

DDESB

Blast Effects Computer – Open (BEC-O) Version 1 User’s Manual and Documentation



Department of Defense Explosives Safety Board

Alexandria, Virginia

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14. ABSTRACT The Department of Defense Explosives Safety Board (DDESB) has had an active role in producing various explosion effects computation aids for over 35 years. In 1978, this culminated in the release of a circular slide rule called the "Blast Effects Computer (BEC)." This slide rule was designed to solve problems and provide data related to the expected damage to various potential targets due to blast effects resulting from an explosion of ammunition or explosives stored above ground or in earth-covered magazines (ECMs). In the late 1990's, the DDESB sponsored an effort to develop a new version of DDESB Blast Effects Computer (BEC) in the form of an Excel spreadsheet. This work later included development of a technical paper (TP), TP-17, to provide documentation on the basis for the BEC. TP-17 and the BEC are a compendium of the best available pressure/impulse data based on empirical evidence. This paper, TP-20 and the BEC-Open (BEC-O), are based on TP-17 and the BEC but have been revised appropriately to achieve a Distribution Statement A designation.					
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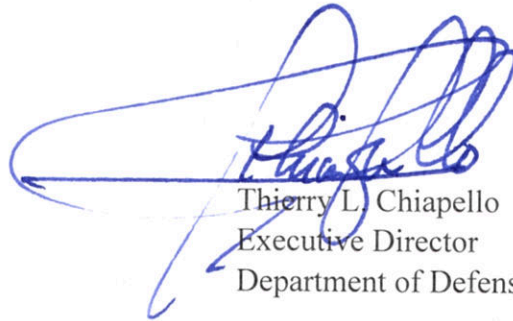
FOREWORD

Department of Defense Explosives Safety Board (DDESB) Technical Paper (TP) 20 provides documentation and a user's guide for the DDESB Blast Effects Computer – Open (BEC-O) Version 1.

TP 20 and BEC-O Version 1 are unlimited distribution versions of TP 17, Revision 3 and the BEC V7, from which all weapons and structure test data, and weapons blast prediction algorithms, have been removed.

TP 20 and BEC-O Version 1 can be found at <https://www.denix.osd.mil/ddes/home/>

This TP has been reviewed by the DDESB staff and the voting board members.



Thierry L. Chiapello
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Department of Defense Explosives Safety Board

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CHAPTER 1: INTRODUCTION

1.1. BACKGROUND. The Department of Defense Explosives Safety Board (DDESB) has had an active role in producing various explosion effects computation aids for over 35 years^{1-7*} (copies of References 3 through 7 are provided as Appendices A through E in Reference 8). In 1978, this culminated in the release of a circular slide rule called the “Blast Effects Computer” (BEC). This slide rule was designed to solve problems and provide data related to the expected damage to various potential targets due to blast effects resulting from an explosion of ammunition or explosives stored above ground or in earth-covered magazines (ECMs). In the late 1990’s, the DDESB sponsored an effort to develop a new version of DDESB BEC in the form of an Excel spreadsheet. This work later included development of Technical Paper (TP) 17 to provide documentation on the basis for the BEC. TP 17 and the BEC are a compendium of the best available pressure/impulse data based on empirical evidence. This TP, and the BEC-Open (BEC-O), are based on TP 17 and the BEC but have been revised appropriately to achieve a Distribution Statement A designation.

1.2. USE OF TP 20 AND THE BEC-O

The BEC-O is a computational aid representing a “compilation of available explosion effects information used to estimate the risk of damage or injury from blast at various distances from the source to the target.”² TP 20 is a technical paper detailing the methods and algorithms used within the BEC-O while also providing a user’s manual for the tool itself. Data and equations in this TP are given in English units (e.g., foot or feet (ft), pounds (lbs), pounds per square inch (psi)), with the International System of Units (SI) metric equivalents shown in yellow highlighting (e.g., meters (m), kilograms (kg), kilopascals (kPa)).

The BEC-O may be used to understand and assess risks for risk-based site plans and risk assessments, especially in situations where minimum quantity-distance (QD) requirements cannot be met. An additional use for the BEC-O and the TP 20 is test planning. During the process of planning a test, it is important to begin by determining the expected results. The BEC-O can be useful to test planners because TP 20 and the BEC-O represent a compilation of the best available test data combined with analytical methods. For example, the BEC-O can be used to determine locations for pressure gauges, targets, and other equipment during testing. Equipment can be located in hopes of achieving a specific result at a given distance from the detonation site using site specific test conditions.

*Superscript numbers designate references listed at the end of this document.

TP 20 and the BEC-O should not be used in lieu of the procedures in Unified Facilities Criteria (UFC) 3-340-02 and criteria in DoD Manual (DoDM) 6055.09 to determine blast loads for protective construction analyses and designs to be submitted for DDESB approval. Furthermore, the BEC-O shall not be used to reduce DoDM 6055.09 minimum QD requirements to or from ammunition and explosives (AE) facilities or to calculate design blast loads on ECMs.

1.3. CAPABILITIES OF BEC-O VERSION 1

The BEC-O computes the airblast and the airblast effects produced by a detonation either in the open or inside selected potential explosion sites (PESs). The BEC-O is optimized for airblast predictions. It takes into account each of the following:

- The effect of the PES.
- The type of munition.
- The trinitrotoluene (TNT) equivalence of the explosive (based on both peak pressure and positive impulse).
- The atmospheric conditions (altitude/barometric pressure and temperature) of the event.

It provides for input and output in both English and SI units. The BEC-O's algorithms are based on reported, experimental results and its outputs are within a few percent of actual measured data for each of the input options.

Note that within BEC-O V1, all munition specific data has been removed in order to generate an unlimited distribution version of the tool. Throughout the remainder of this document there may be references to selection of a weapon type. Within BEC-O V1, the only weapon type is "Bulk/Light Cased." Additionally, the explosive types which may be selected from the drop-down menu have been reduced within BEC-O V1 in order to remove any sensitive data and produce an unlimited distribution version.

The following PES types are considered:

- Open Storage/Hemispherical TNT Standard.
- ECM and High Performance Magazine (HPM) (Front, Side, and Rear orientations).
- Third Generation Hardened Aircraft Shelter (TGHAS) (Front, Side, and Rear orientations).
- Aboveground Structure (AGS) (Masonry and Concrete construction) (Note: An AGS is a non-earth covered aboveground structure).
- International Organization for Standardization (ISO) Container.
- Ship.

The following munition types and their default explosive fills are considered:

- Bulk/Light Cased (TNT)

The BEC-O uses separate, independent TNT equivalences—one based on peak pressure and one based on positive impulse. Table 1-1, provides a listing of the explosive types and their TNT equivalences that are available to the user within the BEC-O. Note that the values in Table 1-1 are from public release documents. Other TNT equivalency values may be substituted based on the explosive type and available information.

Table 1-1. Explosives and Their TNT Equivalences

Explosive	Average Equivalent Weight (pressure)	Average Equivalent Weight (impulse)	Reference
Composition A-3	1.09	1.07	a
Composition B	1.16	1.14	a
Black Powder	0.43	0.43	b
Composition C-4	1.37	1.19	a
Cyclotol (70/30)	1.14	1.09	a
HBX-1	1.17	1.16	a
HBX-3	1.14	0.97	a
H-6	1.38	1.15	a
Minol II	1.2	1.11	a
PETN	1.27	1.27	a
Pentolite (50/50)	1.38	1.14	a
Picratol	0.9	0.93	a
Tetryl	1.07	1.07	a
Tetrytol	1.06	1.06	a
TNETB	1.36	1.1	a
TNT	1	1	Standard
Tritonal	1.07	0.96	a

Table 1-1 References:

- American Society of Civil Engineers ASCE/SEI Standard 59-11, “Blast Protection of Buildings,” 2011.
- Napadensky, Hyla and Swatosh, James, “TNT Equivalency of Black Powder, Volume 1: Management Summary and Technical Discussion,” IITRI Report J6265-3, IIT Research Institute under the technical direction of Manufacturing Technology Directorate.

If none of the table entries satisfy the needs of the User, the Explosive Type “*Other – User Defined*” may be selected via the drop down menu and the TNT equivalences entered into the BEC-O. (Note: The equivalence of an energetic material, munition, or explosion will vary with the distance at which it is computed.¹⁰ If this variation is large, care should be taken to account for this.)

Pressure equivalence is associated with each of the following airblast parameters:

- Time of Arrival
- Over Pressure
- Reflected Pressure
- Dynamic Overpressure

Impulse equivalence is associated with each of the following parameters:

- Positive Phase Duration
- Positive Phase Impulse
- Reflected Impulse
- Dynamic Overpressure Impulse

The following airblast parameters are computed in the BEC-O:

- Time of Arrival
- Overpressure
- Reflected Pressure
- Positive Phase Duration
- Positive Phase Impulse
- Reflected Impulse
- Dynamic Overpressure
- Dynamic Overpressure Impulse

The following airblast effects are estimated:

- Probability of Window Breakage
- Probability of Ear Drum Rupture
- Probability of Lethality Due To Lung Damage

The BEC-O predicts the airblast for sea level conditions (14.696 psi/101.329 kPa and 59 Fahrenheit (°F)/15 Celsius (°C)) and for the input conditions specified at the event site. If the PES is not at or very near sea level conditions, corrections should be made for the atmospheric conditions (barometric pressure and temperature). These corrections are implemented in the BEC-O by entering either an altitude or atmospheric pressure and the temperature at the event site. The BEC-O displays the computed correction factors and two sets of output predictions in the Output Section—one for sea level and one for the conditions specified. It should be pointed out the BEC-O only addresses situations where both the PES and the exposed site (ES) are at the same conditions (temperature and barometric pressure).

Finally, two Summary Tables giving most of the airblast parameters as a function of distance from the PES are generated: one for sea level conditions and one for the conditions at the event site.

1.4. SYSTEM REQUIREMENTS

BEC-O is written as an Excel Spreadsheet template. In order to run the BEC-O, Excel 97 - 2003 (or later) must already be installed on your computer. Simply copy the template to your hard drive.

When you open the template, Excel makes a copy of the spreadsheet for you to use. Changes that are made affect only the copy—*the original template is preserved*. The copy of the template is a new, unsaved document with a temporary name based on the template name. For example, when you open the BEC-O template named BEC-O V1.xlt, Excel gives the copy the temporary name BEC-O V1. When you save or close the copy, the *Save As* dialog box appears. You can type a new name for the document, accept the temporary name suggested by Excel, or you don't save this copy when you close out.

Because it is written as an Excel template, the BEC-O should run on any machine that can run Excel. At this time, however, it has been tested only on Windows machines.

1.5. INCORPORATION OF NEW DATA. The yield functions within the BEC-O are based on experimental data which have been analyzed and incorporated into the BEC-O algorithms. This requires analyzing and curve fitting test data. The DDESB welcomes the opportunity to evaluate additional test data for possible incorporation into the BEC-O, especially data for new and/or unique scenarios which are not currently included in the BEC-O and which are of interest to the DoD. To provide additional data for consideration and/or inclusion into TP 20 and the BEC-O, please contact:

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CHAPTER 2: BEC-O AIRBLAST MODELING

2.1. GENERAL METHODOLOGY

References 3 through 8 document the history and development of the BEC-O. They also provide more detailed information on the development and basis of the algorithms used by the BEC-O.

The BEC-O uses the equations for a hemispherical TNT surface burst¹¹ as its “basic airblast engine” to generate the various airblast parameters. For situations other than a hemispherical TNT surface burst (various types of munitions in the open or detonations inside a PES), the BEC-O calculates two yields called Equivalent Hemispherical Weights for pressure and impulse. These yields are functions of the scaled distance (distance divided by the cube root of the explosive weight) from the center of the event and the type of munition or structure selected. The BEC-O then uses these effective yields in conjunction with the hemispherical TNT surface burst curves and the pressure and impulse equivalences for the energetic materials to generate the appropriate airblast parameters. This process is described in detail within this chapter.

2.2. USER INPUTS AND SELECTION. The first step of using the BEC-O software is for the user to select inputs from the list below. Note that inputs should be entered based on the actual location of the detonation. The BEC-O will automatically compute the corresponding conditions at sea level. In other words, if the detonation is intended to occur at a site that is 4,000 ft above sea level, the user should enter all factors as they would exist at the detonation site.

- PES
- Type of Munition (within BEC-O V1 Bulk/Light Cased is the only option)
- Type of Explosive
- Net Explosive Weight (NEW) Basis (either the Total NEW or the Number of Items)
- Total NEW or Number of Items (depending on the choice for NEW Basis)
- Distance to ES
- Temperature at the PES
- Atmospheric Scaling Basis (either the Altitude of the PES or the Barometric Pressure at the PES)
- Altitude or Pressure (depending on the choice for Atmospheric Scaling Basis)

2.2.1. Select Potential Explosion Site (PES). The PES type is selected via a drop-down menu using the conditions of the PES. For example, if the ES is hazarded by the front of an ECM, the correct selection would be the “*ECM or HPM – Front*” option. The “*Open Storage/Standard*” option assumes that the PES is not a type of structure. Thus, the “*Open Storage/Standard*” does not include directional or structural effects.

2.2.2. Select Type of Munition. The type of munition is selected from a drop-down menu. The munition type selected should be as close a match as possible to the user's actual munition. Within BEC-O V1, the only option is *Bulk/Light Cased* as munition specific data has been removed to create a public release version of the tool.

2.2.3. Select Type of Explosive. When the User selects a Munition Type from a drop down menu, the BEC-O automatically sets the Explosive Type to the default explosive for that munition. The following are the default explosives for each weapon type:

- Bulk/Light Cased: STANDARD—TNT

2.2.3.1. The User then has the option of changing the Type of Explosive via another drop down menu.

2.2.3.2. The explosive type can be used to modify the overpressure and impulse effect of the selected munition such that it more closely approximates the User's munition. If the user selects "Other - User Defined" for the Explosive Type, they will be given the opportunity to enter TNT equivalences for pressure and impulse. If the user selects "Other - User Defined" and does not enter TNT equivalences for pressure and impulse, a value of 2.0 will be assumed for the pressure equivalence and 1.0 for the impulse equivalence.

2.2.4. Select New Basis. The user must select the basis to be used for determining the NEW (i.e., the user must select whether the "Total NEW" or "Number of Items" will be used to determine the NEW).

2.2.5. Total NEW or Number of Items. If the user selects "Number of Items" for the NEW Basis, the BEC-O will request an input for the Number of Items and the total NEW will be based on the product of the number of munition items and the NEW for the selected munition type. If the user selects "Total NEW" for the NEW Basis, the BEC-O will request an input for the total NEW which will be used directly. Note that if the munition type selected is "Bulk/Light Cased: STANDARD," the NEW must be based on a user-entered Total NEW.

2.2.6. Distance to ES. The user should enter the distance between the detonation site (i.e., the PES) and the point at which the detonation effects are to be determined (i.e., the ES).

2.2.7. Temperature. The user should enter the air temperature at the PES. If the temperature is not known, the default value of 59 °F (15 °C) may be left unchanged.

2.2.8. Select Atmospheric Scaling Basis. The user must select the basis to be used for determining the atmospheric scaling effects (i.e., the user must select whether "Altitude" or "Pressure" will be used as the basis to determine the effects of the atmospheric pressure on the airblast).

2.2.9. Altitude or Pressure. If the user selects "Altitude" for the Atmospheric Scaling Basis, the BEC-O will request an input for the Altitude at the location of the PES. If the user selects "Pressure" for the Atmospheric Scaling Basis, the BEC-O will request an input for the barometric pressure at the location of the PES.

2.3. INITIAL CALCULATIONS

Based on the Type of Munition and the Number of Munitions or Total NEW entered, the non-entered value can be determined. Note that if the munition type selected is “Bulk/Light Cased: STANDARD,” the NEW per munition, W_s , will default to a value of 1 lb or 0.454 kg and calculate the Number of Munitions as a number equivalent to the Total NEW.

$$W = N * W_s \quad \text{English or SI Units} \quad (2-1)$$

$$N = W/W_s \quad \text{English or SI Units} \quad (2-2)$$

where,

W = Total NEW of all munitions

N = Number of munitions

W_s = NEW of a single munition⁹

Once the Total NEW has been determined and the Distance to the ES has been entered, the scaled distance at the user-entered altitude (Z_{alt}) can be determined. Note that within the BEC-O it is essential to ensure that the appropriate scaled distance is being used. While the user inputs values at the desired altitude of the PES, equations within the BEC-O are based on tests which were all assumed to occur at sea level. Thus, all scaled distance values within this TP will have a subscript indicating whether the value is determined at the user-entered altitude (alt) or at sea level(s).

$$Z_{alt} = R/W^{1/3} \quad \text{English or SI Units} \quad (2-3)$$

where,

Z_{alt} = Scaled distance to ES at user-entered altitude

R = Distance to ES at the detonation site

2.4. EXPLOSIVE PARAMETERS. In the Output Section of the BEC-O there is a section labeled “Explosive Parameters.” The values presented in this section of the report are intermediate calculations necessary to determine the final airblast parameters at sea level and the entered PES location.

2.4.1. Look-Up/Easily Determined Values

2.4.1.1. The first line in the Explosive Parameters section is the Total NEW for all items. This is either equivalent to the user entered Total NEW or is the total NEW as calculated based on the user entered input for Number of Items as described in Section 2.2.

2.4.1.2. The second line indicates amount of explosives contained within one of the items selected. The NEW per munition for Bulk/Light Cased items is 1.0 lb (0.45 kg).

Table 2-1. Item Description

Type of Munition	Description	Explosive		
		Type	NEW/Item	
			(lbs)	(kg)
Bulk/Light Cased: Standard		TNT	1.000	0.454

2.4.1.3. The third and fourth lines indicate the TNT Equivalence Factor for Pressure and Impulse. These are repeated either from the user input values if the Explosive Type of “Other – User Defined” was chosen or selected from the look-up of available explosive types (Table 1-1).

2.4.2. Equivalent Hemispherical Weights. Note that at this point in the calculations, the BEC-O begins altering output based on the PES type selected. This is because each PES has a different effect on the Equivalent Hemispherical Weight. Sometimes the PES will decrease the Equivalent Hemispherical Weight due to the dampening effect of the PES while other times, like from the front of an ECM, the equivalent hemispherical weight may be increased due to a focusing effect. Also, note that all calculations within this section are still for values at the user-entered altitude.

2.4.2.1. Open Storage/STANDARD PES, Bulk/Light Cased: STANDARD Munition Type

2.4.2.1.1 When an *Open Storage/STANDARD* PES is selected, the BEC-O will adjust the user-entered NEW to a TNT Equivalent NEW. When any PES other than *Open Storage/STANDARD* is selected, the BEC-O will not adjust results based on the user-selected Explosive Type and/or TNT Equivalence. This is because the BEC-O assumes that in all cases except open storage, the effects of the PES will strongly overshadow variations in the items being stored.

2.4.2.1.2. The fourth and fifth lines in the Explosive Parameters section list the Pressure and Impulse TNT Equivalent NEW for Calculations ($W_{TNT,calc,P}$ and $W_{TNT,calc,I}$). For *Open Storage/STANDARD* PES, these values are the Total NEW multiplied by the appropriate TNT Equivalence Factor.

$$W_{TNT,calc,P} = W * E_P \quad \text{English or SI Units} \quad (2-4)$$

$$W_{TNT,calc,I} = W * E_I \quad \text{English or SI Units} \quad (2-5)$$

For PES other than *Open Storage/STANDARD*, these values are equivalent to the total NEW.

$$W_{TNT,calc,P} = W \quad \text{English or SI Units} \quad (2-6)$$

$$W_{TNT,calc,I} = W \quad \text{English or SI Units} \quad (2-7)$$

2.4.2.1.3. The next step is to determine the equivalent hemispherical weight for pressure and impulse, $H_{P,alt}$ and $H_{I,alt}$. These terms represent the equivalent amount of bare hemispherical explosives in the open required to achieve the same effect as the user-input explosive characteristics within the PES. Again, the TNT Equivalency factors will be applied

when an *Open Storage/STANDARD* PES selection is made and not applied when any other PES type is selected.

2.4.2.2. Open Storage/STANDARD PES, Bulk/Light Cased Munition Type. If the PES selected is *Open Storage/STANDARD* and the munition type selected is *Bulk/Light Cased* the equivalent hemispherical weights for pressure and impulse are as shown in Equations 2-8 and 2-9. Note that these equations are only factored by the TNT equivalence. The standard pressure and impulse equations were developed based on a TNT explosive charge. Thus, the only adjustment to any bare explosive is to account for the change in TNT equivalency.

$$H_{P,alt} = W * E_P \quad \text{English or SI Units} \quad (2-8)$$

$$H_{I,alt} = W * E_I \quad \text{English or SI Units} \quad (2-9)$$

where,

$H_{P,alt}$ = Equivalent Bare Hemispherical Weight for Pressure at Altitude

$H_{I,alt}$ = Equivalent Bare Hemispherical Weight for Impulse at Altitude

E_P = Pressure TNT Equivalence based on user selection

E_I = Impulse TNT Equivalence based on user selection

2.4.2.3. PES Types Other Than Open Storage/STANDARD. If the PES selected is anything other than *Open Storage/STANDARD* the equivalent hemispherical weights for pressure and impulse are computed based on the yield functions for that PES structure. Though the munition type in this case should not change the output, if the user opted to enter number of munitions, the munition type selections will affect the total NEW and thus appear to have an effect on the hemispherical weight. For PES selections other than *Open Storage/STANDARD* the equivalent hemispherical weights for pressure and impulse are calculated as shown in Equations 2-10 and 2-11. For those PES selections, the yield function is based on testing of the PES structure only.

$$H_{P,alt} = W * F_P \quad \text{English or SI Units} \quad (2-10)$$

$$H_{I,alt} = W * F_I \quad \text{English or SI Units} \quad (2-11)$$

2.4.3. Pressure and Impulse Yield Functions.

2.4.3.1. The pressure and impulse yield functions (F_P and F_I) used in Equations 2-10 and 2-11 are of the form:

$$F = \exp[A + B * \ln(Z_{alt}) + C * \ln^2(Z_{alt}) + D * \ln^3(Z_{alt}) + E * \ln^4(Z_{alt}) + F * \ln^5(Z_{alt}) + G * \ln^6(Z_{alt})] \quad (2-12)$$

2.4.3.2. Where A, B, C, D, E, F, and G are curve fit constants as shown in Table 2- and Z_{alt} is the scaled distance as defined in Equation 2-3. The curve fit equations are used only when the scaled distance, Z_{alt} , determined using the user inputs is within the valid range of scaled distances shown in the tables. If Z_{alt} is lower than the tested range (Z_{min}), the value of the Yield Function, F, used within the BEC-O is set to the value shown in the tables as F_{min} . If Z_{alt} is higher than the tested range (Z_{max}), the value of the yield function, F, used within the BEC-O is set to the value shown in the tables as F_{max} .

2.4.3.3. The experimental data were used to generate the yield as a function of distance curves that are given in Table 2-2.

Table 2-2a. Yield Functions for PES other than Open Storage (English Units)

Munition Type	Yield Eqn Constants							Valid Data Range (ft/lb ^{1/3})		Step Function Values (lbs)	
	A	B	C	D	E	F	G	Zmin	Zmax	Fmin	Fmax
Pressure											
ECM or HPM--Front	1.5908	-4.0565	3.8820	-1.5798	0.2728	-0.0165	0.0000	2	150	1.1917	0.845
ECM--Side or HPM--Side and Rear	-3.2903	1.2844	0.1866	-0.1045	0.0000	0.0012	0.0000	0.8	150	0.028	0.217
ECM--Rear	-2.6875	0.3110	0.3645	0.0150	-0.0794	0.0183	-0.0012	1	150	0.068	0.264
HAS--Front	2.6201	-6.4924	5.2697	-1.9352	0.3253	-0.0207	0.0000	2	80	1.092	0.375
HAS--Side	-5.0749	1.6664	0.8757	-0.4369	0.0491	0.0000	0.0000	1	100	0.0062	1.8
HAS--Rear	-3.3517	1.3402	-0.0817	-0.0300	0.0000	0.0000	0.0000	0.9	100	0.03	0.158
AboveGround Structure (AGS)--masonry	-3.8389	1.8713	-0.0298	-0.1492	0.0266	-0.0010	0.0000	1.6	148	0.05	0.688
AboveGround Structure (AGS)--concrete	-3.0046	-0.4636	3.2071	-1.8835	0.4216	-0.0330	0.0000	1.8	148	0.081	0.816
ISO Container	-4.0618	5.2177	-1.5737	-0.2673	0.1779	-0.0200	0.0000	1.7	133	0.081	0.195
Ship	-3.6488	1.8595	-0.1159	-0.1538	0.0476	-0.0044	0.0000	3.25	148	0.165	0.62
Impulse											
ECM or HPM--Front	-1.0333	1.6455	-0.5472	-0.0852	0.0539	-0.0054	0.0000	2.6	150	1	0.723
ECM--Side or HPM--Side and Rear	-1.3395	-2.0075	2.9176	-1.2998	0.2570	-0.0225	0.0006	1	150	0.262	0.291
ECM--Rear	-1.4295	-2.1349	2.9981	-1.5542	0.3984	-0.0507	0.0025	2	150	0.149	0.163
HAS--Front	7.6468	-5.0753	1.1757	-0.0986	0.0000	0.0000	0.0000	2	100	106.7	0.65
HAS--Side	-0.5720	0.8926	-0.2817	0.0398	-0.0023	0.0000	0.0000	2	100	0.9249	1.508
HAS--Rear	-0.6616	0.9375	-0.3413	0.0222	0.0000	0.0000	0.0000	1	100	0.5179	0.243
AboveGround Structure (AGS)--masonry	-4.8579	6.4097	-3.3942	0.7491	-0.0585	0.0000	0.0000	1.5	100	0.062	0.622
AboveGround Structure (AGS)--concrete	-1.7629	0.8864	0.1947	-0.2631	0.0620	-0.0043	0.0000	2.35	148	0.368	0.961
ISO Container	-1.6102	2.1551	-1.1996	0.2054	0.0103	-0.0039	0.0000	1	148	0.2	0.4
Ship	-2.3111	1.2965	-0.4230	0.0065	0.0225	-0.0027	0.0000	1.3	175	0.135	1.088

Table 2-2b. Yield Functions for PES other than Open Storage (SI Units)

Munition Type	Yield Eqn Constants							Valid Data Range (m/kg ^{1/3})		Step Function Values (kg)	
	A	B	C	D	E	F	G	Zmin	Zmax	Fmin	Fmax
Pressure											
ECM or HPM--Front	-0.6923	-0.1276	0.7686	-0.7121	0.1964	-0.0165	0.0000	0.7934	59.505	1.1953	0.36
ECM--Side or HPM--Side and Rear	-2.8156	1.3659	-0.0936	-0.0940	0.0057	0.0012	0.0000	0.31736	59.505	0.0127	0.10705
ECM--Rear	-2.9134	0.8344	0.1301	-0.1416	-0.0106	0.0115	-0.0012	0.3967	59.505	0.03084	0.07893
HAS--Front	-0.9742	-0.7579	1.4071	-0.9088	0.2297	-0.0207	0.0000	0.7934	31.736	0.49532	0.17917
HAS--Side	-3.8856	2.3205	-0.0842	-0.2552	0.0491	0.0000	0.0000	0.3967	39.67	0.00281	0.81647
HAS--Rear	-2.9967	1.1122	-0.1649	-0.0300	0.0000	0.0000	0.0000	0.35703	39.67	0.01361	0.07167
AboveGround Structure (AGS)--masonry	-3.0240	1.5139	-0.3152	-0.0594	0.0220	-0.0010	0.0000	0.63472	58.7116	0.02268	0.32205
AboveGround Structure (AGS)--concrete	-2.6851	1.8488	-0.1156	-0.6063	0.2691	-0.0330	0.0000	0.71406	58.7116	0.03765	0.39009
ISO Container	-1.4683	2.1113	-1.5613	0.2192	0.0852	-0.0200	0.0000	0.67439	52.7611	0.078	0.078
Ship	-2.9088	1.3852	-0.3333	-0.0157	0.0271	-0.0044	0.0000	1.28928	58.7116	0.076	0.253
Impulse											
ECM or HPM--Front	-0.8019	0.5655	-0.5501	0.0677	0.0288	-0.0054	0.0000	1.03142	59.505	0.45359	0.305
ECM--Side or HPM--Side and Rear	-2.3463	0.7871	0.4595	-0.5318	0.1610	-0.0190	0.0006	0.3967	59.505	0.11884	0.21001
ECM--Rear	-2.6009	0.5081	0.3580	-0.4739	0.1966	-0.0366	0.0025	0.7934	59.505	0.06759	0.134
HAS--Front	3.0909	-3.1540	0.9023	-0.0986	0.0000	0.0000	0.0000	0.7934	39.67	48.3983	0.29484
HAS--Side	-0.7483	0.4665	-0.1831	0.0313	-0.0023	0.0000	0.0000	0.7934	39.67	0.41953	0.68402
HAS--Rear	-0.8596	0.3634	-0.2796	0.0222	0.0000	0.0000	0.0000	0.3967	39.67	0.23492	0.11022
AboveGround Structure (AGS)--masonry	-2.0743	1.8697	-1.6161	0.5329	-0.0585	0.0000	0.0000	0.59505	39.67	0.02812	0.28894
AboveGround Structure (AGS)--concrete	-1.7331	0.7517	-0.2516	-0.0710	0.0419	-0.0043	0.0000	0.93225	58.7116	0.16692	0.38964
ISO Container	-1.2664	0.4821	-0.6074	0.2105	-0.0076	-0.0039	0.0000	0.3967	58.7116	0.09072	0.20412
Ship	-2.2448	0.5921	-0.3112	0.0663	0.0098	-0.0027	0.0000	0.51571	69.4225	0.06123	0.41277

2.5. ATMOSPHERE PARAMETERS.

2.5.1. The atmosphere parameters section lists the factors necessary to make the adjustments to airblast based on the altitude and temperature at the explosion site. As previously discussed, the user enters input values at the altitude at which the detonation is to occur. The BEC-O then will make adjustments to the user-inputs in order to perform calculations based on sea level conditions. Results of the BEC-O analysis are factored again to display the final predicted blast effects at the user-input altitude. In other words, because the standard blast effects equations (Kingery-Bulmash equations¹⁸) were developed for sea-level conditions, it is necessary to convert the user-inputs to sea level conditions in order to perform the calculations. Then it is also necessary to convert the analysis results from sea level to the user-input altitude in order to predict blast effects at altitude.

2.5.2. The pressure of the atmosphere is either set to a value equivalent to the user entered pressure or determined based on the user entered altitude as:

$$P_{alt} = P_{std} * \exp(-3.7688 \times 10^{-5} * A) \quad \text{English Units} \quad (2-13)$$

$$P_{alt} = P_{std} * \exp(-1.2365 \times 10^{-4} * A) \quad \text{SI Units}$$

where,

$$P_{alt} = \text{Pressure at a specified altitude (psi or kPa)}$$

$$P_{std} = \text{Atmospheric Pressure at sea level (psi or kPa)}$$

$$= 14.696 \text{ psi or } 101.325 \text{ kPa}$$

$$A = \text{Altitude (ft or m)}$$

2.5.3. The temperature for the event is the temperature as listed in the Inputs Section of the BEC-O. This is either user-entered or the default value of 59° F (15° C).

2.5.4. The next four lines within the Atmosphere Parameters section list the scaling factors needed to convert explosion effects from standard sea level conditions to the user-input atmospheric parameters (altitude, barometric pressure, and temperature) and vice versa. The scaling factors shown in Equations 2-14 through 2-17 are used as shown in Sections 3.64 through 3.66 of “The Effects of Nuclear Weapons” by Glasstone²².

$$S_p = P_{alt}/P_{std} \quad \text{English or SI Units} \quad (2-14)$$

$$S_d = (P_{std}/P_{alt})^{1/3} \quad \text{English or SI Units} \quad (2-15)$$

$$S_t = (P_{std}/P_{alt})^{1/3} * (288.16/T)^{1/2} \quad \text{English or SI Units} \quad (2-16)$$

$$S_i = (P_{alt}/P_{std})^{2/3} * (288.16/T)^{1/2} \quad \text{English or SI Units} \quad (2-17)$$

where,

$$S_p = \text{Pressure Scaling Factor}$$

$$S_d = \text{Distance Scaling Factor}$$

$$S_t = \text{Time Scaling Factor}$$

$$S_i = \text{Impulse Scaling Factor}$$

$$T = \text{Atmospheric Temperature (K)}$$

$$P_{std} = \text{Atmospheric Pressure at sea level (psi or kPa)}$$

= 14.696 psi or 101.325 kPa

2.6. AIRBLAST PARAMETERS. At this point, all preliminary calculations are complete. The equivalent hemispherical weights ($H_{P,alt}$ and $H_{I,alt}$) which make adjustments for PES type, munition type, and explosive type as necessary have been determined. Remember, the test data used to develop the yield functions, F , were assumed to be at sea level. Further, the pressure and impulse functions used within the BEC-O are based on the simplified Kingery-Bulmash curves¹¹ for a hemispherical surface burst of TNT at sea level. Thus, in order to use these curves, the distance and scaled distance at the user defined altitude must be adjusted to an equivalent distance and equivalent scaled distance at sea level. The pressure and impulse functions may then be used to calculate airblast parameters at sea level. Finally, the calculated airblast effects at sea level may be scaled to the user-entered altitude conditions in order to provide blast effects at the desired detonation location.

2.6.1. Airblast Parameters at Sea Level

At this point in the calculations the equivalent hemispherical weights for pressure ($H_{P,alt}$) and impulse ($H_{I,alt}$) have been calculated at the user input altitude. These yields have been adjusted to account for TNT equivalence for a *Bulk/Light Cased STANDARD* munition type in *Open Storage/STANDARD* PESs. For other PESs, such as earth-covered magazines, these yields have been adjusted to account for the effects of the PES.

The airblast functions used within the BEC-O are based on the simplified Kingery-Bulmash curves¹¹ for a hemispherical surface burst of TNT at sea level. Thus, in order to use these curves, the distance and scaled distance at the user defined altitude must be adjusted using Equation 2-15 to an equivalent distance and equivalent scaled distance at sea level as shown in Equations 2-18 and 2-19. This equivalent distance at sea level is then used to calculate effective scaled distances for pressure and impulse at sea level, $Z_{eff,P,s}$ and $Z_{eff,I,s}$, as shown in Equations 2-20 and 2-21.

Using the effective scaled distances for pressure and impulse at sea level, the “Simplified Kingery Airblast Calculations”¹¹ are used to determine the airblast parameters at sea level. Then the airblast parameters at sea level will be scaled back to the user defined altitude using Equations 2-13 through 2-17.

2.6.1.1. Distance and Scaled Distance at Sea Level

2.6.1.1.1. The initial two outputs in the Airblast Parameters section are Distance and Scaled Distance. While these values were previously entered and computed for a blast at the user-specified altitude, equivalent values at sea level need to be determined. The sea level equivalent values are simple conversions based on equations presented in Section 2.5.

$$R_s = R/S_d \qquad \text{English or SI Units} \qquad (2-18)$$

$$Z_s = Z_{alt}/S_d \qquad \text{English or SI Units} \qquad (2-19)$$

where,

R_s = Equivalent Distance to ES at sea level (ft or m)

R = Distance to ES at user-entered altitude (ft or **m**)
 S_d = Distance Scaling Factor
 Z_{alt} = Scaled Distance at user-entered altitude
 Z_s = Equivalent scaled distance at sea level

2.6.1.1.2. The effects of the PES, munition type, and explosive type inputs are then incorporated by determining the effective scaled airblast distance for pressure and impulse (Z_{eff,P,s} and Z_{eff,I,s}) at sea level. The effective scaled distance is the equivalent scaled distance at sea level for a detonation of hemispherical bare explosives equivalent in effects to the user-selected PES, munition, and TNT equivalent values.

$$Z_{\text{eff,P,s}} = R_s / H_{\text{P,alt}}^{1/3} \quad \text{English or SI Units} \quad (2-20)$$

$$Z_{\text{eff,I,s}} = R_s / H_{\text{I,alt}}^{1/3} \quad \text{English or SI Units} \quad (2-21)$$

where,

H_{P,alt} = Equivalent Hemispherical Weight for Pressure (Section 2.4.2)

H_{I,alt} = Equivalent Hemispherical Weight for Impulse (Section 2.4.2)

2.6.1.2. Airblast Parameters for Hemispherical TNT Explosion at Sea Level

Traditionally, airblast parameters have been calculated using Figure 2-15 (Positive Phase Shock Wave Parameters for a Hemispherical TNT Explosion on the Surface at Sea Level) of the UFC 3-340-02 (formerly TM 5-1300). The equations in that figure are based on a report by Granstrom.¹⁷ A more recent and complete work is Kingery, C. and Bulmash, G., “Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst.”¹⁸ The English unit equations that are in the BEC-O are taken from a paper by Swisdak entitled “Simplified Kingery Airblast Calculations.”¹¹ Swisdak took the work of Kingery and Bulmash and further simplified the airblast equations into more manageable forms. It should be noted that since 1992 the Swisdak equations have generally been used as the basis for computation of airblast parameters within the DoD explosives safety community. In the 1992 paper, the SI units form of the equations were obtained by re-curve fitting the source data. This led to small differences when the English and SI unit results were compared. For Version 1 of the BEC-O, conversion factors were applied directly to the English unit coefficients to obtain the SI form of the equations. The English Units form of the equations presented in the following sections are exactly as listed in Reference 11. The SI Units form were recalculated as described above to provide consistency with the way that SI units were treated throughout the BEC-O.

Because the equations in this section are a result of Swisdak’s work (Reference 11) to simplify the Kingery-Bulmash curves, many of the equations include a standard curve fit term. Within this section, these standard curve fit equations will be denoted as, S(x), where the “S” indicates the standard curve fit, and the term used in place of the “x” term indicates the independent variable to be applied. Curve fit coefficients (A, B, C, D, etc.) will be included within tables for each airblast parameter. The standard curve fit is shown in Equation 2-22.

$$S(x) = \exp[A+B*\ln(x) + C*\ln^2(x) + D*\ln^3(x) + E*\ln^4(x) + F*\ln^5(x) + G*\ln^6(x)] \quad (2-22)$$

2.6.1.2.1. **Time of Arrival.** The time of arrival, t_A, is determined using Equations 2-23 through 2-25 depending on the determined effective scaled airblast distance at sea level (Z_{eff,P,s}).

Note that when the effective airblast scaled distance falls outside the effective ranges listed in Reference 11, the BEC-O will display an “out of range” message. Curve fit coefficients for use in the standard equation, S(x), are provided in Table 2-3.

When $0.2 \text{ ft/lb}^{1/3} \leq Z_{\text{eff,P,s}} \leq 100 \text{ ft/lb}^{1/3}$ ($0.06 \text{ m/kg}^{1/3} \leq Z_{\text{eff,P,s}} \leq 40 \text{ m/kg}^{1/3}$)
 $t_A = (H_{P,\text{alt}})^{1/3} * S(x)$ English or SI Units (2-23, 2-24)

When $100 \text{ ft/lb}^{1/3} < Z_{\text{eff,P,s}} \leq 500 \text{ ft/lb}^{1/3}$ ($40 \text{ m/kg}^{1/3} \leq Z_{\text{eff,P,s}} \leq 198.5 \text{ m/kg}^{1/3}$)
 $t_A = (H_{P,\text{alt}})^{1/3} * 0.6559951 * [Z_{\text{eff,P,s}}]^{1.0478}$ English Units (2-25)
 $t_A = (H_{P,\text{alt}})^{1/3} * 2.2495832 * [Z_{\text{eff,P,s}}]^{1.0478}$ SI Units

where,

- $H_{P,\text{alt}}$ = Equivalent Hemispherical Weight for Pressure (Section 2.4.2)
- S = Standard Equation (Equation 2-28 with coefficients from Table 2-4)
- x = Effective scaled distance for pressure at sea level, $Z_{\text{eff,P,s}}$ (Equation 2-20)

Table 2-3. Scaled Time of Arrival (ms/lb^{1/3} or ms/kg^{1/3})

Equation Number	Range of Scaled Distance, Z	$t_A/H_P^{1/3} = \text{Function}(Z_{\text{eff,P,s}})$						
		A	B	C	D	E	F	G
2-23a	$0.2 \leq Z < 4.5$	-2.56710	1.53480	0.13130	0.01825	0.00366	-0.00862	0.00000
2-23b	$0.06 \leq Z < 1.50$	-0.76102	1.80448	0.13258	-0.04187	-0.03617	-0.00862	0.00000
2-24a	$4.5 \leq Z < 100$	-1.79097	-0.44021	2.01409	-0.78101	0.13045	-0.00816	0.00000
2-24b	$1.50 \leq Z < 40$	-0.74020	1.66382	0.45234	-0.36834	0.09271	-0.00816	0.00000

2.6.1.2.2. Incident Overpressure

2.6.1.2.2.1. The incident overpressure, P_{so} , is determined using Equations 2-26 through 2-28 depending on the determined effective scaled airblast distance at sea level ($Z_{\text{eff,P,s}}$). Curve fit coefficients for use in the standard equation, S(x), are provided in Table 2-4.

When $0.5 \text{ ft/lb}^{1/3} \leq Z_{\text{eff,P,s}} \leq 500 \text{ ft/lb}^{1/3}$ ($0.2 \text{ m/kg}^{1/3} \leq Z_{\text{eff,P,s}} \leq 198.5 \text{ m/kg}^{1/3}$)
 $P_{\text{so}} = S(x)$ English or SI Units (2-26, 2-27, 2-28)

where,

- S = Standard Equation (Equation 2-22 with coefficients from Table 2-4)
- x = Effective scaled distance for pressure at sea level, $Z_{\text{eff,P,s}}$ (Equation 2-20)

Table 2-4. Incident Overpressure (psi or kPa)

Equation Number	Range of Scaled Distance, Z	$P_{so} = \text{Function}(Z_{\text{eff,P,s}})$						
		A	B	C	D	E	F	G
2-26a	$0.5 \leq Z < 7.25$	6.91370	-1.43980	-0.28150	-0.14160	0.06850	0.00000	0.00000
2-26b	$0.2 \leq Z < 2.9$	7.21060	-2.10690	-0.32290	0.11170	0.06850	0.00000	0.00000
2-27a	$7.25 \leq Z < 60$	8.80350	-3.70010	0.27090	0.07330	-0.01270	0.00000	0.00000
2-27b	$2.9 \leq Z < 23.8$	7.59345	-3.05133	0.40908	0.02633	-0.01270	0.00000	0.00000
2-28a	$60 \leq Z < 500$	5.42330	-1.40660	0.00000	0.00000	0.00000	0.00000	0.00000
2-28b	$23.8 \leq Z < 198.5$	6.05360	-1.40660	0.00000	0.00000	0.00000	0.00000	0.00000

2.6.1.2.2.2. Within the BEC-O the overpressure at distance is also shown in decibels. Converting overpressure (sound pressure level) to decibels is defined as 20 times the logarithm to the base 10 of the ratio of the sound pressure to a reference pressure²⁴. The reference pressure is defined as the quietest noise a healthy young person can hear (20 μPa, 2.92 x 10⁻⁹ psi)²⁵. Thus the conversion of pressure to decibels is:

$$P_{\text{dB}} = 20 \log(P_{\text{psi}}) + 170.7496 \quad \text{English Units} \quad (2-29)$$

$$P_{\text{dB}} = 20 \log(P_{\text{Pa}}) + 93.9794 \quad \text{SI Units}$$

2.6.1.2.3. **Reflected Pressure.** The reflected pressure, P_r , is determined using Equations 2-30 through 2-32 depending on the determined effective scaled airblast distance at sea level ($Z_{\text{eff,P,s}}$). Curve fit coefficients for use in the standard equation, $S(x)$, are provided in Table 2-5.

When $0.3 \text{ ft/lb}^{1/3} < Z_{\text{eff,P,s}} \leq 100 \text{ ft/lb}^{1/3}$ ($0.6 \text{ m/kg}^{1/3} \leq Z_{\text{eff,P,s}} \leq 40 \text{ m/kg}^{1/3}$)

$$P_r = S(x) \quad \text{English or SI Units} \quad (2-30, 2-31)$$

When $100 \text{ ft/lb}^{1/3} < Z_{\text{eff,P,s}} \leq 500 \text{ ft/lb}^{1/3}$ ($40 \text{ m/kg}^{1/3} \leq Z_{\text{eff,P,s}} \leq 198.5 \text{ m/kg}^{1/3}$)

$$P_r = 2 * P_{so} \quad \text{English or SI Units} \quad (2-32)$$

where,

S = Standard Equation (Equation 2-22 with coefficients from Table 2-5)

x = Effective scaled distance for pressure at sea level, $Z_{\text{eff,P,s}}$ (Equation 2-20)

Table 2-5. Reflected Pressure (psi or kPa)

Equation Number	Range of Scaled Distance, Z	$P_r = \text{Function}(Z_{\text{eff,P,s}})$						
		A	B	C	D	E	F	G
2-30a	$0.3 \leq Z < 4.0$	9.07950	-1.75110	-0.28770	-0.21990	-0.01280	0.06960	-0.01180
2-30b	$0.06 \leq Z < 2.00$	9.00178	-2.68104	-0.54254	0.14121	0.15765	0.00414	-0.01180
2-31a	$4.0 \leq Z < 100$	5.15150	9.15826	-11.85735	5.56754	-1.33455	0.16333	-0.00818
2-31b	$2.00 \leq Z < 40$	8.94402	-2.14524	-2.05822	1.89885	-0.68439	0.11795	-0.00818

2.6.1.2.3. **Positive Phase Duration.** The positive phase duration, t_o , is determined using Equations 2-33 through 2-36 depending on the determined effective scaled airblast distance at

sea level ($Z_{eff,I,s}$). Note that this equation is driven by impulse instead of pressure. Curve fit coefficients for use in the standard equation, $S(x)$, are provided in Table 2-6.

When $0.5 \text{ ft/lb}^{1/3} \leq Z_{eff,I,s} \leq 100 \text{ ft/lb}^{1/3}$ ($0.02 \text{ m/kg}^{1/3} \leq Z_{eff,I,s} \leq 40 \text{ m/kg}^{1/3}$)
 $t_o = (H_{I,alt}^{1/3}) * S(x)$ English or SI Units (2-33, 2-34, 2-35)

When $100 \text{ ft/lb}^{1/3} < Z_{eff,I,s} \leq 500 \text{ ft/lb}^{1/3}$ ($40 \text{ m/kg}^{1/3} < Z_{eff,I,s} \leq 198.5 \text{ m/kg}^{1/3}$)
 $t_o = 1.0029 * (H_{I,alt}^{1/3}) * S(x)$ English or SI Units (2-36)

where,

- $H_{I,alt}$ = Equivalent Hemispherical Weight for Impulse (Section 2.4.2)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-6)
- x = Effective scaled distance for impulse at sea level, $Z_{eff,I,s}$ (Equation 2-21)

Table 2-6. Scaled Positive Phase Duration (ms/lb^{1/3} or ms/kg^{1/3})

Equation Number	Range of Scaled Distance, Z (ft/lb ^{1/3})	$t_o/H_I^{1/3} = \text{Function}(Z_{eff,I,s})$						
		A	B	C	D	E	F	G
2-33a	$0.5 \leq Z < 2.5$	-1.72210	0.45000	1.35520	1.12490	-0.05773	-0.60800	0.00000
2-33b	$0.2 \leq Z < 1.02$	0.55208	3.43680	-0.62621	-4.28609	-2.86846	-0.60800	0.00000
2-34a	$2.5 \leq Z < 7.0$	-18.77010	55.05130	-60.43480	32.02360	-8.32560	0.88170	0.00000
2-34b	$1.02 \leq Z < 2.80$	0.55250	2.32380	-7.34364	8.77005	-4.24959	0.88170	0.00000
2-35a	$7.0 \leq Z < 100$	-13.05970	19.78060	-11.29750	3.25520	-0.46470	0.02624	0.00000
2-35b	$2.80 \leq Z < 40$	-1.91410	5.86454	-4.44451	1.76090	-0.34340	0.02624	0.00000
2-36a*	$100 \leq Z < 500$	-0.04469	0.51213	-0.02895	0.00000	0.00000	0.00000	0.00000
2-36b**	$40 \leq Z < 198.5$	0.66760	0.45860	-0.02895	0.00000	0.00000	0.00000	0.00000

* Equation not shown in Reference 11. Only found in BEC-O programming.

** Equation not shown in Reference 11 or BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.6.1.2.4. Incident Impulse. The incident impulse, i_s , is determined using Equations 2-37 through 2-40 depending on the determined effective scaled airblast distance at sea level ($Z_{eff,I,s}$). Curve fit coefficients for use in the standard equation, $S(x)$, are provided in Table 2-7.

When $0.5 \text{ ft/lb}^{1/3} \leq Z_{eff,I,s} \leq 1000 \text{ ft/lb}^{1/3}$ ($0.02 \text{ m/kg}^{1/3} \leq Z_{eff,I,s} \leq 396.7 \text{ m/kg}^{1/3}$)
 $i_s = (H_{I,alt}^{1/3}) * S(x)$ English or SI Units (2-37, 2-38, 2-39, 2-40)

where,

- $H_{I,alt}$ = Equivalent Hemispherical Weight for Impulse (Section 2.4.2)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-7)
- x = Effective scaled distance for impulse at sea level, $Z_{eff,I,s}$ (Equation 2-21)

Table 2-7. Scaled Incident Impulse (psi-ms/lb^{1/3} or kPa-ms/kg^{1/3})

Equation Number	Range of Scaled Distance, Z (ft/lb ^{1/3})	$i_s/H_I^{1/3} = \text{Function}(Z_{\text{eff},I,s})$						
		A	B	C	D	E	F	G
2-37a	0.5 ≤ Z < 2.41	2.97500	-0.46600	0.96300	0.03000	-0.08700	0	0
2-37b	0.2 ≤ Z < 0.96	5.52181	1.11663	0.59998	-0.29175	-0.08700	0	0
2-38a	2.41 ≤ Z < 6.0	0.91100	7.26000	-7.45900	2.96000	-0.43200	0	0
2-38b	0.96 ≤ Z < 2.38	5.46527	-0.30760	-1.46449	1.36232	-0.43200	0	0
2-39a	6.0 ≤ Z < 85	3.24840	0.16330	-0.44160	0.07930	-0.00554	0	0
2-39b	2.38 ≤ Z < 33.7	5.27482	-0.46744	-0.25006	0.05881	-0.00554	0	0
2-40a	85 ≤ Z < 1000*	4.77020	-1.06200	0	0	0	0	0
2-40b	33.7 ≤ Z < 396.7*	5.98260	-1.06200	0	0	0	0	0

* Upper limit of range in Reference 11 is 400 ft/lb^{1/3} (158.7 m/kg^{1/3}). A higher value is used within BEC-O programming.

2.6.1.2.5. Reflected Impulse. The reflected impulse, i_r , is as calculated using Equation 2-41.

When $0.5 \text{ ft/lb}^{1/3} \leq Z_{\text{eff},I,s} \leq 600 \text{ ft/lb}^{1/3}$ ($0.02 \text{ m/kg}^{1/3} \leq Z_{\text{eff},I,s} \leq 238 \text{ m/kg}^{1/3}$)

$$I_r = (H_{I,\text{alt}}^{1/3}) * S(x) \quad \text{English or SI Units} \quad (2-41)$$

where,

$H_{I,\text{alt}}$ = Equivalent Hemispherical Weight for Impulse (Section 2.4.2)

S = Standard Equation (Equation 2-22 with coefficients from Table 2-8)

x = Effective scaled distance for impulse at sea level, $Z_{\text{eff},I,s}$ (Equation 2-21)

Table 2-8. Scaled Reflected Impulse (psi-ms/lb^{1/3} or kPa-ms/kg^{1/3})

Equation Number	Range of Scaled Distance, Z (ft/lb ^{1/3})	$i_r/H_I^{1/3} = \text{Function}(Z_{\text{eff},I,s})$						
		A	B	C	D	E	F	G
2-41a	0.2 ≤ Z < 600*	5.93130	-1.56220	0.13220	-0.01123	0	0	0
2-41b	0.06 ≤ Z < 238*	6.78536	-1.34654	0.10105	-0.01123	0	0	0

* Upper limit of range in Reference 11 is 100 ft/lb^{1/3} (40 m/kg^{1/3}). A higher value is used within BEC-O programming.

2.6.1.2.6. Dynamic Overpressure

2.6.1.2.6.1. The dynamic overpressure, q_o , first appeared in Version 3.0 of the BEC. Dynamic overpressure is the air pressure which results from the mass air flow (or wind) behind the shock front of a blast wave. It is defined by Glasstone and Dolan²² as:

$$q_o = \frac{1}{2} \rho_{\text{air}} u^2 \quad \text{English or SI Units} \quad (2-42)$$

where,

ρ_{air} = density of the air through which the blast wave is traveling

u^2 = particle (or wind) velocity behind the shock front as it impinges on an object or structure

2.6.1.2.6.2. Dynamic overpressure can be related to the incident pressure by the following equation.

$$q_o = P_{so}^2 / [2\gamma * P_{atm} + (\gamma - 1)P_{so}] \quad \text{English or SI Units} \quad (2-43)$$

where,

P_{so} = incident pressure (psi or Pa)

P_{atm} = atmospheric pressure (psi or Pa)

γ = ratio of the specific heats of air (typically taken as 1.4 at moderate temperatures)

2.6.1.2.6.3. Previous versions of the BEC did not contain an explicit algorithm for predicting dynamic overpressure. Models were developed for the Defense Threat Reduction Agency (formerly the Defense Nuclear Agency) that predict the pressure-time waveforms for ANFO and TNT surface burst detonations.^{19, 20} These models were used in conjunction with the CONWEP computer code²¹ to develop estimates for the dynamic overpressure and dynamic impulse as a function of distance and charge weight. These data formed the basis of the algorithm now included in the BEC-O. More information regarding the addition of dynamic overpressure to the BEC-O can be found in Reference 5.

2.6.1.2.6.4. Within the BEC-O programming, the dynamic overpressure, q_o , is determined using Equation 2-44. Curve fit coefficients for use in the standard equation, $S(x)$, are provided in Table 2-9.

$$\text{When } 0.5 \text{ ft/lb}^{1/3} < Z_{\text{eff,P,s}} \leq 150 \text{ ft/lb}^{1/3} \quad (0.198 \text{ m/kg}^{1/3} \leq Z_{\text{eff,P,s}} \leq 59.5 \text{ m/kg}^{1/3})$$

$$q_o = S(x) \quad \text{English or SI Units} \quad (2-44)$$

where,

S = Standard Equation (Equation 2-22 with coefficients from Table 2-9)

x = Effective scaled distance for pressure at sea level, $Z_{\text{eff,P,s}}$ (Equation 2-20)

Table 2-9: Dynamic Overpressure (psi or kPa)

Equation Number	Range of Scaled Distance, Z (ft/lb ^{1/3})	$q_o = \text{Function}(Z_{\text{eff,P,s}})$						
		A	B	C	D	E	F	G
2-44a	$0.5 \leq Z < 150$	8.01662	-1.80686	-0.42462	-0.39399	0.18975	-0.02099	0
2-44b*	$0.2 \leq Z < 59.5$	7.72690	-3.07930	-0.71010	0.12830	0.09270	-0.02099	0

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.6.1.2.7. **Dynamic Impulse.** The dynamic impulse, i_o , is the impulse associated with the results of the dynamic overpressure. The dynamic impulse equation was developed similarly to the dynamic overpressure. Though versions before Version 3.0 of BEC contained simplistic algorithms for predicting dynamic impulse, an explicit algorithm was first added in Version 3.0. Within the BEC-O programming, the dynamic impulse, i_o , is determined using Equations 2-45 and 2-46. Curve fit coefficients for use in the standard equation, $S(x)$, are provided in Table 2-10.

When $0.5 \text{ ft/lb}^{1/3} \leq Z_{\text{eff},s} \leq 150 \text{ ft/lb}^{1/3}$ ($0.02 \text{ m/kg}^{1/3} \leq Z_{\text{eff},s} \leq 59.5 \text{ m/kg}^{1/3}$)
 $i_o = (H_{I,\text{alt}})^{1/3} * S(x)$ English or SI Units (2-45, 2-46)

where,

- $H_{I,\text{alt}}$ = Equivalent Hemispherical Weight for Impulse (Section 2.4.2.)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-10)
- x = Effective scaled distance for impulse at sea level, $Z_{\text{eff},s}$ (Equation 2-21)

Table 2-10. Scaled Dynamic Impulse (psi-ms/lb^{1/3} or kPa-ms/kg^{1/3})

Equation Number	Range of Scaled Distance, Z (ft/lb ^{1/3})	$i_o/H_{I,\text{alt}}^{1/3} = \text{Function}(Z_{\text{eff},s})$							
		A	B	C	D	E	F	G	H
2-45a	$0.5 \leq Z < 6$	5.02669	-1.49770	0.38207	-2.91667	0.09869	4.11776	-2.92807	0.58457
2-45b*	$0.2 \leq Z < 2.4$	5.22050	-2.22740	1.54220	1.31490	-2.24000	-1.63160	0.85529	0.58457
2-46a	$6 \leq Z < 150$	-43.57590	106.51300	-96.61740	44.33270	-11.15370	1.46535	-0.07877	0
2-46b*	$2.4 \leq Z < 59.5$	2.33461	11.31770	-20.14010	14.36423	-5.38957	1.02839	-0.07877	0

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.6.2. Airblast Parameters at Altitude

2.6.2.1. Once the airblast parameters at sea level have been computed as described in Section 2.6.1, determining the airblast parameters at the user-entered altitude is a simple matter of using the conversion factors computed in Section 2.5. In order to track the appropriate elevation of computed parameters within this section, the subscripts “s” and “alt” will be used in conjunction with the typical variable definitions to describe effects at sea level and altitude, respectively. These calculations will complete the calculations for all remaining outputs within the Airblast Parameters section of the BEC-O output screen.

2.6.2.2. Within the airblast parameters at altitude section, the BEC-O repeats a user-input as well as displaying a second previously calculated value. The Distance to Exposed Site field reiterates the user-input value from the inputs section. The scaled distance field displays the scaled distance value based on user inputs at altitude, Z_{alt} , as calculated in Equation 2-3.

2.6.2.3. The time of arrival at the distance and user-entered altitude, $t_{A,\text{alt}}$, is computed using the time scaling factor, S_t , and the value computed for sea level conditions (Equations 2-22 through 2-25).

$$t_{A,\text{alt}} = S_t (t_{A,s}) \quad \text{English or SI Units} \quad (2-47)$$

2.6.2.4. The incident pressure at the distance and user-entered altitude, $P_{\text{so,alt}}$, is computed using the pressure scaling factor, S_p , and the value computed for sea level conditions (Equations 2-26 through 2-28). The same equation previously used is employed to again make the conversion from psi to decibels.

$$P_{\text{so,alt}} = S_p (P_{\text{so,s}}) \quad \text{English or SI Units} \quad (2-48)$$

2.6.2.5. Reflected pressure at distance and user-entered altitude, $P_{r,alt}$, is computed similarly to P_{so} .

$$P_{r,alt} = S_p (P_{r,s}) \quad \text{English or SI Units} \quad (2-49)$$

2.6.2.6. Positive phase duration, t_o , again utilizes the time scaling factor, S_t .

$$t_{o,alt} = S_t (t_{o,s}) \quad \text{English or SI Units} \quad (2-50)$$

2.6.2.7. Positive phase impulse, i_s , and reflected impulse, i_r , use the impulse scaling factor, S_i .

$$i_{s,alt} = S_i (i_{s,s}) \quad \text{English or SI Units} \quad (2-51)$$

$$i_{r,alt} = S_i (i_{r,s}) \quad \text{English or SI Units} \quad (2-52)$$

2.6.2.8. Dynamic overpressure, q_o , is adjusted using the pressure scaling factor, S_p .

$$q_{o,alt} = S_p (q_{o,s}) \quad \text{English or SI Units} \quad (2-53)$$

2.6.2.9. Lastly, dynamic overpressure impulse, i_o , is adjusted using the impulse scaling factor, S_i .

$$i_{o,alt} = S_i (i_{o,s}) \quad \text{English or SI Units} \quad (2-54)$$

2.7. OTHER INFORMATION

2.7.1. Probability of Window Breakage

Probability of window breakage, p_w , calculations are conducted at sea level conditions. These calculations are based on References 12 and 13. Paul Wilde provided tables of breakage probability versus incident pressure for each window type/area shown. Mike Swisdak then performed curve fits for each of the window types/areas in order to provide the window breakage equations below. The approach is an approximation but does seem to work well when compared to actual data. Note that the probability of window breakage is strongly related to the incident pressure.

Like many of the airblast effect equations, the equations in this section are a result of curve fitting. As such, many of the equations include the same standard curve fit term shown previously as Equation 2-28. Thus, within this section, these standard curve fit equations will again be denoted as, $S(x)$, where the “S” indicates the standard curve fit, and the term used in place of the “x” term indicates the independent variable to be applied. Curve fit coefficients (A, B, C, D, etc.) will be included within tables for each window type. The standard curve fit equation is repeated below.

$$S(x) = \exp[A+B*\ln(x) + C*\ln^2(x) + D*\ln^3(x) + E*\ln^4(x) + F*\ln^5(x) + G*\ln^6(x)] \quad (2-55)$$

2.7.1.1. For a 2 square feet (ft²) (0.19 square meter (m²)) Float Annealed Window. These equations assume the window has dimensions of 12 x 24 x 0.088 inches (30.5 x 61 x 0.224 centimeters (cm)).

When $P_{so} < 0.001$ psi (0.0069 kPa)
 $p_w = 0.000001\%$ English or SI Units (2-56)

When $0.001 \text{ psi} \leq P_{so} \leq 1.5$ psi (0.0069 kPa $\leq P_{so} < 10.34$ kPa)
 $p_w = 100 * S(x)$ English or SI Units (2-57)

When $P_{so} > 1.5$ psi (10.34 kPa)
 $p_w = 100 \%$ English or SI Units (2-58)

where,

- p_w = Probability of Window Breakage (%)
- P_{so} = Overpressure at Distance (sea level); (psi or kPa)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-11)
- x = Overpressure at Distance, P_{so} (sea level); (psi or kPa)

Table 2-11. Probability of Window Breakage (%) for a 2 ft² (0.19 m²) Window

Equation Number	Overpressure, P_{so} (psi or kPa)	$p_w/100 = \text{Function}(P_{so})$						
		A	B	C	D	E	F	G
2-57a	$0.001 \leq P < 1.5$	-0.3489	1.285	-1.0516	-0.057981	0.0339	0.00464	0
2-57b*	$0.0069 \leq P < 10.34$	-5.9863	4.0438	-0.2915	-0.1468	-0.0109	0.0046	0

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.7.1.2. For a 4 ft² (0.37 m²) Float Annealed Window. These equations assume the window has dimensions of 24 x 24 x 0.088 inches (61 x 61 x 0.224 cm).

When $P_{so} < 0.005$ psi (0.0345 kPa)
 $p_w = 0.000001\%$ English or SI Units (2-59)

When $0.005 \text{ psi} \leq P_{so} < 0.061$ psi (0.0345 kPa $\leq P_{so} < 4.137$ kPa)
 $p_w = 100 * S(x)$ English or SI Units (2-60, 2-61)

When $P_{so} > 0.6$ psi (4.137 kPa)
 $p_w = 100\%$ English or SI Units (2-62)

where,

- p_w = Probability of Window Breakage (%)
- P_{so} = Overpressure at Distance (sea level); (psi or kPa)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-12)
- x = Overpressure at Distance, P_{so} (sea level); (psi or kPa)

Table 2-12. Probability of Window Breakage (%) for a 4 ft² (0.37 m²) Window

Equation Number	Overpressure, P _{so} (psi or kPa)	p _w /100 = Function (P _{so})						
		A	B	C	D	E	F	G
2-60a	0.0005 ≤ P < 0.061	939.32200	1544.34000	1042.11000	371.57500	73.79180	7.74879	0.33640
2-60b*	0.0345 ≤ P < 0.421	2.93758	35.49853	52.74422	42.11506	17.79704	3.85176	0.33640
2-61a	0.061 ≤ P < 0.6	1.03300	7.48201	19.75260	23.27570	12.30060	3.09898	0.29998
2-61b*	0.421 ≤ P < 4.137	-3.76272	3.85318	0.11770	0.32142	-0.76480	-0.38419	0.29998

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.7.1.3. For a 10.5 ft² (0.98 m²) Float Annealed Window. These equations assume the window has dimensions of 42 x 63 x 0.12 inches (107 x 160 x 0.305 cm).

When P_{so} < 0.001 psi (0.0069 kPa)

$$p_w = 0.000001\% \quad \text{English or SI Units} \quad (2-63)$$

When 0.001 ≤ P_{so} < 0.36 (0.0069 kPa ≤ P_{so} ≤ 2.482 kPa)

$$p_w = 100 * S(x) \quad \text{English or SI Units} \quad (2-64, 2-65)$$

When P_{so} > 0.36 (2.482 kPa)

$$p_w = 100\% \quad \text{English or SI Units} \quad (2-66)$$

where,

p_w = Probability of Window Breakage (%)

P_{so} = Overpressure at Distance (sea level); (psi or kPa)

S = Standard Equation (Equation 2-22 with coefficients from Table 2-13)

x = Overpressure at Distance, P_{so} (sea level); (psi or kPa)

Table 2-13. Probability of Window Breakage (%) for a 10.5 ft² (0.98 m²) Window

Equation Number	Overpressure, P _{so} (psi or kPa)	p _w /100 = Function (P _{so})						
		A	B	C	D	E	F	G
2-64a	0.001 ≤ P < 0.05	1211.2300	1513.0300	742.5640	179.1080	20.5895	0.7756	-0.0196
2-64b*	0.0069 ≤ P < 0.345	36.9748	109.0757	106.7262	51.8351	12.0037	1.0031	36.9748
2-65a	0.05 ≤ P < 0.36	25.4579	94.0793	137.0850	100.0280	38.5388	7.5737	0.5988
2-65b*	0.345 ≤ P < 2.482	-1.7404	3.6938	-0.6053	-1.4739	-1.0917	0.6366	-1.7404

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.7.1.4. For a 17.5 ft² (1.625 m²) Plate Annealed Window. These equations assume the window has dimensions of 60 x 42 x 0.22 inches (152.5 x 107 x 0.56 cm).

When P_{so} < 0.001 psi (0.0069 kPa)

$$p_w = 0.000001\% \quad \text{English or SI Units} \quad (2-67)$$

When 0.001 ≤ P_{so} < 0.5 (0.0069 kPa ≤ P_{so} ≤ 3.45 kPa)

$$p_w = 100 * S(x) \quad \text{English or SI Units} \quad (2-68, 2-69)$$

When P_{so} > 0.5 psi (3.45 kPa)

$$p_w = 100\% \quad \text{English or SI Units} \quad (2-70)$$

where,

- p_w = Probability of Window Breakage (%)
- P_{so} = Overpressure at Distance (sea level); (psi or kPa)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-14)
- x = Overpressure at Distance, P_{so} (sea level); (psi or kPa)

Table 2-14. Probability of Window Breakage (%) for a 17.5 ft² (1.625 m²) Window

Equation Number	Overpressure, P_{so} (psi or kPa)	$p_w/100 = \text{Function}(P_{so})$						
		A	B	C	D	E	F	G
2-68a	$0.001 \leq P < 0.19$	-11.63690	-21.00560	-16.58650	-6.61077	-1.60083	-0.21209	-0.01164
2-68b*	$0.0069 \leq P < 1.31$	-2.48910	2.33697	-1.26146	-0.47864	-0.20407	-0.07728	-0.01164
2-69a	$0.19 \leq P < 0.5$	-45.28890	-268.89600	-655.19100	-836.37900	-587.31600	-213.91100	-31.54590
2-69b*	$1.31 \leq P < 3.45$	-5.17990	31.60948	-126.57418	266.30621	-286.23144	151.53467	-31.54590

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.7.1.5. For a 30 ft² (2.8 m²) Plate Annealed Window. These equations assume the window has dimensions of 72 x 60 x 0.22 inches (183 x 152.5 x 0.56 cm).

- When $P_{so} < 0.007$ psi (0.048 kPa)
 - $p_w = 0.00001\%$ English or SI Units (2-71)
- When 0.007 psi $\leq P_{so} < 0.25$ psi (0.048 kPa $\leq P_{so} < 1.724$ kPa)
 - $p_w = 100 * S(x)$ English or SI Units (2-72, 2-73)
- When $P_{so} > 0.25$ psi (1.724 kPa)
 - $p_w = 100\%$ English or SI Units (2-74)

where,

- p_w = Probability of Window Breakage (%)
- P_{so} = Overpressure at Distance (sea level); (psi or kPa)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-15)
- x = Overpressure at Distance, P_{so} (sea level); (psi or kPa)

Table 2-15. Probability of Window Breakage (%) for a 30 ft² (2.8 m²) Window

Equation Number	Overpressure, P_{so} (psi or kPa)	$p_w/100 = \text{Function}(P_{so})$						
		A	B	C	D	E	F	G
2-72a	$0.007 \leq P < 0.063$	1845.5	3003.31	2019.41	719.089	142.989	15.0645	0.657201
2-72b*	$0.048 \leq P < 0.434$	16.099	71.497	105.19	81.749	34.307	7.451	0.6572
2-73a	$0.063 \leq P < 0.25$	101.349	324.407	240.918	283.803	105.396	20.6109	1.66409
2-73b*	$0.434 \leq P < 1.724$	-1.7405	3.6938	-0.6051	-1.4738	-1.0918	0.6365	0.5988

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.7.1.6. For a 50 ft² (4.64 m²) Plate Annealed Window. These equations assume the window has dimensions of 120 x 60 x 0.30 inches (305 x 152.5 x 0.76 cm).

- When $P_{so} < 0.0034$ psi (0.023 kPa)
 - $p_w = 0.00001\%$ English or SI Units (2-75)

When $0.0034 \text{ psi} \leq P_{so} < 0.29 \text{ psi}$ ($0.023 \text{ kPa} \leq P_{so} < 2.00 \text{ kPa}$)
 $p_w = 100 * S(x)$ English or SI Units (2-76)

When $P_{so} > 0.29 \text{ psi}$ (2.00 kPa)
 $p_w = 100\%$ English or SI Units (2-77)

where,

- p_w = Probability of Window Breakage (%)
- P_{so} = Overpressure at Distance (sea level); (psi or kPa)
- S = Standard Equation (Equation 2-22 with coefficients from Table 2-16)
- x = Overpressure at Distance, P_{so} (sea level); (psi or kPa)

Table 2-16. Probability of Window Breakage (%) for a 50 ft² (4.64 m²) Window

Equation Number	Overpressure, P_{so} (psi or kPa)	$p_w/100 = \text{Function}(P_{so})$						
		A	B	C	D	E	F	G
2-76a	$0.0034 \leq P < 0.29$	1.35390	6.16015	8.74679	5.24398	1.41124	0.18541	0.00972
2-76b*	$.023 \leq P < 2.00$	-0.53694	1.71924	-1.38220	-0.14203	0.16468	0.07284	0.00972

* Equation not in BEC v6.3 or earlier. Developed to correspond to English unit equation.

2.7.2. Probability of Eardrum Rupture

2.7.2.1. The probability of eardrum rupture is also computed using sea level conditions. Equations for probability of eardrum rupture are based on Reference 14. The lines plotted in Figure 2.2.2 of Reference 14 were approximated and curve fitted in order to generate Equations 2-78 through 2-80.

2.7.2.1.1. The probit function for probability of minor damage is expressed as:

When $0.9 \text{ ft/lb}^{1/3} \leq Q \leq 3.7 \text{ ft/lb}^{1/3}$ ($2.3 \text{ m/kg}^{1/3} \leq Q \leq 9.3 \text{ m/kg}^{1/3}$)
 $f_{e,minor} = 13.051 - 3.3 * \ln(Q)$ English Units (2-78)
 $f_{e,minor} = 10 - 3.3 * \ln(Q)$ SI Units

2.7.2.1.2. The probit function for probability of moderate damage is expressed as:

When $0.7 \text{ ft/lb}^{1/3} \leq Q \leq 2.7 \text{ ft/lb}^{1/3}$ ($1.8 \text{ m/kg}^{1/3} \leq Q \leq 6.8 \text{ m/kg}^{1/3}$)
 $f_{e,mod} = 12.636 - 3.5 * \ln(Q)$ English Units (2-79)
 $f_{e,mod} = 9.4 - 3.5 * \ln(Q)$ SI Units

2.7.2.1.3.. The probit function for probability of major damage is expressed as:

When $0.5 \text{ ft/lb}^{1/3} \leq Q \leq 1.67 \text{ ft/lb}^{1/3}$ ($1.4 \text{ m/kg}^{1/3} \leq Q \leq 4.2 \text{ m/kg}^{1/3}$)
 $f_{e,major} = 12.876 - 4.3 * \ln(Q)$ English Units (2-80)
 $f_{e,major} = 8.9 - 4.3 * \ln(Q)$ SI Units

2.7.2.2. Reference 14 was written by Andreas Dorr of Germany. Within the Dorr equations, the term “QD” is used. Within this document, that term has been simplified to “Q.” Unfortunately, the QD term is not explicitly defined within Reference 14. However, QD has units (distance/mass^{1/3}) which are typically associated with a scaled distance term in the United

States. Note that the English Unit equations for Equations 2-78 through 2-80 are not shown within Reference 14 or BEC v6.3 and earlier. The English Unit equations were developed as part of the TP-17 revision 2 effort. These equations were curve fitted to result in the exact same unitless value of the probit function, f_e , for equivalent English Unit values of Q .

2.7.2.3. Within the BEC-O programming, the Q term is determined using Equation 2-81. Equation 2-81 takes the same form of the standard equations used for probability of window breakage (see Equation 2-55) and is based on curve fits performed by Swisdak.

$$Q = S(x) \quad \text{English or SI Units} \quad (2-81)$$

where,

Q = a scaled distance term as determined using Equations 2-81 and 2-82

P_{so} = Overpressure at Distance (sea level); (psi or kPa)

S = Standard Equation (Equation 2-22 with coefficients from Table 2-17)

x = Overpressure at Distance, P_{so} (sea level); (psi or kPa)

Table 2-17. Scaled Distance, Q , for Eardrum Rupture Approximations

Equation Number	Q = Function (P_{so})					
	A	B	C	D	E	F
2-81a*	3.8112	-0.7782	0.0186	0.0224	-0.0046	0.0002
2-81b	4.2258	-0.44829	-0.23285	0.067411	-0.007007	0.0002455

* Equation not in BEC v6.3 or earlier. Developed to correspond to SI unit equation.

2.7.2.4. Because the equations from Reference 14 are probit functions, they require further transformation before an actual probability can be computed. At this point it is important to note that in BEC V6.3 and earlier, the results of Equations 2-78 through 2-81 were used with the Gauss Error Function and Complementary Gauss Error Function to determine probability of eardrum rupture. This method was changed in more recent versions of BEC and the BEC-O to be more similar to the methods used in TP 14. Though the methods are slightly different, the results are identical.

2.7.2.5. The transformation from the probit function, f_e , to a probability is the same for all three conditions (minor injury, moderate injury, major injury). This transformation is accomplished by using the cumulative normal distribution and the “Z-factor” associated with the probit function. The probability of eardrum rupture is computed using a normal distribution where the probability is equal to the area under the standard normal distribution to the left of the z_{er} value. The z_{er} value can be used with built in Excel functions (e.g., NORMSDIST) or a unit normal distribution lookup table in order to translate this value to a probability that eardrum rupture will occur.

$$z_{er} = f_e - 5 \quad (2-82)$$

2.7.3. Probability of Lung Rupture

2.7.3.1. The probability of lethality due to lung damage is computed at sea level based on References 15 and TP 14. Like the eardrum rupture approximations, the lung rupture approximations assume a normal distribution of probability. The probability of lethality due to lung damage is computed using a normal distribution where the probability is equal to the area under the standard normal distribution to the left of the z_{lr} value.

2.7.3.2. The initial step is to determine the scaled pressure. Within the BEC-O, if either the overpressure or dynamic overpressure is out of range, the scaled pressure is set to an arbitrary value of 0.00001 (regardless of units).

$$\text{When } 0.5 \text{ ft/lb}^{1/3} \leq Z_{\text{eff.P,s}} \leq 150 \text{ ft/lb}^{1/3} \quad (0.2 \text{ m/kg}^{1/3} \leq Z_{\text{eff.P,s}} \leq 59.5 \text{ m/kg}^{1/3})$$

$$P_{\text{scaled}} = (P_{\text{so}} + q_o) * 0.01 \quad \text{English or SI Units} \quad (2-83)$$

Otherwise,

$$P_{\text{scaled}} = 0.00001 \quad \text{English or SI Units} \quad (2-84)$$

2.7.3.3. The scaled impulse is then determined using Equation 2-85.

$$I_{\text{scaled}} = i_s * 0.001 * 0.7673 \quad \text{English or SI Units} \quad (2-85)$$

where,

- P_{scaled} = scaled pressure (psi or kPa)
- I_{scaled} = scaled impulse (psi-ms or kPa-ms)
- P_{so} = incident overpressure (psi or kPa)
- q_o = dynamic overpressure (psi or kPa)
- i_s = incident impulse (psi-ms or kPa-ms)

2.7.3.4. The normal distribution terms for lung rupture are then determined using Equations 2-86 and 2-87.

$$s_{lr} = (0.609/P_{\text{scaled}}) + (0.189/I_{\text{scaled}}) \quad \text{English Units} \quad (2-86)$$

$$s_{lr} = (4.2/P_{\text{scaled}}) + (1.3/I_{\text{scaled}}) \quad \text{SI Units}$$

$$z_{lr} = -5.74 * \ln(s_{lr}) \quad \text{English or SI Units} \quad (2-87)$$

2.7.3.5. At this point it is again important to note that in BEC V6.3 and earlier, the results of Equations 2-83 through 2-87 were used with the Gauss Error Function and Complementary Gauss Error Function to determine probability of eardrum rupture. This method was changed in more recent versions of the BEC and the BEC-O to be more similar to the methods used in TP 14. Though the methods are slightly different, the results are identical. In versions of BEC newer than V6.3 and the BEC-O, the z_{lr} value is used with built in Excel functions (e.g., NORMSDIST) or a unit normal distribution lookup table in order to translate this value to a probability that lung rupture will occur.

2.8. SUMMARY TABLES. To the right of the main BEC-O output screen the user will note two separate summary tables. These tables show the variation of the computed airblast parameters with distance at sea level conditions and at the altitude and temperature conditions entered.

2.8.1. Summary Table User Inputs

Each summary table has an initial distance input value. This results in the following two additional inputs to the BEC-O interface:

- Initial Distance for Sea Level Summary Table
- Initial Distance for Altitude Summary Table

While these are termed “initial distance” values they are not actually the top row of the summary table. The distances represented by these user inputs are highlighted in yellow within the summary table on the main BEC-O output screen. Distances nearer than the user-input value will be shown in rows above the yellow row, and distances farther than the user-input value will be shown in rows below the yellow row.

2.8.1.1. Initial Distance for Sea Level Summary Table. The initial distance for the sea level summary table is input as a distance at sea level conditions including standard temperature and pressure.

2.8.1.2. Initial Distance for Altitude Summary Table. The initial distance for the altitude summary table is input as a distance at the user-entered altitude and temperature conditions specified in the main BEC-O input section.

2.8.2. Summary Table (Sea Level Conditions)

The summary table to the immediate right of the main BEC-O output is the Summary Table for Sea Level Conditions. Values shown in this table will match values in the main output if the user enters an altitude height of 0 (ft or m) at standard temperature and pressure conditions in the main BEC-O output.

The outputs may be calculated using the same methods described in Section 2.6. However, within the BEC-O programming a “What-If Analysis” data table is employed in order to reduce the number of programmed equations. (See Section 2.8.4 for a detailed explanation of the “What-If Analysis” data table.)

The following outputs are provided as columns of the summary table:

- Distance at Sea Level – The user-entered distance factored within each row.
- Scaled Distance – The corresponding scaled distance at sea level.
- Time of Arrival
- Incident Pressure

- Incident Impulse – Equivalent to the Positive Phase Impulse.
- Positive Duration
- Reflected Pressure
- Reflected Impulse
- Dynamic Pressure
- Dynamic Impulse

There is one additional output within the Summary Table for Sea Level conditions which is typically hidden from view of the user. This output is the Distance at Altitude and is contained within a hidden column between the Distance at Sea Level and Scaled Distance columns. The use of the “What-If Analysis” data table mandates the addition of this column. Values in the Distance at Altitude column are determined by multiplying the value from the Distance at Sea Level column by the S_d atmospheric scaling factor.

The “What-If Analysis” data table operates by substituting the value from the Distance at Altitude column of the summary table into the “Distance to ES” user-input in the main tool and documenting the results within the summary table outputs for sea level conditions. Remember that the user-input “Distance to ES” value is always assumed to be at the user-entered altitude and temperature conditions. Thus, in order to obtain information for sea level conditions, it is necessary to transform the sea level distance from the first column of the summary table into the equivalent distance at altitude. This conversion of distance to and from sea level is purely to facilitate use of the “What-If Analysis” tool. Stated differently, the BEC-O takes the sea level distance from the first column, transforms that to an equivalent distance at altitude, uses the equivalent distance as a new “Distance to ES” input, runs all of the BEC-O calculations, and reports the sea level airblast parameter output data within the summary table.

2.8.3. Summary Table (Altitude and Temperature Conditions)

The summary table to the right of Summary Table for Sea Level Conditions is the Summary Table for Altitude and Temperature Conditions. Values shown in this table will match values in the altitude column of the main BEC-O output.

The outputs may be calculated using the same methods described in Section 2.6. However, within the BEC-O programming a “What-If Analysis” data table is employed in order to reduce the number of programmed equations. (See Section 2.8.4 for a detailed explanation of the “What-If Analysis” data table.)

The following outputs are provided as columns of the summary table:

- Distance at Altitude – The user-entered distance factored within each row.
- Scaled Distance – The corresponding scaled distance at altitude and temperature conditions.
- Equivalent Distance at Sea Level – The distance at altitude converted to an equivalent distance at sea-level conditions.

- Time of Arrival
- Incident Pressure
- Incident Impulse – Equivalent to the Positive Phase Impulse.
- Positive Duration
- Reflected Pressure
- Reflected Impulse
- Dynamic Pressure
- Dynamic Impulse

Unlike in the Sea Level Summary Table, there is no need to transform the user-entered initial distance for the summary table. This is because the altitude table assumes that the user-entered initial distance is already at the altitude and temperature conditions specified in the main BEC-O user-input.

2.8.4. “What-If Analysis” Data Table Methodology

The “What-If Analysis” tool within Excel is used within the BEC-O programming to auto-generate the data for the rows of the summary tables. The “What-If Analysis” tools within Excel are used to simplify answers to questions like “What if the Distance to ES changes to a different value?” While this question could be answered by simply changing the BEC-O inputs and observing the differences, capturing and comparing the changes is a tedious and time-consuming task.

Within the BEC-O, the “What-If Analysis” data table operates by substituting the value from the Distance at Altitude column of the summary table into the “Distance to ES” user-input in the main tool and documenting the results within the summary table outputs. Stated differently, the BEC-O takes the Distance at Altitude value from the table, uses the value as a new “Distance to ES” input, runs all of the BEC-O calculations, and reports the airblast parameter output data within the summary table.

In order to fully illustrate the use of the “What-If Analysis” data table, consider the Summary Table at Altitude and Temperature conditions. To begin setting up the data table, the first row of the table is set up with formulas which simply reference the correct value from the BEC-O output. The values in this row are usually not shown within the BEC-O, but have been darkened in Figures 2-1a and 2-1b below for purposes of this illustration. Note that the formulas in these cells simply reference the output data shown within the main BEC-O output.

Next, the first column of data (Distance at Altitude) is set up with varying values which serve as alternate values in the Distance to ES field. These values are auto-populated as percentages of the user-entered Initial Distance for Summary Table values. Remember that the yellow row in the summary table on the main BEC-O output screen represents the user-entered initial distance value.

Note that Figure 2-1 is only a partial view of the summary table. However, the remaining programming within the summary table is similar and not exceptionally complex so a partial view is sufficient.

The final step will be establishing the data table. The formulas shown in Figure 2-1b which are equivalent to “=TABLE(I6)” cannot simply be typed into the remaining table cells. The “What-If Analysis” data table must be set up through the Excel *Data Tools* menu. The *Data Tools* menu is located on the *Data* ribbon of Excel. Within the *Data Tools* menu one of the icons is labeled *What-If Analysis*.

In order to set up the data table, begin by selecting all cells which the programmer wishes to be part of the data table. Keep in mind that this should include the column of data which the programmer wishes to vary and the upper-most row containing the references to the BEC-O output cells (see Figure 2-2).

Then select the *What-If Analysis* icon and click “Data_Table...” in the drop down menu that appears (see Figure 2-3). A pop-up window will appear to set the Data Table parameters (Figure 2-4). Since the objective is to vary the “Distance to ES” value with the data in the column, enter the cell reference for the “Distance to ES” field or “\$I\$6” in the Column Input cell field.

Select “OK” and the “What-If Analysis” Data Table feature will populate the fields within the summary table (Figure 2-5). The summary table will update dynamically should the user change inputs within the main BEC-O input section or the initial distance for summary table field.

Figure 2-1a. What if Analysis Data Table Set Up - Values

DISTANCE AT ALTITUDE (feet)	SCALED DISTANCE (ft/lb ^{1/3})	RANGE @ Sea Level (feet)	TIME OF ARRIVAL (ms)	INCIDENT PRESSURE (psi)	INCIDENT IMPULSE (psi-ms)
100.0	10.0	94.6	41.1	9.0	74.2
37.5	3.8	35.5	6.9	78.4	182.4
45.0	4.5	42.6	9.8	51.5	153.5
52.5	5.3	49.7	13.0	36.1	132.3
60.0	6.0	56.8	16.7	26.6	116.8
67.5	6.8	63.9	20.7	20.4	103.1
75.0	7.5	71.0	25.0	16.3	94.7
90.0	9.0	85.2	34.4	11.1	81.3
105.0	10.5	99.4	44.6	8.2	71.1
120.0	12.0	113.5	55.2	6.4	63.2
135.0	13.5	127.7	66.3	5.2	56.8

Figure 2-1b. What if Analysis Data Table Set Up - Formulas

DISTANCE AT ALTITUDE (feet)	SCALED DISTANCE (ft/lb ^{1/3})	RANGE @ Sea Level (feet)	TIME OF ARRIVAL (ms)	INCIDENT PRESSURE (psi)	INCIDENT IMPULSE (psi-ms)
=SFS\$34	=SFS\$36	=SES\$34	=SFS\$38	=SFS\$40	=SFS\$48
=0.5*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=0.6*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=0.7*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=0.8*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=0.9*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=1*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=1.2*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=1.4*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=1.6*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=1.8*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=2*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)
=2.25*\$BLS\$16	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)	=TABLE(I6)

Figure 2-2. Selection of Data Table Cells

Enter initial distance for Altitude Summary 1 (distance to be entered at altitude and temp c					
DISTANCE AT ALTITUDE (feet)	SCALED DISTANCE (ft/lb ^{1/3})	RANGE @ Sea Level (feet)	TIME OF ARRIVAL (ms)	INCIDENT PRESSURE (psi)	INCIDENT IMPULSE (psi-ms)
=F\$34	=F\$36	=E\$34	=F\$38	=F\$40	=F\$48
=0.5*\$BL\$16					
=0.6*\$BL\$16					
=0.7*\$BL\$16					
=0.8*\$BL\$16					
=0.9*\$BL\$16					
=1*\$BL\$16					
=1.2*\$BL\$16					
=1.4*\$BL\$16					
=1.6*\$BL\$16					
=1.8*\$BL\$16					
=2*\$BL\$16					
=2.25*\$BL\$16					

Figure 2-3. What-If Analysis Drop-Down Menu

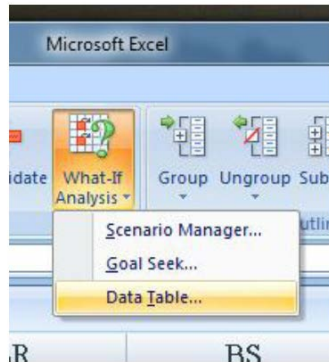


Figure 2-4. Data Table Pop-Up Menu

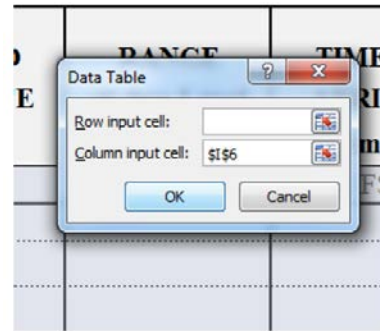


Figure 2-5. Completed Data Table

DISTANCE AT ALTITUDE (feet)	SCALED DISTANCE (ft/lb ^{1/3})	RANGE @ Sea Level (feet)	TIME OF ARRIVAL (ms)	INCIDENT PRESSURE (psi)	INCIDENT IMPULSE (psi-ms)
100.0	10.0	94.6	41.1	9.0	74.2
37.5	3.8	35.5	6.9	78.4	182.4
45.0	4.5	42.6	9.8	51.5	153.5
52.5	5.3	49.7	13.0	36.1	132.3
60.0	6.0	56.8	16.7	26.6	116.8
67.5	6.8	63.9	20.7	20.4	103.1
75.0	7.5	71.0	25.0	16.3	94.7
90.0	9.0	85.2	34.4	11.1	81.3
105.0	10.5	99.4	44.6	8.2	71.1
120.0	12.0	113.5	55.2	6.4	63.2
135.0	13.5	127.7	66.3	5.2	56.8

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CHAPTER 3: GETTING STARTED WITH BEC-O, VERSION 1

3.1. INTRODUCTION.

To use the program, either double click on the BEC-O V1 filename or launch EXCEL and then use the **OPEN** command located in the **FILE** menu.

The next screen to appear will be a “**Start**” screen, giving the version number, date, and contact information. At the bottom of this screen there are five EXCEL worksheet tabs:

- Start
- English Units
- English-to-Metric Conversion
- Metric Units
- Metric-to-English Conversion

These refer to the various worksheets that are available. At the start of a session, the user simply selects the appropriate units (*English Units* or *Metric Units*) and clicks on the corresponding tab. The two “**Conversion tabs**” work as follows. The “**English-to-Metric Conversion**” converts what is shown on the “**English Units**” worksheet into the corresponding Metric units. The “**Metric-to-English Conversion**” converts what is shown on the “**Metric Units**” worksheet into English units.

English Units were chosen for this demonstration; select this tab to follow this walkthrough. Figure 3-1 shows the **Input Section** of the screen that appears:

Figure 3-1. Input Section

INPUT SECTION			
Metric Units (kg, m, kPa, kPa-ms, ms, °C)			
Select Potential Explosion Site (PES)	Select NEW Basis (No. Items/ Total NEW)	Enter Distance To ES (m)	Select Atmospheric Scaling Basis
Open Storage/STANDARD	Total NEW (kg)	500.0	Altitude (meters)
Select Type of Munition	Enter		
Bulk/Light Cased: STANDARD	Total NEW (kg)	Enter Temperature (°C)	
	27,000.0	20.0	
Select Type of Explosive			Enter Altitude (m)
Tritonal			1,500.0
Warning Messages			

The toolbar across the top of the screen is the basic EXCEL toolbar with all of the EXCEL functions/commands available.

The following menus have their own drop-down selections:

- Select Potential Explosion Site (PES)
- Select Type of Munition
- Select Type of Explosive
- Select Number of Items or Total NEW
- Select Atmospheric Condition Basis

Menu 3 is used to select the type of explosive or the TNT equivalence. The default value is to base the TNT Equivalency value on the type of explosive contained within the selected munition. If the munition selected is a *Bulk/Light Cased: Standard* item, the TNT equivalency values default to 1.0. The user may select alternate explosive types from the drop-down menu or may choose “Other – User Defined” to manually input the TNT equivalencies for both pressure and impulse.

Menu 4 determines how the amount of explosives is entered—either as a weight in pounds (or kilograms) or as a number of weapons. If the latter is chosen, the default weight of each of the weapon types is used to calculate the appropriate total explosive weight.

Menu 5 determines how the atmospheric conditions are described—either in terms of an altitude and temperature or a barometric pressure and temperature.

Another feature of the BEC-O is the automatic generation of summary tables. These tables show the variation of the computed airblast parameters with distance at sea level conditions and at the altitude and temperature conditions entered. The user selects an initial distance and the table is automatically generated with values ranging from 0.5 to 60 times the user-entered value. The default distances used to generate the summary tables are chosen relative to the initial distance, R:

- 0.5*R, 0.6*R, 0.7*R, 0.8*R, 0.9*R
- 1.0*R, 1.2*R, 1.4*R, 1.6*R, 1.8*R
- 2.0*R, 2.25*R, 2.5*R, 2.75*R
- 3.0*R, 3.5*R, 4.0*R, 4.5*R, 5.0*R, 5.5*R, 6.0*R, 6.5*R, 7.0*R
- 8.0*R, 9.0*R, 10*R, 12*R, 14*R, 16*R, 18*R
- 20*R, 25*R, 30*R, 35*R, 40*R, 45*R, 50*R, 60*R

In addition, the first line of the summary tables will always be the airblast parameters for the “**Distance to ES**” that was selected.

3.2. INPUT SUMMARY.

The following steps should be followed to use the BEC-O:

- Launch the template—either by double clicking on the template icon or by starting EXCEL and using the *open* command (under the **File** menu).
- Select either English Units or Metric Units from the tabs at the bottom (Note: For ease of programming the terms NEW and net explosive quantity (NEQ) are used interchangeably.)
- Enter the required information in the **INPUT SECTION**.
 - Use the *Potential Explosion Site* menu to choose the PES.
 - Use the *Select Type of Munition* menu to choose the type of munition. Within BEC-O V1, the only munition available is *Bulk/Light Cased*.
 - Use the *Type of Explosive* menu to change the default explosive type (if necessary).
 - Choose either a **Total NEW** or **Number of Items** from the *Select NEW Basis* menu.
 - Enter either the **Total NEW** or the **Number of Munitions** as required.
 - Enter **Distance to ES**.
 - Use the *Select Atmospheric Description* menu to choose either altitude or barometric pressure (If altitude corrections are not required, this step may be omitted).
 - Enter either the **Altitude** or the **Barometric Pressure** as required (If altitude corrections are not required, this step may be omitted).
 - Enter **Temperature** (If altitude corrections are not required, this step may be omitted).
 - Enter **Initial Distance for Summary Table in both the Sea Level and Altitude Summary Tables** (User must scroll to the right to view Summary Tables and input this distance.).

3.3. INPUT EXAMPLE.

Twenty-seven Metric tons (27,000 kg) NEQ of Tritonal will be detonated inside a concrete AGS at a site where the altitude is 1,500 m and the temperature is 20°C. What are the expected airblast effects at a distance of 500 m from the event? Generate summary tables for the event with an initial distance of 50 m.

Launch the program and select *Metric Units*. Figure 3-2 illustrates the input section of the program after the inputs have been completed.

Figure 3-2. Input Example

INPUT SECTION

Metric Units (kg, m, kPa, kPa-ms, ms, °C)

<p>Select Potential Explosion Site (PES)</p> <p>Open Storage/STANDARD</p> <hr/> <p>Select Type of Munition</p> <p>Bulk/Light Cased: STANDARD</p> <hr/> <p>Select Type of Explosive</p> <p>Tritonal (TNT/Al=80/20)</p>	<p>Select NEW Basis (No. Items/ Total NEW)</p> <p>Total NEW (kg)</p> <hr/> <p style="text-align: center;">Enter</p> <p>Total NEW (kg)</p> <p style="text-align: center; color: red; font-weight: bold;">27,000.0</p>	<p>Enter Distance To ES (m)</p> <p style="text-align: center; color: red; font-weight: bold;">500.0</p> <hr/> <p>Enter Temperature (°C)</p> <p style="text-align: center; color: red; font-weight: bold;">20.0</p>	<p>Select Atmospheric Scaling Basis</p> <p>Altitude (meters)</p> <hr/> <p style="text-align: center;">Enter Altitude (m)</p> <p style="text-align: center; color: red; font-weight: bold;">1,500.0</p>
--	---	--	---

Warning Messages

3.4. BEC-O VERSION 1, OUTPUTS. The BEC-O Outputs are divided into four sub-sections:

- Explosive Parameters
- Atmosphere Parameters
- Airblast Parameters
- Other Information

3.4.1. Explosive Parameters and Atmosphere Parameters

In the above example, twenty-seven Metric tons (27,000 kg) of Tritonal filled will be detonated in open storage at a site where the altitude is 1,500 m and the temperature is 20°C. What are the expected airblast effects at a sea level distance of 500 m from the event? Figure 3-3 shows the first portion of the *Output Section*:

Figure 3-3. Output Section – Explosive and Atmosphere Parameters

EXPLOSIVE PARAMETERS		ATMOSPHERE PARAMETERS	
Total NEW (kg)	27,000.00	Pressure (kPa)	84.17
NEW per Munition (kg)	0.45	Temperature (°C)	20.00
Explosive Type Used	Tritonal (TNT/Al=80/20)	Pressure (S _p)	0.8307
TNT Equivalence--Pressure	1.07	Distance (S _d)	1.0638
TNT Equivalence--Impulse	0.96	Time (S _t)	1.0547
TNT Eq. NEW for Calcs -- Pressure (kg)	28,890.00	Impulse (S _i)	0.8761
TNT Eq. NEW for Calcs -- Impulse (kg)	25,920.00		
Eq. Hemispherical Weight (Pressure) (kg)	28,890.00		
Eq. Hemispherical Weight (Impulse) (kg)	25,920.00		

(Note: Weights and Yields are in kgs of TNT)

Within the *Explosive Parameters* Section:

- The first line is the total NEW/Quantity that has been entered: 27,000 kg.
- The second entry is the amount of explosive contained within a single weapon of the type selected: 0.45 kg is the equivalent of 1 lb of bare explosives.
- The third line is the final explosive type used for the analysis.
- The fourth line is the pressure TNT equivalence factor for the fill chosen: 1.07 for Tritonal.
- The fifth line is the impulse TNT equivalence factor for the fill chosen: 0.96 for Tritonal.
- The sixth entry is the TNT Equivalent NEW for Calculations involving Pressure; this is the Total NEW multiplied by the pressure TNT Equivalence Factor for munitions in the open; for munitions inside a PES, it is simply the Total NEW.
- The seventh entry is the TNT Equivalent NEW for Calculations involving Impulse; this is the Total NEW multiplied by the impulse TNT Equivalence Factor for munitions in the open; for munitions inside a PES, it is simply the Total NEW.
- The eighth entry is the Equivalent Hemispherical Weight (pressure). The value calculated and shown here will vary with the Distance that is selected. This value in combination with the Distance is used as the input for the pressure-related functions of the Hemispherical TNT Surface Burst Equations.
- The final entry is the Equivalent Hemispherical Weight (impulse). The value calculated and shown here will vary with the Distance that is selected. This value in combination with the Distance is used as the input for the impulse-related functions of the Hemispherical TNT Surface Burst Equations.

In the *Atmosphere Parameters* Section, the first two lines are the pressure and temperature for the event. If the atmospheric pressure option is chosen as part of the input, then that pressure is repeated here. The altitude option shows the computed atmospheric pressure for that altitude. The remaining four entries are the Scaling Factors needed to convert Sea Level conditions to those for the altitude/barometric pressure selected.

3.4.2. Airblast Parameters

Airblast parameters are presented for two conditions: Sea Level and at the altitude/barometric pressure specified. Figure 3-4 is a sample of Airblast Parameters portion of the *Output Section*:

The following airblast parameters are presented:

- Distance to Exposed Site
- Scaled Distance
- Time of Arrival
- Overpressure at Distance
- Reflected Pressure
- Positive Phase Duration
- Positive Phase Impulse
- Reflected Impulse
- Dynamic Overpressure
- Dynamic Overpressure Impulse

Figure 3-4. Output Section - Airblast Parameters

AIRBLAST PARAMETERS		
	SEA LEVEL	ALTITUDE (m) 1,500
Distance to Exposed Site (m)	470.0	500.0
Scaled Distance (m/kg ^{1/3})	15.7	16.7
Time of Arrival at Distance (ms)	1111.5	1,172.3
Incident Pressure at Distance (kPa)	8.531	7.1
Incident Pressure at Distance (dB)	172.6	171.0
Reflected Press. at Distance (kPa)	17.6	14.6
Positive Phase Duration at Distance (ms)	164.5	173.5
Positive Phase Impulse at Distance (kPa-ms)	588.4	515.5
Reflected Impulse at Distance (kPa-ms)	1080.0	946.2
Dynamic Overpressure at Distance (kPa)	0.2	0.2
Dynamic Impulse at Distance (kPa-ms)	14.4	12.6

3.4.3. Other Information

Other available information includes:

- Probability of Window Breakage (for selected window size/pane thickness/material),^{12, 13}
- Probability of Ear Drum Rupture,¹⁴ and
- Probability of Lethality Due to Lung Damage.¹⁴

Window breakage probabilities are estimated for six different combinations of glass; size/type/thickness using the GLASSC model developed by ACTA, Inc. (Note: The user has no choice/control on the window parameters).^{12,13} These are shown in Figure 3-5 – again for our example problem.

Figure 3-5. Output Section - Window Breakage

WINDOW BREAKAGE	
Probability of Window Breakage (percent) at Sea Level Distance	
Area = 0.19 m ² 30.5 cm x 61 cm x 0.224 cm Float annealed	88.4%
Area = 0.37 m ² 61 cm x 61 cm x 0.224 cm Float annealed	100.0%
Area = 0.98 m ² 107 cm x 160 cm x 0.3 cm Float annealed	100.0%
Area = 1.625 m ² 152.5 cm x 107 cm x 0.56 cm Plate annealed	100.0%
Area = 2.8 m ² 183 cm x 152.5 cm x 0.56 cm Plate annealed	100.0%
Area = 4.64 m ² 305 cm x 152.5 cm x 0.76 cm Plate annealed	100.0%

Three estimates, based on information contained in Reference 14, are given for the probability of eardrum rupture (Figure 3-6):

- Minor Damage
- Moderate Damage
- Major Damage

Figure 3-6. Output Section - Eardrum Rupture

EARDRUM RUPTURE	
Probability of Eardrum Rupture (percent) at Sea Level Distance	
Minor Damage	0.0%
Moderate Damage	0.0%
Major Damage	0.0%

The final estimate is the probability of lethality due to lung rupture (Note: Lung Rupture is the primary airblast lethality mechanism).¹⁵ This is shown in Figure 3-7 (for the example problem).

Figure 3-7. Output Section - Lung Rupture

LUNG RUPTURE	
Probability of lethality due to lung damage (percent) at Sea Level Distance	
0.0%	

Portions of the summary tables referred to at the bottom of the Airblast Parameters section are shown in Figure 3-8A and 3-8B.

Figure 3-8a. Output Summary Table - Sea Level

SUMMARY TABLE (SEA LEVEL CONDITIONS)

Explosion Site (ES)	<i>Open Storage/STANDARD</i>	
Type of Munition	<i>Bulk/Light Cased: STANDARD</i>	
Total NEW (kg)	<i>27,000.0</i>	
Explosive Type Used	<i>Tritonal</i>	
Explosive Type or Pressure Equivalence		<i>1.07</i>
Explosive Type or Impulse Equivalence		<i>0.96</i>

Enter initial distance for Sea Level Summary Table (m)
(distance to be entered at sea level conditions)

50

DISTANCE AT SEA LEVEL (m)	SCALED DISTANCE (m/kg ^{1/3})	TIME OF ARRIVAL (ms)	INCIDENT PRESSURE (kPa)	INCIDENT IMPULSE (kPa-ms)	POSITIVE DURATION (ms)	REFLECTED PRESSURE (kPa)	REFLECTED IMPULSE (kPa-ms)	DYNAMIC PRESSURE (kPa)	DYNAMIC IMPULSE (kPa-ms)
25.0	0.8	10.0	2054.6	6244.3	28.8	13730.2	32960.5	4134.1	8265.9
30.0	1.0	13.8	1419.3	6963.3	53.9	8621.1	25710.4	2430.8	5313.8
35.0	1.2	18.2	1020.5	6413.3	64.2	5653.0	20949.1	1494.7	3952.4
40.0	1.3	23.3	758.8	5773.0	65.4	3851.6	17608.2	956.6	3265.7
45.0	1.5	29.1	580.7	5185.9	63.4	2716.1	15147.3	634.4	2858.5
50.0	1.7	35.4	455.7	4687.1	61.4	1975.8	13266.0	434.3	2549.8
60.0	2.0	49.9	298.9	3932.7	60.7	1134.4	10591.3	220.8	1958.4
70.0	2.3	66.5	210.1	3410.3	65.1	710.3	8790.6	122.9	1371.4

Figure 3-8b. Output Summary Table - At Altitude and Temperature

SUMMARY TABLE (AT ALTITUDE AND TEMPERATURE CONDITIONS)

Explosion Site (ES)	<i>Open Storage/STANDARD</i>		
Type of Munition	<i>Bulk/Light Cased: STANDARD</i>		
Total NEW (kg)	<i>27,000.0</i>		
Explosive Type Used	<i>Tritonal</i>		
Explosive Type or Pressure Equivalence	<i>1.07</i>		
Explosive Type or Impulse Equivalence	<i>0.96</i>		
Altitude (m)	<i>1,500</i>	Pressure (kPa)	<i>84.17</i>
	Temperature (°F)	<i>68.00</i>	

Enter initial distance for Altitude Summary Table (m)
(distance to be entered at altitude and temp conditions)

50

DISTANCE AT ALTITUDE (m)	SCALED DISTANCE (m/kg ^{1/3})	EQ. DISTANCE AT SEA LEVEL (m)	TIME OF ARRIVAL (ms)	INCIDENT PRESSURE (kPa)	INCIDENT IMPULSE (kPa-ms)	POSITIVE DURATION (ms)	REFLECTED PRESSURE (kPa)	REFLECTED IMPULSE (kPa-ms)	DYNAMIC PRESSURE (kPa)	DYNAMIC IMPULSE (kPa-ms)
25.0	0.8	23.5	9.4	1924.3	5192.3	24.8	13238.2	31465.3	4065.2	8518.9
30.0	1.0	28.2	13.0	1340.2	6153.2	45.9	8421.9	24486.2	2431.2	5359.7
35.0	1.2	32.9	17.2	969.3	5843.9	64.5	5578.4	19914.0	1515.0	3860.1
40.0	1.3	37.6	21.9	723.8	5325.5	69.1	3828.7	16712.2	979.7	3104.1
45.0	1.5	42.3	27.3	555.4	4812.1	68.2	2713.2	14357.7	655.0	2678.8
50.0	1.7	47.0	33.2	436.5	4358.9	66.0	1979.2	12560.3	451.2	2391.1
60.0	2.0	56.4	46.8	286.4	3654.8	63.6	1137.2	10009.6	231.3	1905.7
70.0	2.3	65.8	62.5	200.9	3161.0	66.1	709.2	8295.8	129.3	1409.5

3.5. OTHER FEATURES

After selecting a PES, weapon type, and explosive type, the explosion effects are then dependent upon the inter-relationship of three sets of data: the NEW (or Number of Munitions), the selected distance, and the type of explosion effect (time of arrival, peak pressure, probability of fatality due to lung rupture, etc.). If two of these are known, then the third can be computed. When the NEW and distance are known, the BEC-O computes the effect. This is the procedure described above. However, it is sometimes useful to reverse the process (i.e., to enter the effect and either the distance or NEW/Number of Munitions and compute the other variable). This reverse process is referred to as “Back Calculation.”

When back calculating, either the distance or the NEW must be entered at the top of the spreadsheet. An arbitrary value for the other input variable must also be used—any number greater than zero. Make the appropriate selections from the other inputs: *Select Explosion Site*, *Select Type of Munition*, and *Select Type of Explosive*. When the other inputs are complete, select the *Goal Seek* Function under the Data Tab in the Ribbon using the *What-If Analysis* drop-down menu. When this option is selected, the following dialog box is displayed:

Enter the Cell Reference of the cell that Goal Seek will compute into the *Set Cell:* box. Enter the value the cell should equal (i.e., the measured or known value) in the *To Value:* box. Enter the Cell Reference of the Cell that Goal Seek will change into the *By Changing Cell:* box. The Cell Reference can be set by first placing the cursor in the appropriate *GOAL SEEK* dialog box and then left-clicking the mouse on the cell of choice in the BEC-O.

As an example of this process, consider the example problem. Suppose an analyst wishes to know at what distance a Positive Phase Impulse of 700 Pa-s would occur. Examining the *Output Section*, the Positive Phase Impulse is located in cell E48. The Distance is located in cell I6. The following *GOAL SEEK* dialog box defines the problem:

Once the appropriate information is entered, click **OK**. When the iteration process is completed, the following dialog box will appear:

Click **OK**. Figure 3-9 shows a portion of both the *Input* and *Output* Sections:

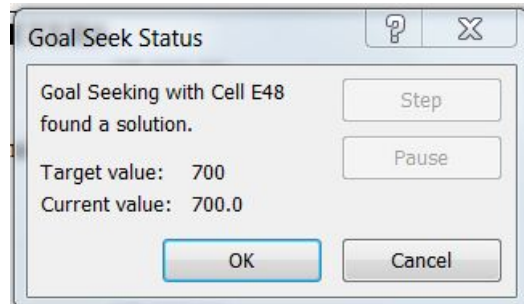
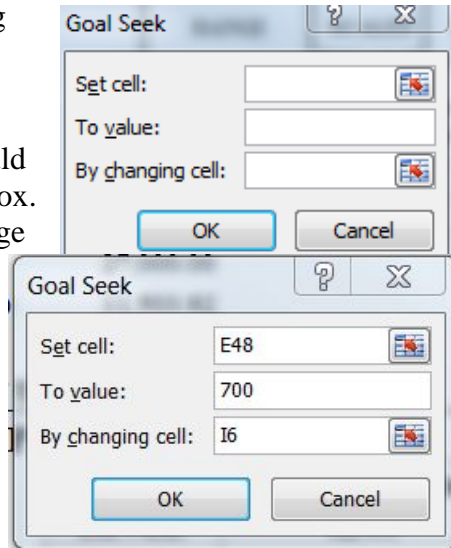


Figure 3-9. Goal Seek Example

INPUT SECTION

Metric Units (kg, m, kPa, kPa-ms, ms, °C)

Select Potential Explosion Site (PES) <input type="text" value="Open Storage/STANDARD"/>	Select NEW Basis (No. Items/ Total NEW) Total NEW (kg) <input type="text" value="27,000.0"/>	Enter Distance To ES (m) <input type="text" value="417.8"/>	Select Atmospheric Scaling Basis <input type="text" value="Altitude (meters)"/>
Select Type of Munition <input type="text" value="Bulk/Light Cased: STANDARD"/>	Enter Total NEW (kg) <input type="text" value="27,000.0"/>	Enter Temperature (°C) <input type="text" value="20.0"/>	Enter Altitude (m) <input type="text" value="1,500.0"/>
Select Type of Explosive <input type="text" value="Tritonal"/>	Warning Messages		

OUTPUT SECTION

EXPLOSIVE PARAMETERS		ATMOSPHERE PARAMETERS	
Total NEW (kg)	27,000.00	Pressure (kPa)	84.17
NEW per Munition (kg)	0.45	Temperature (°C)	20.00
Explosive Type Used	Tritonal	Pressure (S _p)	0.8307
TNT Equivalence--Pressure	1.07	Distance (S _d)	1.0638
TNT Equivalence--Impulse	0.96	Time (S _t)	1.0547
TNT Eq. NEW for Cals -- Pressure (kg)	28,890.00	Impulse (S _i)	0.8761
TNT Eq. NEW for Cals -- Impulse (kg)	25,920.00		
Eq. Hemispherical Weight (Pressure) (kg)	28,890.00		
Eq. Hemispherical Weight (Impulse) (kg)	25,920.00		

(Note: Weights and Yields are in kgs of TNT)

AIRBLAST PARAMETERS			WINDOW BREAKAGE	
	SEA LEVEL	ALTITUDE (m)	Probability of Window Breakage (percent) at Sea Level Distance	
	392.8	1,500		
Distance to Exposed Site (m)	392.8	417.8	Area = 0.19 m ²	
Scaled Distance (m/kg ^{1/3})	13.1	13.9	305 cmx61 cmx0.224 cm	100.0%
Time of Arrival at Distance (ms)	897.3	946.3	Float annealed	
Incident Pressure at Distance (kPa)	10.729	8.9	Area = 0.37 m ²	
Incident Pressure at Distance (dB)	174.6	173.0	61 cmx61 cmx0.224 cm	100.0%
Reflected Press. at Distance (kPa)	22.3	18.6	Float annealed	
Positive Phase Duration at Distance (ms)	155.5	164.0	Area = 0.98 m ²	
Positive Phase Impulse at Distance (kPa-ms)	700.0	613.3	107 cmx160 cmx0.3 cm	100.0%
Reflected Impulse at Distance (kPa-ms)	1303.5	1,142.0	Float annealed	
Dynamic Overpressure at Distance (kPa)	0.4	0.3	Area = 1.625 m ²	
Dynamic Impulse at Distance (kPa-ms)	21.4	18.7	1525 cmx107 cmx0.56 cm	100.0%
			Plate annealed	
			Area = 2.8 m ²	
			183 cmx152.5 cmx0.56 cm	100.0%
			Plate annealed	
			Area = 4.64 m ²	
			305 cmx152.5 cmx0.76 cm	100.0%
			Plate annealed	

EARDRUM RUPTURE	LUNG RUPTURE
Probability of Eardrum Rupture (percent) at Sea Level Distance	Probability of lethality due to lung damage (percent) at Sea Level Distance
Minor Damage	0.0%
Moderate Damage	0.0%
Major Damage	0.0%

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CHAPTER 4: BEC-O, VERSION 1, WARNING MESSAGES

Warning messages appear in an information box located in the right-center area of the Input Section. These warning messages are of two types:

- If the NEW that has been entered is greater than the limit that is set for each type of PES
(Out of Range (Total NEW must be less than _____))
- If the calculated Scaled Distance is outside the data range for the yield algorithms
(WARNING: Scaled Distance (too small/too large). $Z_{eff,p,s}$ and $Z_{eff,l,s}$ must be _____). When the scaled distance is in this regime, the yield algorithms use either the Low Z or High Z asymptotes.

All of these warning messages are informational (i.e., the BEC-O will produce answers even if a warning message is displayed).

The NEW limits for each PES type associated with a Type 1 warning are shown in 4-1.

Table 4-1. New Limits

PES	NEW Limit	
	(lbs)	(kg)
Open Storage/STANDARD	5,000,000	2,267,962
ECM or HPM--Front	500,000	226,792
ECM--Side or HPM--Side and Rear	500,000	226,792
ECM--Rear	500,000	226,792
TGHAS--Front	20,000	9,072
TGHAS--Side	20,000	9,072
TGHAS--Rear	20,000	9,072
AboveGround Structure (AGS)--masonry	200,000	226,792
AboveGround Structure (AGS)--concrete	200,000	226,792
ISO Container	5,000,000	2,267,962
Ship	5,000,000	2,267,962

The Scaled Distance limits for each PES and weapon type associated with a Type 2 warning are shown in Table4-2. These limits are based on the range of validity of the curve fits associated with the pressure and impulse yield functions for each item and PES type. The minimum Z_{eff} values presented in this table represent the greater of the minimum Z_{eff} values for pressure and impulse shown in Table 2-2. The maximum Z_{eff} values presented in Table 4-2 represent the lesser of the minimum Z_{eff} values for pressure and impulse shown in Table 2-2. This will result in a warning message being displayed at any time that the effective scaled distance value is outside the valid range of the test data.

Table 4-2. Scaled Distance Limits

PES/Weapon Type	Z _{eff} for Warning Flags			
	Min	Max	Min	Max
	(ft/lb ^{1/3})		(m/kg ^{1/3})	
ECM or HPM--Front	2.6	150	1.031	59.505
ECM--Side or HPM--Side and Rear	1	150	0.397	59.505
ECM--Rear	2	150	0.793	59.505
TGHAS--Front	2	80	0.793	31.736
TGHAS--Side	2	100	0.793	39.670
TGHAS--Rear	1	100	0.397	39.670
AboveGround Structure (AGS)--masonry	1.6	100	0.635	39.670
AboveGround Structure (AGS)--concrete	2.35	148	0.932	58.712
ISO Container	1.7	133	0.674	52.761
Ship	3.25	148	1.289	58.712

In addition to the informational messages just discussed, there are limits associated with the airblast algorithms themselves that come from the curve fits described in Reference 11. “**Out of Range**” may be displayed as the output for any of the output parameters when the scaled distance is outside the range shown in Table4-3. The limits associated with window breakage, eardrum rupture and lung rupture are the limits associated with the incident pressure function given in Reference 11.

Table 4-3. Scaled Distance Limits of Output Parameters

Output Parameter	Min	Max	Min	Max
	(ft/lb ^{1/3})		(m/kg ^{1/3})	
Time of Arrival	0.2	500	0.06	198.35
Incident Pressure	0.5	500	0.20	198.35
Reflected Pressure	0.3	500	0.12	198.35
Positive Phase Duration	0.5	500	0.20	198.35
Positive Phase Scaled Impulse	0.5	1000	0.20	396.70
Reflected Impulse	0.2	600	0.08	238.02
Dynamic Overpressure	0.5	150	0.20	59.50
Dynamic Impulse	0.5	150	0.20	59.50
Window Breakage	0.5	500	0.20	198.35
Eardrum Rupture	0.5	500	0.20	198.35
Lung Rupture	0.5	500	0.20	198.35

*(based on Incident Pressure Limits)

LIST OF ACRONYMS

AE	ammunition and explosives
AGS	aboveground structure
BEC	Blast Effects Computer
BEC-O	BEC-Open
°C	degrees Celsius
cm	centimeter
DDESB	Department of Defense Explosives Safety Board
DoDM	DoD manual
ECM	earth-covered magazine
ES	exposed site
°F	degrees Fahrenheit
ft	foot or feet
ft ²	square feet
H-6	high blast explosive
HBX	high blast explosive
HPM	high performance magazine
kg	kilograms
kPa	kilopascal
lbs	pounds
m	meter
m ²	square meter
NEQ	net explosive quantity
NEW	net explosive weight
PES	potential explosion site
PETN	pentaerythritol tetranitrate
psi	pounds per square inch

Q	scaled distance term
QD	quantity distance
SI	International System of Units
TGHAS	third generation hardened aircraft shelter
TNETB	trinitroethyl trinitrobutyrate
TNT	trinitrotoluene
TP	technical paper
UFC	Unified Facilities Criteria

REFERENCES

1. Fugelso, L. E., Weiner, L. M., and Schiffman, T. H., “Explosion Effects Computation Aids Final Report,” GARD Project No. 1540, June 1972.
2. Department of defense Explosives Safety Board Blast Effects Computer, Government Printing Office: 1978 0—266-197, (Circular Slide Rule).
3. Swisdak, Michael M., Montanaro, Paul E., and Ward, Jerry M., “The DDESB Blast Effects Computer—From Circular Slide Rule To EXCEL Template,” Minutes of PARARI '97—Australian Safety Seminar, November 1997.
4. Swisdak, Michael M. and Ward, Jerry M., “The New DDESB Blast Effects Computer,” Minutes of the 28th DoD Explosives Safety Seminar, August 1998.
5. Swisdak, Michael M. and Ward, Jerry M., “The DDESB Blast Effects Computer—Version 3.0,” Minutes of PARARI '99—Australian Safety Seminar, November 1999.
6. Swisdak, Michael M. and Ward, Jerry M., “The DDESB Blast Effects Computer—Version 4.0,” Minutes of the 29th DoD Explosives Safety Seminar, July 2000.
7. Swisdak, Michael M. and Ward, Jerry M., “DDESB Blast Effects Computer—Version 5.0,” Minutes of PARARI 2001—Australian Safety Seminar, November 2001.
8. Swisdak, Michael M., “DDESB Blast Effects Computer Users Manual And Documentation,” DDESB Technical Paper No. 17, 1 May 2003.
9. Crull, Michelle and Hamilton, Susan, “Methodologies For Calculating Primary Fragment Characteristics,” DDESB Technical Paper 16 Revision 4, 2 August 2012.
10. Swisdak, Michael M. “Characterization Of Event Yields With A Discussion of Possible Causes For The Observed Output or “*Where Has All The Output Gone?*” Minutes of PARARI 2003—Australian Safety Seminar, October 2003.
11. Swisdak, Michael M., “Simplified Kingery Airblast Calculations,” Minutes of the 26th DoD Explosives Safety Seminar, August 1994.
12. Wilde, Paul and Collins, Jon, “Computation of Explosion Induced Window Breakage And Associated Casualties,” Minutes of the 28th DoD Explosives Safety Seminar, August 1998.
13. Wilde, Paul, personal communication with Mike Swisdak, 13 October 1998.
14. Doerr, Andreas, Gürke, Gerhard, Ruebarsch, Dieter, “Consequence Models For Small Netto Explosives Quantities,” Minutes of the 31st DoD Explosives Safety Seminar, August 2004.
15. Eisenberg et al, “Vulnerability Model. A Simulation System For Assessing Damage Resulting From Marine Spills,” AD-A015-245, 1975.

16. Porzel, F. B., Technology Base Of The Navy Explosives Safety Improvement Program,” Minutes of the 19th DoD Explosives Safety Seminar, September 1980.
17. Granstrom, S.A, Loading Characteristics of Air Blasts From Detonating Charges, Transactions of the Royal Institute of Technology, Stockholm, Sweden, Nr.100, 1956.
18. Kingery, C. and Bulmash, G., “Airblast Parameters From TNT Spherical Air Burst and Hemispherical Surface Burst,” ARBRL TR 02555, April 1984.
19. Kennedy, et. al., New Features of PC Model ANFO and Comparisons With Experimental Data,” S-cubed sss-dtr-90-11305, 1990.
20. Kelly, S., “New Computational Aids Now Available From DNA,” Science and Technology Digest, Volume 1, November 1994.
21. Hyde, David W., Users Guide For Microcomputer Program CONWEP Application of TM 5-855-1. “Fundamentals OF Protective Design For Conventional Weapons”, Instruction Report SL-88-1, Revised June 17, 1992.
22. Glasstone, Samuel and Dolan, Philip J., The Effects of Nuclear Weapons, US Department of Defense and the Energy Research and Development Administration, 1977.
23. Swisdak, Michael M., “DDESB Blast Effects Computer Users Manual And Documentation,” DDESB Technical Paper No. 17, Revision 1, 10 March 2005.
24. Harris, Cyril M. and Crede, Charles E., Shock and Vibration Handbook, Volume 3, McGraw-Hill, New York, 1961.
25. Occupational Safety and Health (OSHA) Technical Manual - Noise, Section III, Appendix B, 15, August 2013, https://www.osha.gov/dts/osta/otm/new_noise/appendixb.pdf.

ADDITIONAL REFERENCES

- American Society of Civil Engineers ASCE/SEI Standard 59-11, “Blast Protection of Buildings,” 2011
- Department of Defense Explosives Safety Board Technical Paper 14, “Approved Methods and Algorithms for DoD Risk-Based Explosives Siting,” July 21, 2009
- Department of Defense Explosives Safety Board Technical Paper 17, “Blast Effects Computer (BEC), Version 7, User’s Manual and Documentation,” DATE
- DoD Manual 6055.09, “DoD Ammunition and Explosives Safety Standards,” February 29, 2008, as amended
- Napadensky, Hyla and Swatosh, James, “TNT Equivalency of Black Powder, Volume 1: Management Summary and Technical Discussion,” IITRI Report J6265-3, IIT Research Institute under the technical direction of Manufacturing Technology Directorate

Unified Facilities Criteria 3-340-02, “Structures to Resist the Effects of Accidental Explosions,”
December 05, 2008, as amended