

A COMPARISON OF TWO PERSONNEL INJURY
CRITERIA BASED ON FRAGMENTATION

by

Frank McCleskey
Kilkeary, Scott and Associates
and
D. N. Neades
Ballistic Research Laboratories, Aberdeen Md.
and
R. R. Rudolph
Ketron, Inc.

FOR INFORMATION CONTACT:

Frank McCleskey
Rt. 3 Box 105
King George, VA 22485
703-775-7210
24th DOD Explosives Safety Seminar
28-30 August 1990

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE AUG 1990		2. REPORT TYPE		3. DATES COVERED 00-00-1990 to 00-00-1990	
4. TITLE AND SUBTITLE A Comparison of Two Personnel Injury Criteria Based on Fragmentation				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Kilkeary, Scott and Associates,2301 S. Jefferson Davis Hwy Suite 1328,Arlington,VA,22202				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADA235006, Volume 2. Minutes of the Explosives Safety Seminar (24th) Held in St. Louis, MO on 28-30 August 1990.					
14. ABSTRACT see report					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 20	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

ABSTRACT

This paper includes a comparison of two Personnel Injury Criteria based on fragmentation. The first is the 58 ft-lb rule (Kinetic Energy Criterion) which has been in vogue since about 1900. The second is a new criterion, based on Kinetic Energy Density, which has been established by BRL over the last three decades. Both criteria are compared using four weapons for which suitable fragmentation data are available. The comparison is inconclusive as far as recommending one or the other criterion for use with the DDESB FRAGHAZ Computer Program. The paper contains recommendations to assist in making a choice between the two injury criteria.

The first 11 pages of this paper represent the presentation made by David Neades, Ballistic Research Laboratories, at the Explosives Safety Seminar held in Atlanta, Georgia in August 1988. It serves as background to pages 12-17 which comprise the paper for presentation by Frank McCleskey at the Explosives Safety Seminar held in St. Louis, Missouri in August 1990.

An Examination of Injury Criteria for Potential Application to Explosive Safety Studies

D. N. Neades

**U.S. Army Ballistic Research Laboratory
Aberdeen Proving Ground, Maryland 21005**

R. R. Rudolph

**Ketron, Inc.
Towson, Maryland 21204**

1. Preface

The work described in this paper was sponsored and funded by the Department of Defense Explosive Safety Board (DDESB) in March 1983 under Project 4A665805M857.

2. Introduction

Present Department of Defense Explosive Safety Board (DDESB) doctrine establishes the acceptable fragmentation hazards to personnel exposed to accidental explosions. Presently, the acceptable limit is exposure to not more than 1/600 square feet of hazardous fragments. Current DDESB policy is to define a "hazardous fragment" as one which has at least 58 foot-pounds of kinetic energy. Clearly, the use of this, or any other injury criterion will effect the calculated distances required to limit personnel to the acceptable exposure limit.

Use of the 58 ft-lb criterion to define fragmentation hazards has been criticized in recent years because, 1) it is not based on any well defined injury classification scheme, 2) it is overly simplistic in nature, and 3) a general feeling that there must be something better available in light of all the research into wounding phenomena and effects that has taken place over the last several decades.

The objectives of this investigation were to review the literature on kinetic energy wounding, assess the state-of-the-art, determine the applicability of existing data and models to explosive safety studies, and if appropriate, recommend new criteria. In addition, since the far-field hazards relate mainly to large (ranging from a few grams to several kilograms), relatively slow moving fragments with speeds approaching their free-fall velocity, the range of variables over which the various criteria are valid was to be determined and methods for extrapolating to the mass range of interest considered. The discussion

- 2 presented here will focus on the major findings of the investigation with respect to the availability of a suitable 58 ft-lb law replacement candidate. Additional details concerning other important research not covered in this paper, along with the bibliography which resulted from the current study, can be found in a soon to be published BRL report.

3. Literature Search

The survey of the literature was conducted by a contractor, Ketron, Inc. Several hundred technical reports and journal articles were compiled, reviewed, and analyzed with the above mentioned objectives in mind. A majority of the documentation was located by querying the DTIC (Defense Technical Information Center), NTIS (National Technical Information Service), TRIS (Transportation Research Information Service), BIOSIS (Biological Research Abstracts), and MEDLINE (Medical Literature Analysis and Retrieval Systems) automated data bases. In addition, a significant amount of relevant information was obtained through numerous informal discussions with various researchers in ballistics and related fields. A comprehensive bibliography containing 304 citations was compiled from the reviewed literature.

4. Penetrating Trauma

In the search for relevant literature, a natural division seemed to occur between penetrating injury and non-penetrating injury data. Accordingly, the documents reviewed were categorized as relating to either one or the other. The overwhelming majority of data and models located pertain to research into penetrating injury phenomena. The following discussion will focus on only a few of the criteria which were established as a result of this research.

4.1. 58 Ft-Lb Criterion

The literature abounds with references to the 58 ft-lb energy criterion. Rohne is usually given credit for establishing this criterion which was probably intended as nothing more than a rough rule of thumb. The date usually attributed to its origin is 1906. The actual quote, translated from the 1906 article by Rohne is "To remove a human from the battlefield, a kinetic energy of 8 mkg is sufficient according to the prevailing view in the German artillery community;....". Actually, an earlier article by Rohne, written in 1896 under the same title, contains the same statement; in neither case does he cite any data, experimental or otherwise, to substantiate this view. Interestingly, in a subsequent paragraph, he states that "Horses require a larger impetus to incapacitate them. Colonel Langlois set forth a kinetic energy of 19 mkg in his report 'L'artillerie de campagne en liason avec les autres armes',... Again, it is unfortunate that the basis for these statements is not explained. Rohne, while not discussing the validity of the 58 ft-lb criterion, used it to determine ranges at which various military rifles ceased to be effective.

¹ Rohne, H.; Schiesslehre fur Infanterie, 1906.

3

While the exact origin and basis for the 58 ft-lb figure remains obscured, other researchers have considered its validity as a criterion with varying results. Sterne², for example, in 1955, suggested that Rohne's criterion applied to lethality rather than to a sublethal effect. Indeed, penetrating injury research shows that lethal injuries can occur at impact kinetic energy levels significantly less than 58 ft-lbs. Without giving additional consideration to other parameters such as missile shape, size, mass, and possibly impact location, energy based hazard assessments can be misleading.

4.2. Incapacitation Criteria

In the years since Rohne, numerous researchers have investigated projectile induced kinetic energy wounding usually in hopes of relating, in some fashion, some form of ballistic dose to the projectile's casualty producing potential. The U.S. Army's incapacitation criteria, which resulted from extensive research conducted over the last three decades, were established to predict the incapacitating effects of wounding by fragmenting munitions, bullets, and flechettes. Certain of these criteria have, on occasion, been applied to hazard type analyses, but in general they are used as effectiveness criteria in the context of weapon system analyses. Briefly, the approach taken to establish these criteria was as follows.

An initial set of four steel fragment simulators was chosen to represent the class of munition fragments of interest. The projectile masses and the velocities at which they were assessed are shown in the following table.

Table 4-1. Incapacitation Projectile Data Base

Projectile	Mass	Experimental Striking Velocities
0.85 gr, steel sphere	0.055 gram	305, 914, 1524 meters/second
2.1 gr, steel cube	0.136 gram	305, 914, 1524 meters/second
16.0 gr, steel cube	1.04 gram	305, 914, 1524 meters/second
225 gr, steel cube	14.58 gram	152, 305, 762 meters/second

Basically, for each of these mass-velocity combinations, firings were conducted against biological targets to generate actual wound data. The nature of the observed wounds was delineated by assigning to it a

² Sterne, T. E., and A. J. Dziemian; "Provisional Probabilities of Incapacitation by a Caliber 0.30 Rifle-Bullet, Ball M-2," BRLM 949, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Dec 1955.

- 4 wound class which related incapacitation to loss of arm and leg function.

The most widely applied criteria of this type are the curves published by Kokinakis and Sperrazza in 1965³. The correlation relates striking mass and velocity of an impacting steel fragment to the conditional expected level of incapacitation given a single random hit. The functional form of the relationship is:

$$P(I/H) = 1 - e^{-a(mv)^A - b}$$

where e = base of natural logarithm
 m = fragment mass (grains)
 v = fragment striking velocity (ft/sec)
 A, a, b, n = fitted constants which depend on tactical role, time after wounding, and body part hit.

Since these criteria are based upon the physical requirements and tactical functions related to infantry soldiers in the assault, defense, reserve, and supply roles, it would be inappropriate to apply them to situations involving threshold injury levels to non-military personnel.

4.3. Other Penetrating Trauma Models

In 1967, Kokinakis and Sperrazza⁴ published data on the ballistic limits of skin and clothing, based on experimental firings of steel projectiles. Until recently, this skin penetration criterion was used by the U.S. Army as the "official" safety criterion for assessing threshold fragmentation hazards. However, in 1978 Lewis⁵, et al developed an empirical formula for estimating the probability of skin penetration by various projectiles, including low density fragments. Of interest to

³ Kokinakis, W. and Sperrazza; "Criteria for Incapacitating Soldiers with Fragments and Flechettes," BRL Report 1269, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1965, (CONFIDENTIAL).

⁴ Sperrazza, J. and W. Kokinakis, "Ballistic Limits of Tissue and Clothing," BRL TN 1645, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1967.

⁵ Lewis, J. H., P. A. Coon, V. R. Clare, L. M. Sturdivan; "An Empirical/Mathematical Model to Estimate the Probability of Skin Penetration by Various Projectiles," ARCSL-TR-78004, U.S. Army Armament Research & Development Command, Chemical Systems Laboratory, Aberdeen Proving Ground, MD, 1978.

- 5 them was the environmental debris such as rocket motor fragments and other secondary projectiles that pose a hazard to personnel. Backblast debris from small rocket-motor launched weapons could include wood fragments from vegetation and structures, metal fragments from the weapon, rocklike fragments from stone or concrete structures and stones from the ground. Accordingly, they included in their investigation three sizes of wood cylinders having diameters and lengths equal to 0.5 inch (1.27 cm), 1.0 inch (2.54 cm), and 1.5 inch (3.81 cm) and irregular gravel weighing approximately 2 grams. Other missiles were 4 grain (0.259 gram), 16 grain (1.035 gram), and 64 grain (4.14 gram) steel cubes, a 0.85 grain (0.055 gram) steel sphere and a 16 grain (1.035 gram) tungsten cube. These projectiles were fired at sections of goat skin backed with 20 percent gelatin at 10 degrees C. Striking velocity was treated as a test variable.

One objective of the study was to determine the probability of complete skin perforation (full-thickness skin laceration) since the authors had equated this occurrence to a hazardous condition- the assumption being that given a complete penetration of the skin layer, the potential for deeper penetration into various parts of the body also exists. Since a fragment perforates or fails to perforate the skin, the Walker - Duncan Method⁶ could be used to estimate the probability in terms of a single variable X defined by some function of the test variables. In this instance, the authors selected for their model

$$X = \ln [(MV^2)/A]$$

where m = mass of the projectile (grams)
 v = velocity of the projectile (meters/sec)
 A = presented area of the projectile (sq cm).

The Walker-Duncan estimation is then given by

$$P = \frac{1}{1 + \exp [-(a + bx)]}$$

where: a and b are curve fitting constants
 and x is as defined above.

Employing curve fitting techniques, the authors determined a and b values for the targets shown in Table 4-2.

⁶ Walker, S. H. and D. B. Duncan; "Estimation of the Probability of an Event as a Function of Several Independent Variables", Biometrika 54:167-179, (1967).

Table 4-2 Logistic Function Coefficients

Target	a	b
Bare Skin	-28.42	2.94
Two-Layer Uniform	-48.47	4.62
Six-Layer Uniform	-50.63	4.51

Probability curves for skin penetration as a function of $\ln [(MV^2)/A]$ are shown in Figure 4.1.

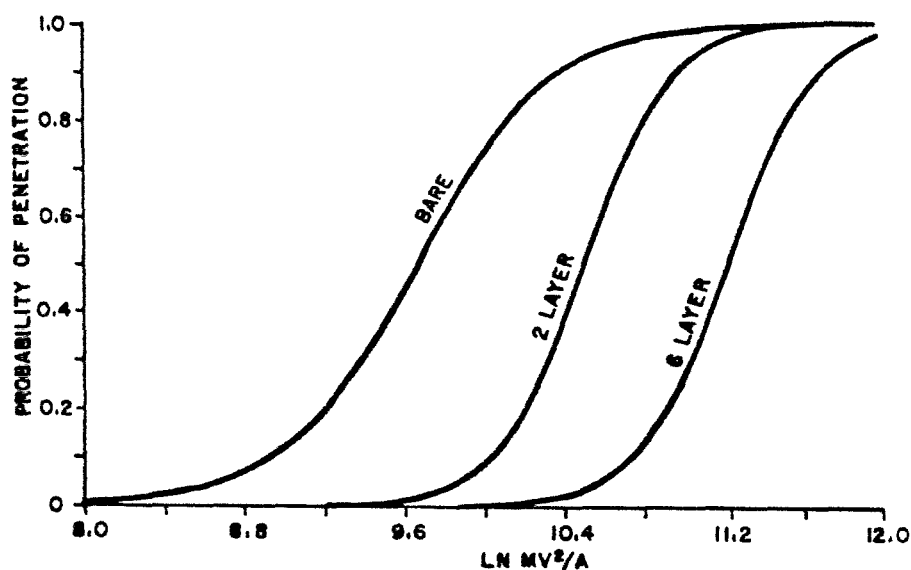


Figure 4.1 Walker-Duncan Curves Estimating the Probability of Skin Penetration as a Function of Projectile Parameters. (Reproduced from Reference 5).

5. Non-Penetrating Trauma

Although penetration is the primary damage mechanism of interest here, it was felt that the potential for injury from non-penetrating missiles exists as well. Non-penetrating injury, or blunt trauma, generally refers to any injury caused by a victim either striking or being struck by a non-piercing object. Objects causing projectile induced blunt trauma are characterized by their low velocity, lack of cutting and piercing features and size.

Most of the research pertaining to projectile-induced blunt trauma has occurred since the passage of The Omnibus Crime Control and Safe

7 Streets Act of 1968. Much of the research was sponsored by The National Institute of Law Enforcement and Criminal Justice and performed by multi-disciplined teams of researchers from the U.S. Army's Biophysics Laboratory located at Edgewood Arsenal (EA), Maryland and Land Warfare Laboratory (LWL) at Aberdeen Proving Ground Maryland, and various contractors.

The LWL team of Shank, Thein, Campbell and Wargovich conducted valuable research⁷ into the physiological response to the effects of non-lethal weapons⁷. An interesting part of their work involved the classification system they established for measuring these responses.

With regards to the availability of injury criteria for non-penetrating missiles the four-parameter model of Clare, et al⁸, apparently represents the "state of the art" in blunt trauma modeling. Given knowledge of the input parameters, (projectile mass, velocity and diameter and target (body) mass) the model predicts the probability of lethality as a result of impact to the thorax. Their model is of the form:

$$P(r) = f(mv^2)/wD$$

where

P(r) = probability of response (death, serious injury, etc)

m = mass of projectile in grams.

v = impact velocity of the projectile in meters/second.

w = body mass of the animal in kilograms.

D = diameter of the projectile in centimeters.

The same model, with appropriate adjustment of the discriminant line intercept, was extended by the authors to fracture/no-fracture data for the liver.

⁷ Shank, E. B., B. K. Thein, D. Campbell and M. J. Wargovich; "A Comparison of Various Less Lethal Weapons," LWL TR-74-79, U.S. Army Land Warfare Laboratory, Aberdeen Proving Ground, MD, June 1974.

⁸ Clare, V. R., J. H. Lewis, A. P. Michiewicz and L. M. Sturdivan; "Handbook of Human Vulnerability Criteria Chapter 9. Projectile-Induced Blunt Trauma," EB-SP-76011-9, Department of the Army, Headquarters, Edgewood Arsenal, Aberdeen Proving Ground, MD, May 1976.

- 8 As shown in Figures 5.1 and 5.2, the model discriminates between low, medium, and high regions of response/no response. The authors emphasize that they consider the model to be provisional, pending availability of additional data for further validation.

6. Applicability to Explosive Safety

The relevancy of models described in the previous sections can be summarized from an examination of Figure 6.1. To facilitate comparisons of the various relationships, the masses and velocities corresponding to each model's predicted measure were determined. For example, for line B, the masses and velocities are those which correspond to a 50% probability of skin penetration (for steel cubes) according to the model of Lewis.

The presently employed 58 ft-lb law (line A) is shown in comparison with two pairs of penetrating injury relationships. The upper pair, represented by lines B and C, are based on the skin penetration model of Lewis et al. The test mass upper bound was 4.08 grams. Line B is for steel cubes; line C was derived assuming a spherical shape factor. The second pair of lines, represented by lines D and E describe the penetration law of Sperrazza and Kokinakis. The test mass upper bound was 15 grams. Line D is based on steel cubes; line E was derived assuming a spherical shape factor. In addition, the calculated DDESB mass interval of interest⁺ is shown in the shaded area.

The two lines labeled "G" represent the relationship of Clare, et al for threshold liver fracture. The bottom solid G-line most directly reflects the test data for which the average animal weight, w , was about, 11.3 kg. The upper dashed G-line is an extrapolation to a man's body weight of 70 kg. Both lines are for low density (average 1.31 g/cm³) projectiles and the mass test data interval was from 3 grams to 381 grams. Also shown is the LWL blunt trauma relationship for the first damage level (line F).⁺⁺ The LWL relationship was not discussed here since it is not directly applicable to humans. It is included because it corresponds to a low level of injury (LWL damage level 1) and is therefore of interest from an injury threshold perspective. Unfortunately, the model is not appropriate for human body weights. With the EA model, weight of the target is an input parameter.

⁺ The interval depicted represents a crude estimate of the relevant mass range based on 155 mm projectile data published by Feinstein, D. I., in "Fragmentation Hazards to Unprotected Personnel," IITRI J6176, Engineering Mechanics Division, IIT Research Institute, Chicago, IL for the Department of Defense Explosive Safety Board (DDESB), Washington, DC, January 1972.

⁺⁺ The LWL team of Shank et al used a six valued damage level grading system to describe the effects of blunt trauma wounds. Damage level 1, corresponds in general to superficial or slight damage. See reference 7 bottom of page 7.

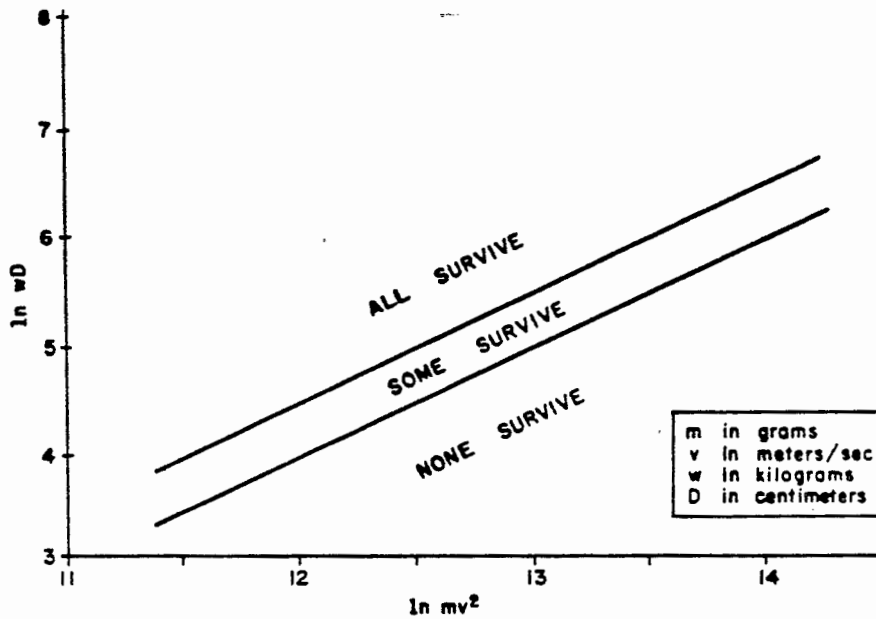


Figure 5.1 Lethal/Non-Lethal Discriminant Lines, Based on EA Four-Parameter Model Applied to Animal Blunt Trauma Data.

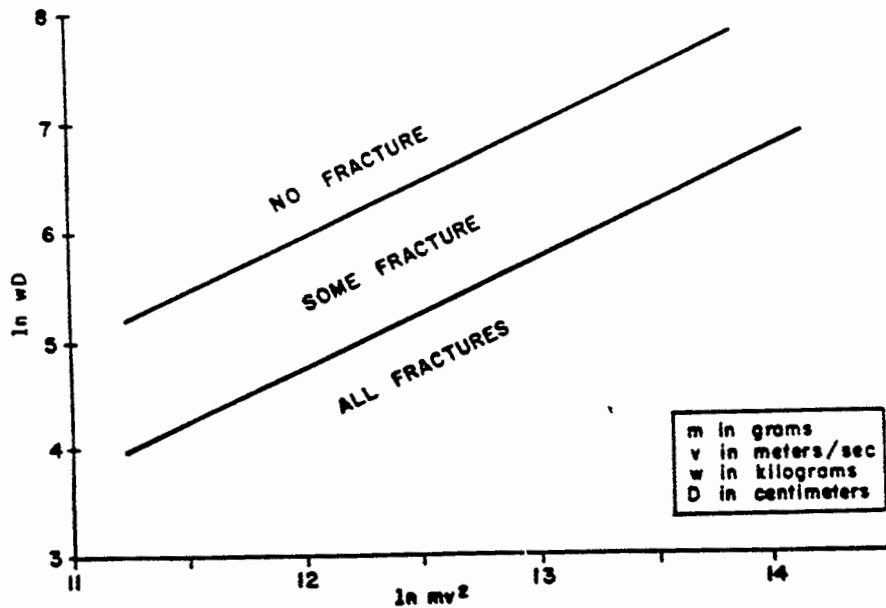


Figure 5.2 Liver Fracture/No Fracture Discriminant Lines, Based on EA Four-Parameter Model Applied to Blunt Trauma Data.

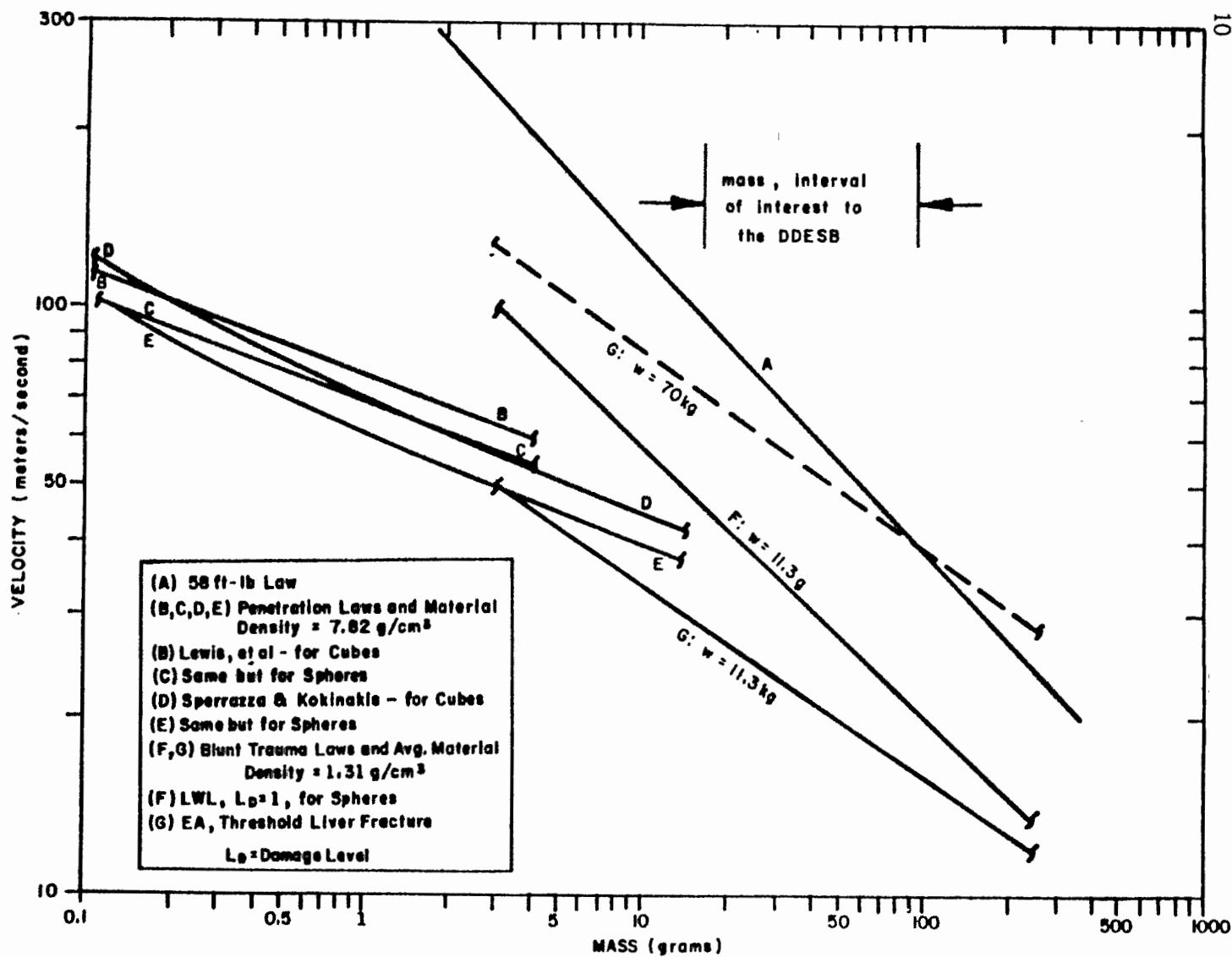


Figure 6.1 Laws, Mass Bounds on Data and DDESB Mass Interval of Interest.

11 7. Summary and Conclusions

In the attempt to locate criteria which represent an improvement over the currently used 58 ft-lb law, it became obvious that an accurate assessment of the hazards for typical far-field fragments by application of the various criteria located was not possible due to two noted shortcomings, namely:

- 1.) the lack of non-penetrating injury data for projectiles with densities greater than about 1.31 gm/cm^3 ,
- 2.) the lack of penetrating injury data for projectiles with mass greater than about 15 grams.

The above deficiencies are a result of wounding/injury research being concentrated on the effects of small, high velocity, steel projectiles. Where investigations were conducted into non-penetrating trauma, the projectiles of interest were, by design, of low density materials. The assessments and comparisons made in the analysis then are, in some cases, based on severe extrapolations of the existing data bases. For example, in comparing Lewis's skin penetration model with the 58 ft-lb rule, it was necessary to assume the model was valid for fragment masses an order of magnitude larger than those upon which the model is based. Accordingly, there is a critical need to verify the skin penetration curves in the mass ranges of interest, and the blunt trauma relationship for high density materials. Given these model validations/modifications, it is felt that a viable solution to the problem of determining far-field fragment hazards to personnel could involve simultaneous application of the two models mentioned above to quantify the potential for both penetrating and non-penetrating injury. A hazardous condition would be indicated if either criterion was met.

A methodological change of this nature would of course require a concomitant change in philosophy as to just what constitutes an unacceptable hazard to personnel. The economic, social, and political implications of adopting the skin penetration model as a replacement for the 58 ft-lb rule have not been considered in this investigation. In conclusion, we find numerous arguments against the continued use of the 58 ft-lb criterion, the strongest of which concerns its inability to predict a well defined injury level on the basis of mass and velocity alone, and suggest that after further investigation, more meaningful criteria can be formulated by validating other scientifically based models by extending and/or modifying those models through additional experimentation and analysis.

8. Injury Criteria Comparisons

8.1 Background

Previous portions of this paper have discussed the 58 ft-lb personnel injury criterion and a number of other alternate criteria. These data were presented to the explosive safety community in the August, 1988 seminar held in Atlanta, Georgia.

The 58 ft-lb criterion is currently used by the Department of Defense Explosives Safety Board (DDESB) in the FRAGHAZ⁹ computer program to evaluate fragment hazards from stored munitions. Since 1988, the Ballistic Research Laboratories (BRL) have established and recommended the skin penetration model attributed to Lewis et. al. as a replacement for the 58 ft-lb criterion.

Since 1988, FRAGHAZ runs have been made using the two criterion with four weapons - MK 82 Bombs, 155mm Projectiles, MK 64 Projectiles and 105mm Projectiles. Fragmentation data for these four weapons are the only sets currently available for use with the FRAGHAZ computer program. This work was done to provide a quantitative estimate of the difference in results for the two personnel injury criteria. The two injury criteria are defined as follows:

8.1.1 58 Ft-Lb Kinetic Energy Criterion

$$KE = \frac{mv^2}{2g}$$

where

KE = Kinetic Energy (ft-lbs)

M = Mass of fragment (lbs)

V = Striking Velocity (ft/sec)

g = Acceleration due to gravity (32.174 ft/sec²)

In this criterion, a fragment is considered hazardous if it has at least 58 ft-lbs of kinetic energy when it strikes the target person. If the fragment has less than 58 ft-lbs of kinetic energy when striking the person, it is considered non-hazardous. This, then, is a threshold criterion, with no transition zone, having a probability of injury of either 0 or 1. As explained in the first part of this paper, the 58 ft-lb rule was developed around 1900 and does not specify the severity of the injury inflicted except to state something like.... "remove a soldier from the battlefield".

⁹McCleskey, Frank "Quantity - Distance Fragment Hazard Computer Program (FRAGHAZ)" NSWC TR 87-59, Naval Surface Warfare Center, Dahlgren, Virginia, Feb 1988

8.1.2 Continuous Probability of Injury Criterion (CPIC)

This is the criterion proposed by BRL as a replacement for the 58 ft-lb rule. It is based on the work of Lewis et. al. and involves bare skin penetration as the injury criterion. It is stated as a probability of injury as follows:

$$P_I = \frac{1}{1 + \text{EXP}(-(A + B \ln \frac{MV^2}{C}))}$$

where:

- P_I = Probability of Injury (skin penetration)
- EXP = Exponential (base e)
- A = Constant = -27.35
- B = Constant = 2.81
- ln = Natural Log (base e)
- M = Striking fragment mass (grams)
- V = Striking fragment velocity (meters/sec)
- C = Average fragment presented Area (cm²)

Note that the constants A and B are slightly different than those given previously. This resulted from the tests with 100 gram fragments which were completed since the 1988 paper. Since fragments always have a finite velocity at strike, the probabilities of injury are always greater than 0. Likewise at the other end of the scale, the probabilities of injury are always less than 1. This is truly a transitional criterion providing injury probabilities between 0 and 1. Also note that this criterion involves the average striking area (C) which is certainly a consideration for skin penetration. The 58 ft-lb rule ignores this variable.

8.2 Comparisons

Comparisons for the two personnel injury criteria are shown in Figures 8.1 and 8.2. Figure 8.3 shows the mass and impact velocity combinations for the two injury criteria.

Figure 8.1 shows comparisons for the three mass detonating munitions currently available for the FRAGHAZ computer program. Mass detonating implies near simultaneous detonation of a stack from 1 or more detonating donor munitions.

Figure 8.2 shows two comparisons for the non-mass detonating 105mm projectiles. Plot A is for 0-200 projectiles and Plot B is for 0-8000 projectiles. The two plots are required because of the number of projectile differences for the two injury criteria. Non-mass detonating implies sequential detonating that results when the stack is engulfed by fire. Detonations may be seconds, minutes, or even hours apart.

For both plots, sea level and no wind conditions apply. Hazard density in both cases is one hazardous fragment per 600 square feet (1/600 = .001667). The plots then show the number of munitions required to produce the hazard density (1/600) at the hazardous ranges indicated. Only hazardous fragments meeting the requirements shown in Figure 8.3 are included. The number of munitions apply to the 90th percentile currently specified by the DDESB. The 90th percentile implies that 10 percent of the time, hazard ranges will be greater than those shown.

Figure 8.1 - Injury Criteria Comparisons

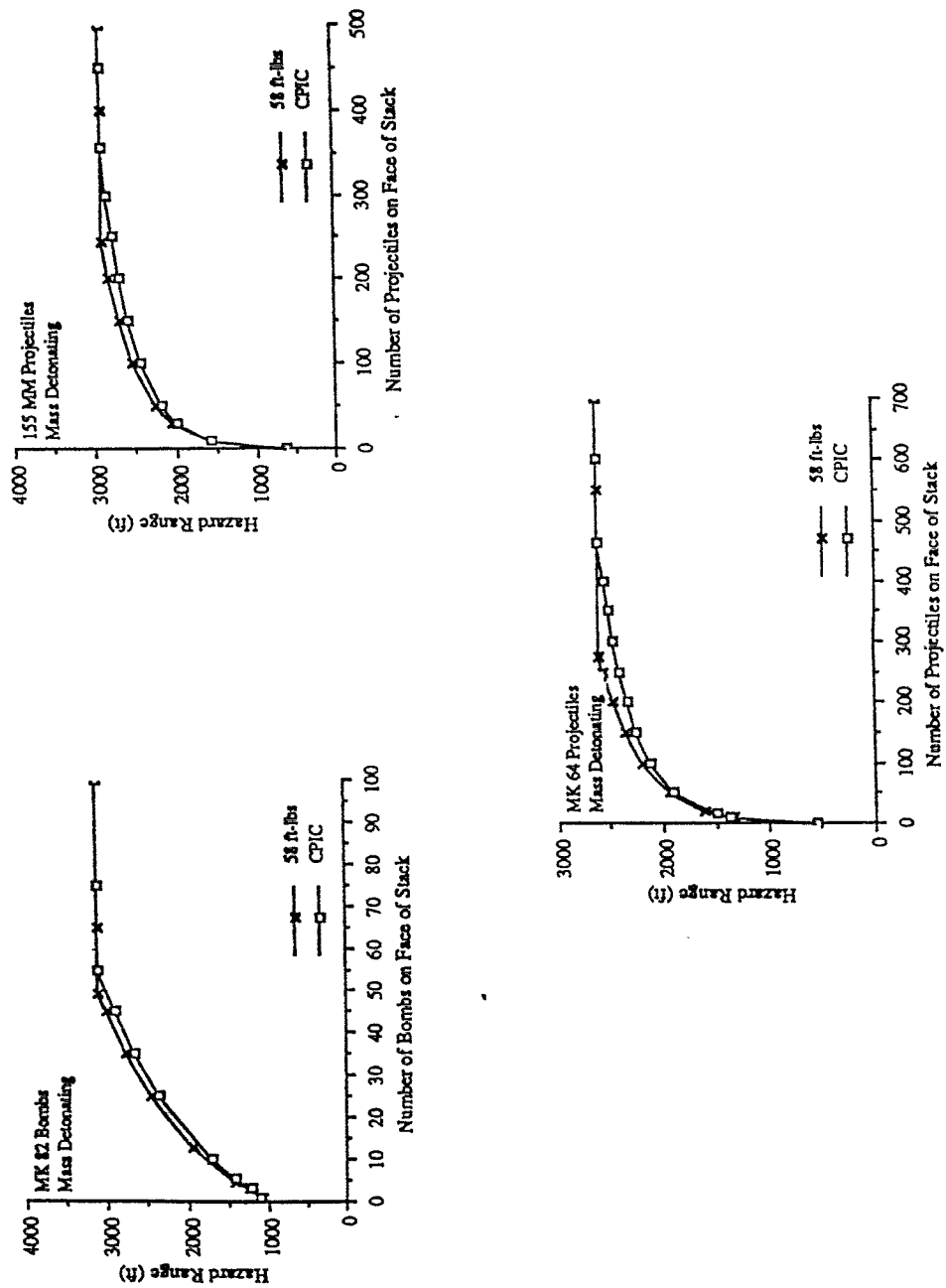
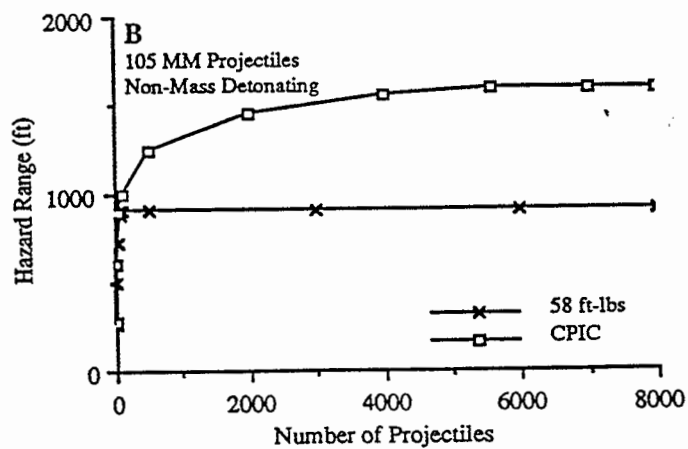
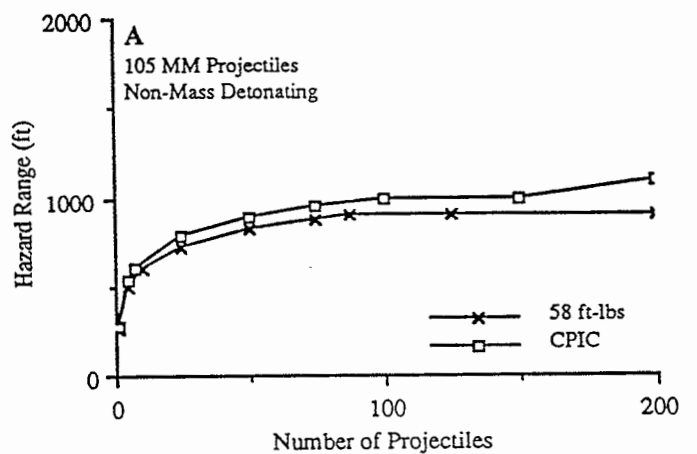


Figure 8.2 - Injury Criteria Comparisons

**Figure 8.3 - Personnel Injury Criteria Thresholds
(M, V Requirements)**

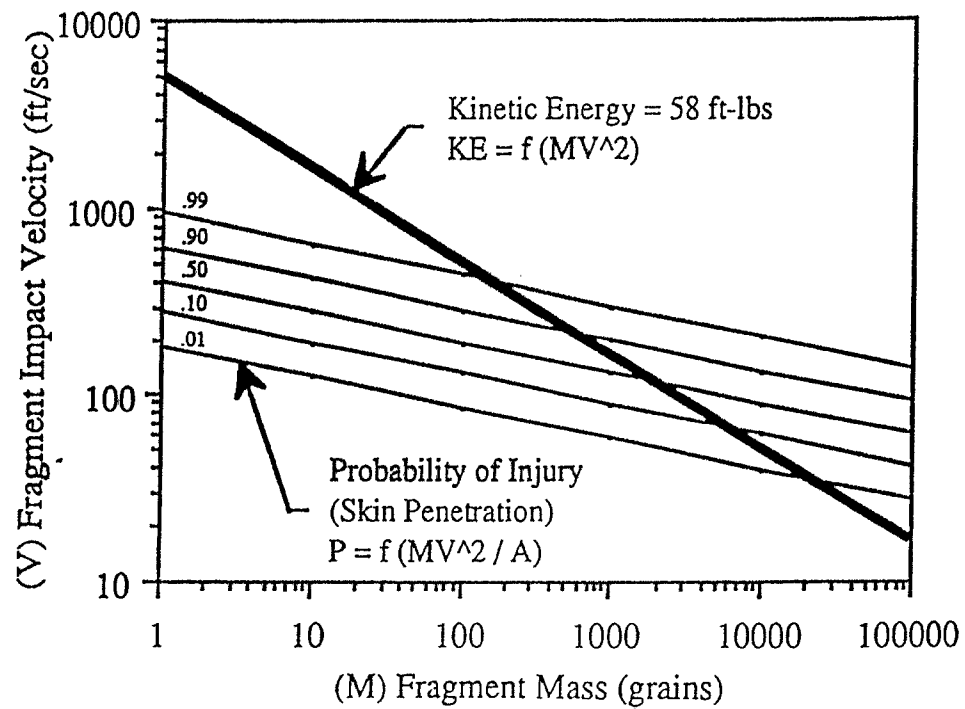


Figure 8.3 shows the threshold injury levels for the two injury criteria as a function of mass and velocity for an impacting fragment. The slopes for the two criteria are quite different, which could result in large differences, especially for small fragment masses.

8.3 Discussion

8.3.1 Figure 8.1 shows no significant difference for the two injury criteria for the three mass detonating munitions.

8.3.2 Figure 8.2 shows an A and B plot for non-mass-detonating 105mm projectiles. Plot A is for 0 to 200 projectiles and plot B is for 0 to 8000 projectiles. There is hardly any significant difference for 0 to 200 projectiles as shown in plot A. In plot B however, there is a significant difference when we exceed 200 projectiles. In plot B, the maximum hazard range for the 58 ft-lb criterion is 900 feet while the maximum hazard range for the CPIC (skin penetration) criterion is 1600 feet. This is due mainly to the fact that fragments going to the maximum range are less than 1000 grains. They do not meet the 58 ft-lb criterion but do produce a small probability of injury with the CPIC (skin penetration) criterion.

8.3.3 In figure 8.3 it is shown that the 58 ft-lb line crosses the .99 probability of injury line at about 100 grains. At the other end it crosses the .01 probability of injury line at about 20,000 grains. Oddly enough this is about the range of fragment weights for the four munitions investigated. Experimental verification for the 58 ft-lb rule is very limited while the CPIC (skin penetration) criterion has a very large quantity of experimental verification over a wide range of fragment masses.

8.4 Conclusions and Recommendations

8.4.1 Results currently available are not sufficient to make a definite recommendation for shifting from the 58 ft-lb criterion to the CPIC (skin penetration) criterion for use with the DDESB FRAGHAZ computer program. This is partly due to the uncertainty in the personnel, time and money required to change all the reports and manuals currently active in the DDESB files.

8.4.2 The DDESB should evaluate the conditions and requirements for non-mass-detonating munitions like the 105mm projectiles considered here. The reevaluation should include:

1. Time element - the successive detonations of non-mass-detonating munitions may go on for hours. A time limit expressed as a limiting number of projectiles should be considered to reflect a reasonable time exposure for the personnel target.
2. Projectile alignment - successive explosions will rearrange the alignment of projectiles with respect to the hazard area.

8.4.3 Figure 8.3 shows a marked departure of the 58 ft-lb line from the .99 probability of skin penetration below 100 grains. As such, an evaluation of the hazards from anti-personnel munitions should be conducted with the Army to compare the two injury criteria.

