth versus stress profiles beneath near surface explosions. The DUG1C computer code is described in detail in its user's guide (Ref. 2) and technical manual (Ref. 3). In addition to down axis depths-to-effect, DUG1C specifies a geometry for constructing iso-stress contours, as shown in Figure 3.

The DUG1C code reproduces most observed contained burst explosion data in media ranging from loose soil to hard rock, and is accurate to a factor of two in stress at a given depth.

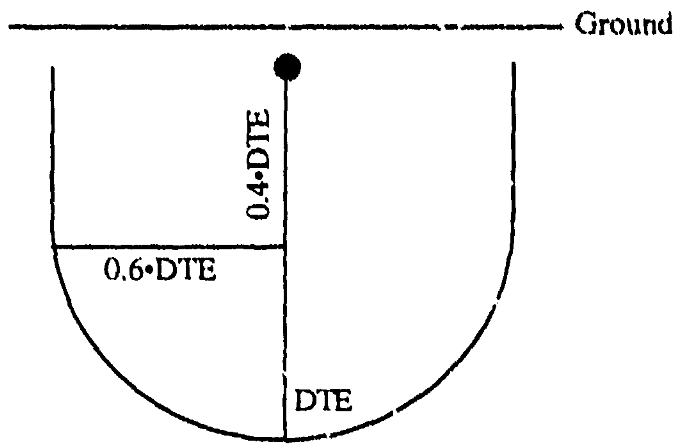

Figure 3. DUG1C-defined iso-stress contour.

Internal to DUG1C is a coupling curve (see Figure 4) which defines the portion of energy that is coupled into the ground. All coupling values are relative to 1.0 for a fully coupled burst. Depending on where the DOB is on the coupling curve, even a small uncertainty in DOB can have a large effect on the coupling factor, which is directly related to the determined DTE.

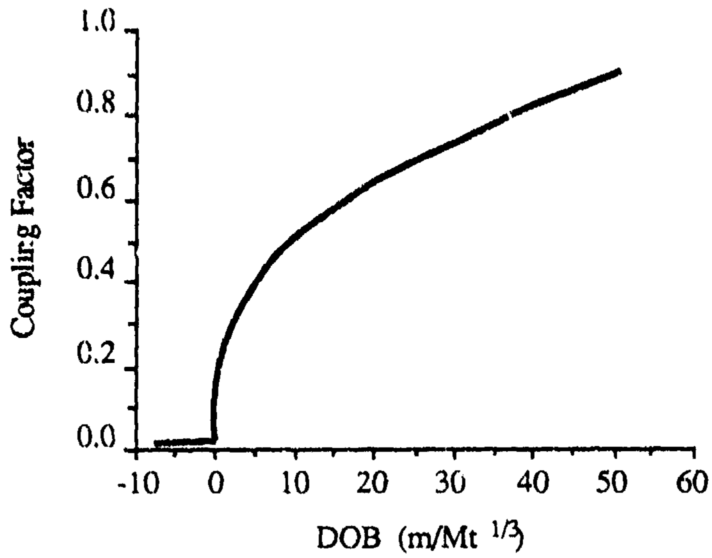

Figure 4. Coupling curve inherent in DUG1C.

Figure 5 integrates the penetration and ground shock models to show the effect on DTE of an uncertainty in DOB (10 m ± a factor of 2) for a 1 MT EPW.

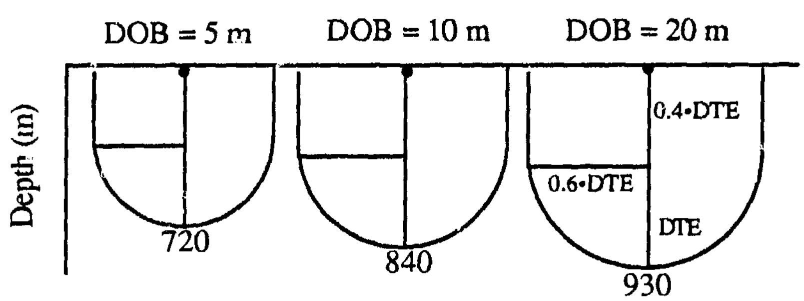

Figure 5. Effect of DOB uncertainty on DTE.

2.1.3 Calculation of Relative Contributions.

Recall that 81 (3^4) DTEs are calculated, where each DTE value is from a different combination of values for each error source. By calculating all combinations and storing which combination of inputs resulted in each DTE value, an analysis of variance (ANOVA) technique is used to determine the relative contribution of each error source to the uncertainty in DTE.

The ANOVA methodology is comparable to a four-way ANOVA. Two modifications to the classical ANOVA technique were made to suppress the impact of potential outliers which might arise through use of only three points to describe the uncertainty in each error source. The methodology uses median values rather than means, and uses sums of absolute differences rather than the sums of squares. The methodology, described below, was originally documented by Binninger and Wright (Ref. 1, p 111-115).

Tables are created for each error source in which the dispersion in each row is due only to the dispersion in that particular error source. Figure 6 shows the table created for target hardness.

Row	Geology	Impact Velocity	DUG Model	DTE when Target Hardness is: N	L	U
1	N	N	N	—	—	—
2	L	N	N	—	—	—
3	U	N	N	—	—	—
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
25	N	U	U	—	—	—
26	L	U	U	—	—	—
27	U	U	U	—	—	—

N: Nominal L: Lower U: Upper

Figure 6. Table used to calculate relative contribution for target hardness.

Contributions from each row are summed for each table, e.g., for target hardness

$$Sum_H = \sum_{\text{all rows}} \left| DTE_{row,N} - DTE_{row,L} \right| + \left| DTE_{row,U} - DTE_{row,N} \right| \quad (1)$$

Then the relative contributions are calculated

$$\%_H = \frac{Sum_H}{(Sum_{IV} + Sum_G + Sum_D + Sum_H)} \quad (2)$$

where $\%_H$ is the percentage of the error in DTE due to target hardness, Sum_{IV} is the sum calculated for impact velocity, Sum_G is for geology, Sum_D is for DUG1C modeling error, and Sum_H is for target hardness.

When examining the calculated relative contributions, it is also important to look at the corresponding DE uncertainty bounds (discussed below). For example, a large contributor when the DE uncertainty bounds are small may not be an important factor if its contribution decreases as the uncertainty bounds change. Also, relative contributions of error sources whose uncertainties may be decreased by research should be weighed against contributions from those error sources whose uncertainty bounds cannot be reduced.

2.1.4 Determination of Three Points to Describe DTE Uncertainty.

While 81 DTE values are calculated in the DTE analysis, the next part of the analysis (DE analysis) requires that the uncertainty for each error source be entered in the 3-point format. To this end. the calculated distribution for DTE is fit to a log normal distribution from which the 5th, 50th, and 95th percentiles are calculated (Ref. 1, p 134-140).

The calculated DTE distribution may not follow any known distribution, and while the 5th, 50th, and 95th percentiles could be read from the calculated distribution, this would put too much confidence in the outliers which arise from using only three points to define the uncertainty in each error source. Instead a scheme was developed to construct a log normal cdf (cumulative distribution function) from the 3-point output distribution.

First, from the 3-point output distribution, the median and quartiles are determined (call them d50, d25, and d75). The quartiles are used to avoid potential outliers, and the median is used instead of the mean since the median is a more robust statistic (small changes in input values have a small effect on robust statistics).

Secondly, the log normal parameters—median (μ), dispersion (β)—are calculated.

$$\text{Let } \mu = d50 \quad (3)$$

$$\beta_U = |\ln(d75/d50)| \quad (4)$$

$$\beta_L = |\ln(d50/d25)| \quad (5)$$

$$\beta = \sqrt{\beta_U \cdot \beta_L} \quad (6)$$

The log normal cdf is then defined so that the 5th, 50th, and 95th percentiles can be easily found.

$$F(d) = \int_{-\infty}^{z(d)} \frac{1}{\sqrt{2\pi}} \cdot \exp(-x^2/2)\, dx \quad (7)$$

$$\text{where } z(d) = \ln(d/\mu) / \beta \quad (8)$$

2.2 DE ANALYSIS.

Outputs from the DTE analysis include three points describing the uncertainty in DTE due to uncertainty in EPW impact velocity, geology, target hardness, and ground shock model; relative contributions of each error source to the uncertainty in DTE; and a probability of successful penetration (PSP) which considers both rebounding and excessive axial loading. Both the calculated uncertainty in DTE and the calculated value for PSP are used as inputs to the second part of the targeting uncertainty methodology—DE analysis.

The DE analysis is concerned with the calculation of the targeting prediction measure DE (damage expectancy), and the evaluation and ranking of the error sources on the uncertainty in DE.

Before discussing the potential error sources treated in the DE analysis and the details of the DE analysis, some of the major targeting prediction measures will be defined to ensure a common vocabulary.

Damage expectancy (DE) is the probability of achieving at least the specified level of target damage, and is the product of two probabilities—probability of arrival and probability of damage.

Probability of arrival (PA) is the probability associated with the weapon successfully arriving and detonating in the target area as planned. PA accounts for pre-launch survivability of the delivery platform, penetration of defenses, weapon system reliability, successful penetration, and other factors depending on the specific delivery platform.

Probability of damage (PD) is the probability of achieving at least the specified level of target damage, assuming arrival and detonation of the weapon in the target area. PD is calculated using a modified version of the mathematics in PDCALC-4 (the official targeting algorithm used by the Joint Strategic Target Planning Staff, JSTPS). The modifications allow for the explicit treatment of target depth, and incorporate the DUG1C-defined iso-stress contour geometry. In order to explicitly treat target depth, the distance damage prediction function (as shown in Figure 7) is defined in terms of the slant range instead of the commonly used ground range. The distance damage prediction function defines the target damage probability when the actual weapon impact location is known. PD is, then, the integral over all potential weapon impact locations of the distance damage prediction function.

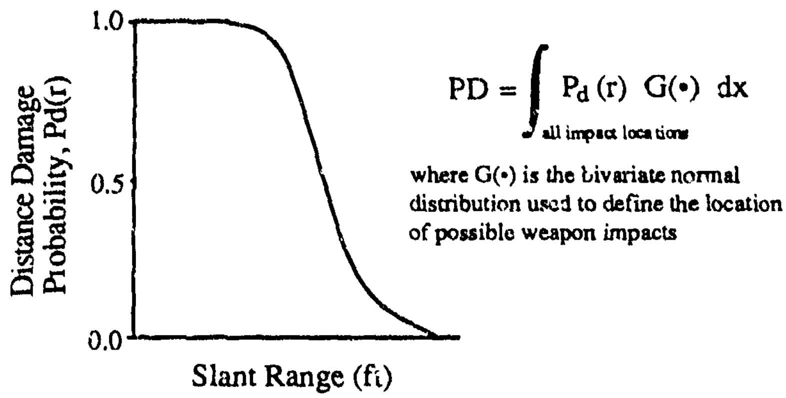

Figure 7. Calculation of probability of damage.

Potential error sources treated in the DE analysis include DTE (calculated in the DTE analysis), target depth, target location, target size, weapon aiming accuracy, and distance damage prediction model. Each error source is described in the three-point format. Uncertainty in target location is measured horizontally, while uncertainty in target depth is measured vertically.

The uncertainty in the distance damage prediction model is described in terms of the slant range damage sigma—a slight modification of the definition of the damage sigma used in the target vulnerability system. The slant range damage sigma is a measure of how rapidly the distance damage prediction function degrades. Figure 8 shows the effect of uncertainty in the slant range damage sigma on the distance damage prediction function.

If uncertainties are assigned to each of the six potential error sources, the DE analysis would calculate 729 (3^6) DE values—one for each combination of error source values. The calculated values for DE are sorted to form a cdf. The nominal (planning value), minimum, maximum, median and quartile values for DE are reported, along with one sigma type bounds for the uncertainty in DE.

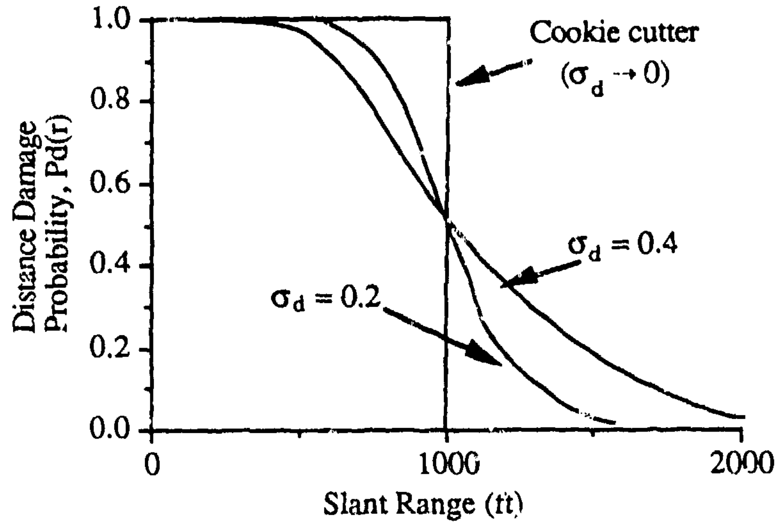

Figure 8. Effect of slant range damage sigma on the distance damage prediction function.

The 5th and 95th percentiles are not of interest as measures of the uncertainty in DE since they are prone to outliers and often span the entire range space for DE (from 0 to 1). Much more informative are one sigma type bounds, the average absolute deviation about the nominal DE value, calculated by the following equations.

$$DE_U = \sum_{DE_i > DE_N} \left| \frac{DE_i - DE_N}{n'} \right| \tag{9}$$

$$DE_L = \sum_{DE_i < DE_N} \left| \frac{DE_i - DE_N}{n^*} \right| \tag{10}$$

where DE_U is the average absolute deviation above the nominal DE value, DE_N is the nominal DE value found by calculating DE with all error sources at their nominal values, n' is the number of DE values greater than the nominal value, DE_L is the average absolute deviation below the nominal DE value, and n* is the number of DE values less than the nominal value.

In addition to all the mentioned statistics which quantify the uncertainty in DE due to the uncertainty in the potential error sources, the same procedure used in the DTE analysis is used to calculate the relative contribution of each error source to the uncertainty in DE.

Comparisons have been made between the distribution of DEs calculated using the 3-point method with that using Monte Carlo techniques (Ref. 1, p 119-148). Continuous distributions (uniform, normal, chi-square, reverse chi-square) were assigned to selected error sources and propagated through the DE formulation using a Monte Carlo sampling scheme. The resulting distributions of DE values were compared to log normal distributions constructed from the 3-point output distributions (where the uncertainty in each error source is defined in the 3-point format using the 5th, 50th, and 95th percentiles from the assumed distribution). The method for constructing a log normal distribution from an output distribution derived using the 3-point method was discussed earlier in this paper. The comparisons of distributions exhibited very good agreement. It was this study that found the best agreement with the Monte Carlo output to occur when the three points for each error source are defined as the 5th, 50th and 95th percentiles.

SECTION 3
EXAMPLE PROBLEM

3.1 PROBLEM DEFINITION.

The example problem involves the application of a low yield EPW against a target sited in a layered geology beneath a one foot layer of concrete. The EPW is assumed to have a yield of 200 Kt, and to impact the ground at a velocity of 800 fps. It is desired to assess the effectiveness of the EPW against targets over a wide range of depths. The target of interest is a point target of moderate hardness.

Uncertainties are assigned to the following error sources.

• Impact Velocity	800 fps ± 10%
• Geology Layer Penetrability	± 10% (±5% for concrete)
• Target Hardness	Nominal ± 40%
• Ground Shock Model	x 1.5 (in stress at a given depth)
• CEP (Circular Error Probable)	175, 250 ft
• Slant Range Damage Sigma	0.3 ± 0.1
• Target Depth	± 20% over a wide range of depths

All error bounds are defined in terms of 5th, 50th, and 95th percentiles, except for penetrability and CEP. The bounds for layer penetrability represent a one standard deviation spread. CEP is expressed in terms of two candidate values. The intent of varying target depth over a range of values is to show how the uncertainty in DE as well as the major contributors vary with different input values.

3.2 EXAMPLE OUTPUT.

3.2.1 DTE Analysis Output.

Applying the PENDEPTH code with the mentioned uncertainty in geology and impact velocity results in a probability of successful penetration (PSP) of 1.0 (i.e., no problem with either rebounding or excessive axial loads), and nine depths of penetration ranging from 3.7 to 6.7 meters. Using DUG1C, the best estimate for depth-to-effect is 460 meters, with 5th and 95th percentiles of 33.. and 637 meters. The contributions of each error source to the uncertainty in DTE are shown in Figure 9.

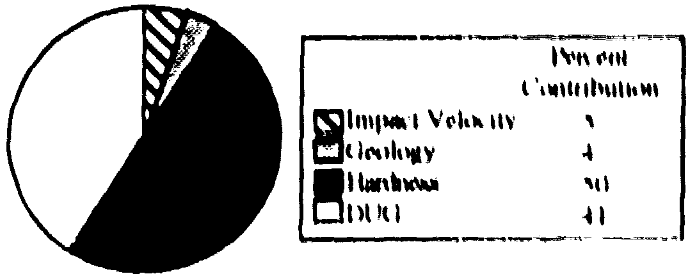

Figure 9. Relative contributions to DTE uncertainty

3.2.2 DE Analysis Output.

Best estimates and uncertainties for damage expectancy are shown in Figure 10 as a function of target depth. The uncertainty bounds correspond to a "one standard deviation" type bound; actually they represent the average dispersion above and below the nominal DE value. This allows the bounds to be asymmetric, and ensures that the bounds stay within the 0 to 1 interval for which DE is defined.

Notice that high DEs are achieved for target depths less than [illegible] meters, and that the uncertainty bounds are widest when the best estimate for DE is between [illegible] and [illegible].

Also shown in Figure 10 are the relative contributions to the uncertainty in DE for four target depths. Notice that uncertainty in target depth is not a major error source for shallow targets but increases in importance as the target gets deeper. Also, it can be seen that uncertainty in CEP becomes less a factor as target depth increases, and finally DTE uncertainty is a major contributor for all target depths. These conclusions regarding DTE and DE uncertainty and relative contributions are specific to the example problem inputs.

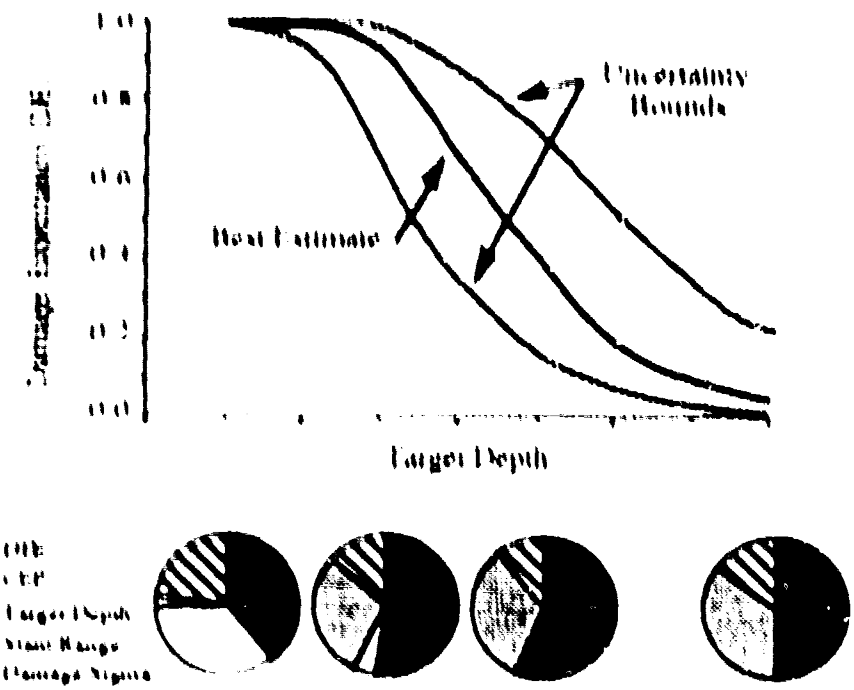

Figure 10. Damage expectancy as a function of target depth.

SECTION 4
SUMMARY OBSERVATIONS

The methodology discussed in this paper quantifies the effect of systematic errors on the targeting prediction measure DE (damage expectancy). It evaluates and ranks the effects of uncertainties for applications involving a single buried target and a single earth penetrating weapon.

The methodology makes minimal use of assumed distributions. Instead it describes the uncertainty in all but one of the error sources with three points. All combinations of values for the error sources are propagated through the methodology, creating a distribution of outcomes. Uncertainty in the outcome is evaluated and the relative contributions of each error source to the uncertainty in outcome is calculated using an analysis of variance technique.

Benefits of the methodology include its simple design, its capability to run on personal computers, its fast run time, the freedom allowed in specifying uncertainties in error sources, and its analysis of major contributors to outcome uncertainties. The ranking of error sources can provide insight into deeply buried targeting problems, possibly affecting system design and design tradeoffs, revealing the need for more research into ground shock environments, or isolating the effect of uncertainties associated with intelligence data.

SECTION 5
RUNTIME PROCEDURES

This section explains the requirements of the uncertainty methodology, and the steps required to run the code. The uncertainties methodology consists of two codes — DTEUA, the first part of the methodology which calculates uncertainty in depth-to-effect; and DUGDE, the second part of the methodology which calculates uncertainty in damage expectancy.

DTEUA (Depth-to-effect Uncertainty Analysis) is written in Microsoft Quick Basic, a compiled language. DUGDE is written in Microsoft Fortran, version 3.3. Both codes will run on any IBM PC-compatible machine with at least 512 K RAM. A math coprocessor is not required, but will improve execution time. Neither a hard disk nor graphics capability are required. DTEUA does require a printer.

Conventions used in these codes and in this documentation will now be discussed. All input to be entered by the user is shown underlined. Each command must be followed by a return. Options are often given inside parentheses and separated by the symbol "/". For example, "(Y/N)" means that the user should input either a **Y** or an **N**. Options are not case sensitive, i.e., the input "Y" and "y" are treated identically. If the user does not enter a satisfactory input, the program will prompt the user with the same question. All values entered by the user are checked to ensure their validity.

Default values are given inside angle brackets. For example, "(Y/<N>)". In this case, "N" is the default value. If the user wants to input "Y", he must enter either **Y** or **y**. Otherwise the default value is used. The easiest way to get the default is just to hit return.

5.1 RUNNING DTEUA (DEPTH-TO-EFFECT UNCERTAINTY ANALYSIS).

Steps required to run DTEUA are listed below. DTEUA does require a printer. Before running the code, the user should make sure that the DTEUA disk or subdirectory contains the following files required by the program: DTEUA.EXE, DUG1C.EXE, DUG1C.MSG, PROPERTY.DAT, and a DUG1C input file which specifies the geology.

- Insert the DTEUA disk into drive A:.
- At the DOS prompt, type **A:** to set the default drive to A:.
- Type **DTEUA** to begin execution.
- The program will load and will check to see if the printer is turned on and is on-line. If not, the user will see a "testing printer" message on the screen. That message will not disappear until the printer is ready.
- A banner screen will appear on the monitor; to continue the user should hit the return key.
- DTEUA will prompt for the user to enter the filename to which results should be written.
- The user will be prompted to enter the DUG geology filename. This is one of the files read by DUG1C and which must exist prior to running DTEUA.
- The code prompts

  Save DUG output files? (<Y>/N):

  If the user wants to save the files created by DUG1C, he should hit return; otherwise type **N**.
- The user is asked for information concerning impact velocity. First the user is asked if uncertainty bounds are desired. If so, the user is asked to enter a nominal value, a lower bound, and an upper bound for impact velocity. If no uncertainty bounds are desired, the user is asked to enter a single value for impact velocity. Each parameter has a default value.
- Similar information for target hardness is requested next, along with a single value for weapon yield.
- Other weapon inputs, those required to calculate depth of penetration, are prompted for — including impact angle, penetrator weight, penetrator diameter, nose shape (cone or ogive), nose performance coefficient, and nose length.
- Weapon inputs are followed by geology inputs. After the user specifies the number of layers (between 1 and 15), a worksheet for entering geological information by layer appears on the screen. Thickness in feet, S-number, and layer type (soil, rock, concrete, or frozen soil) must be entered for each layer.

  The user may use the TAB key or any of the keyboard arrows to move the highlighted cell about the screen. All inputs goes into this cell. After entering a value, move to the next cell by pressing return, TAB, or an arrow key.

  To change the layer type, position the highlighted cell anywhere on the desired layer, then press the space bar to toggle to layer type from soil to rock to concrete to frozen soil back to soil. As the user toggles the layer type, default values for that layer's S-number may appear in the correct cell on the screen. The default value for concrete is 1, and for frozen soil it is 1.7. A note about the layer types: As mentioned previously, there is a constraint as to which layers may be frozen. Normally only the top layer may be frozen. The exception is when the top layer is concrete; only then can the second layer may be frozen. If the layer cannot be frozen, the space bar will toggle the layer type from soil to rock to concrete back to soil, skipping the frozen soil layer type.

The user may not place the highlighted cell at the thickness for the bottom layer. It is assumed that this thickness is infinite. If in doubt about an S-number, the user may type **h** (note the lower case) for a help screen. After typing **h**, the user may hit any key to return to the input screen. If the user types an invalid key, the program beeps.

After entering thicknesses and S-numbers for all layers, the user should hit the escape key (ESC). All values are checked to make sure they are valid. If any errors are found, the input screen reappears, complete with error messages, and with those cells in error highlighted.

- In addition to nominal values for layer thickness and penetrability (S-number), uncertainty values are also entered. First the user is asked for the number of desired Monte Carlo trials — at least 20 must be specified so that the 5th percentile may be found.

  Then a table of nominal thicknesses and S-numbers is printed to the screen. The user must enter lower and upper bounds for thickness and a one standard deviation for the S-number uncertainty. If no uncertainty is desired for a given layer thickness or S-number, the user should hit the return key. If no uncertainty is chosen for any layer (thickness and S-number), the code will perform only one Monte Carlo trial regardless of the number entered by the user.

- Lastly, the remaining inputs pertain to calculating PSP (probability of successful penetration) — including constraints on rebounding depth and maximum axial loading.

- The program will ensure that all necessary files are available; if not, it will notify the user of the missing file. The designated number of Monte Carlo trials will be run for each specified impact velocity. DUG1C will then be run three times for each impact velocity, once for each if no uncertainty was assigned to the geological information. After DUG1C is run, its output is examined to determine depths-to-effect. Relative contributions of each error source are calculated, along with a PSP value, and predicted uncertainty in DTE. An output file (previously named by the user) is created and execution stops.

5.2 RUNNING DUGDE (DAMAGE EXPECTANCY UNCERTAINTY ANALYSIS).

Required steps to run the second part of the uncertainties methodology, DUGDE, are explained below. No files other than the executable (DUGDE.EXE) are required. DUGDE may be run after running DTEUA; or if a DTE is provided by some other means, DUGDE may be run without any input provided by DTEUA.

- Insert the DUGDE disk into drive A:.
- At the DOS prompt, type **A:** to set the default drive to A:.
- Type **DUGDE** to begin execution.
- The program will load and will prompt the user if output should go to the printer or to the screen. The user should enter **P** for printer; the screen is the default.
- The next input is if the target is a point or an area target. Area targets are assumed to be circular and to follow a circular normal distribution, where size is measured in terms of an R95 (the radius of a circle which encompasses 95% of the target elements).
- Next the user is asked whether the weapon detonates at depth of burst (DOB). If so, the user is asked to supply a DOB in feet. The user is not asked to specify an uncertainty in DOB — this effect is taken into account by the depth-to-effect parameter. The DOB is used to calculate an "effective" target depth, the vertical distance between weapon and target equal to the actual target depth minus the DOB. In addition, when the user specifies a DOB, a different iso-stress contour is used compared to that used for a surface burst. The difference in the contours is illustrated in Figure 11.

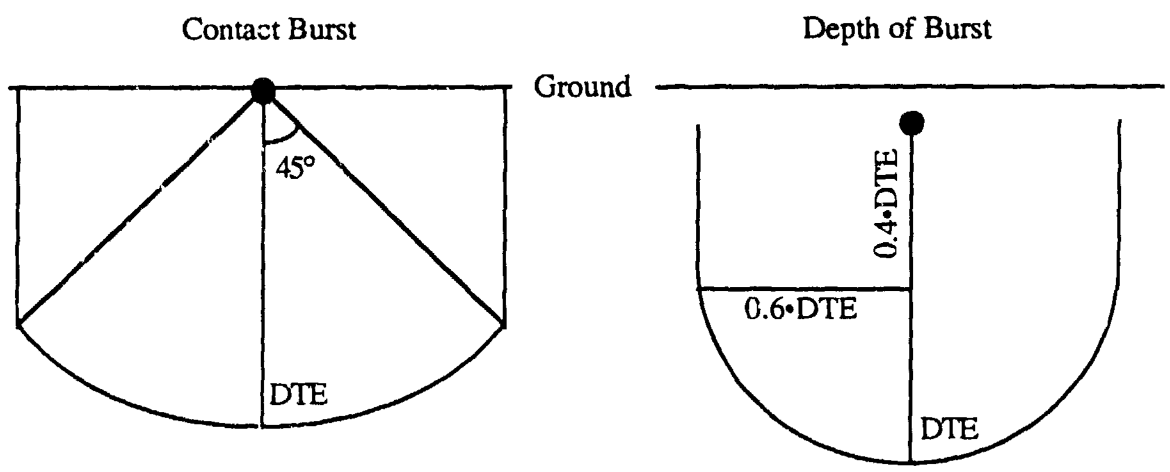

Figure 11. Two DUG1C iso-stress contours.

- The next four inputs pertain to the probability of arrival. The user is asked to enter values for PLS (pre-launch survivability), PTP (probability to penetrate), WSR (weapon system reliability), and PSP (probability of successful penetration). Each is a factor between 0 and 1. PSP is calculated by DTEUA.
- The user is asked to hit return to continue.
- The 3-point parameter input screen appears. For more information on the 3-points, see Section 2.

The user may use the TAB key or any of the keyboard arrows to move the highlighted cell about the screen. All input goes into this cell. As the user moves the cursor around the screen, the program prints a three line message describing the parameters at the bottom of the screen.

Nominal values must be entered for all parameters. There is no requirement that both upper and lower values be input, or that bounds be symmetric about the nominal value. When the user is satisfied with the inputs, he should move the highlighted cell down to the bottom of the worksheet, next to the "Accept?:" prompt (alternatively hit the end key). Then type either **Y** to continue or **N** to reinitiate the input process. The return key should not be hit. If the user enters **N**, he will be instructed to enter all inputs again. Otherwise, the program will check to make sure that all parameters have nominal bounds, and that all inputted lower/upper bounds are indeed less than/greater than the nominal value. Any inconsistencies or missing values will be brought to the user's attention by flashing parameter names. The user must correct his input and again move the highlighted cell to the "Accept?:" prompt and enter **Y**.

- The program will perform its calculation and print the output to the screen or to the printer, as specified by the user. If the output device is the screen, the user may have to hit the return key to see the Figures of Merit chart. (The Figures of Merit chart is only printed if at least one bounding value was entered.)

- The program prompts whether the user would like to write the data to disk. If the user enters **Y**, he will then be asked to enter the save file name.

- The program prompts the user for more calculations. If additional calculations are not required, the user should type **N**. Otherwise, type **Y**; execution will begin again, and all previously inputted 3-point parameter values will be remembered.

SECTION 6

LIST OF REFERENCES

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