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THE BIOLOGICAL EFFECTS OF REPEATED BLASTS

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30 April 1981

Final Report for Period 30 April 1980-30 April 1981

DNA IACRO No. 81-832

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DNA 5842F	2. GOVT ACCESSION NO. AD-A113 113	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE BIOLOGICAL EFFECTS OF REPEATED BLASTS		5. TYPE OF REPORT & PERIOD COVERED Final Report for Period 30 Apr 80-30 Apr 81
7. AUTHOR(s) Donald R. Richmond John T. Yelverton E. Royce Fletcher		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lovelace Biomedical & Environmental Research Institute, Inc. P.O. Box 5890, Albuquerque, NM 87185		8. CONTRACT OR GRANT NUMBER(s) DNA IACRO 81-832
11. CONTROLLING OFFICE NAME AND ADDRESS Director Defense Nuclear Agency Washington, D.C. 20305		10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS Subtask U99QAXMK00C-08
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 30 April 1981
		13. NUMBER OF PAGES A2
		15. SECURITY CLASS (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B384081466 U99QAXMK00008 H2590D.		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Multiple Blasts Blast Biology Blast Injury Blast Criteria		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The results of investigations on the biological effects of repeated blasts were reviewed. In the present study, sheep and swine were subjected to multiple blasts at a rate of one per minute in a high-explosive-driven shocktube. Three 1/2 lethal doses (LD ₁) resulted in 100-percent mortality in 1 hour. Blast injuries to the organs in the neck (larynx, pharynx, and trachea) and the gastrointestinal tract occurred at blast overpressure		

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20. ABSTRACT (Continued)

levels lower than those necessary for lung hemorrhage for both single and multiple exposures.

Curves estimating the LD₁ for man as a function of incident overpressure and number of blasts were compiled. For a standing man the LD₁ incident overpressure was 27 psi (186 kPa) for a single blast and 18 psi (124 kPa) for five blasts. The overpressures from one or five blasts required to inflict selected injuries in man were presented.

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PREFACE

This report presents the results of an investigation conducted to determine the effects of multiple blasts on sheep and swine along with a review of the literature on the subject. Based on the findings, predictions were made of man's response to long-duration blasts. The latter should provide a data base for the development of risk and casualty criteria for personnel subjected to multiple blasts.

The authors wish to acknowledge the technical assistance of William Hicks, Jess Hunley, Takeshi Minagawa, Keith Saunders, Allie Shaw, and the secretarial and editorial assistance of Berlinda Martinez.

The research described in this report involved animals maintained in animal care facilities fully accredited by the American Association of Accreditation of Laboratory Care.

This research was conducted according to the principles enunciated in the Guide for Laboratory Animal Facilities and Care prepared by the National Academy of Sciences-National Research Council.



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INTRODUCTION

The literature contains a limited number of reports on investigations dealing with the biomedical effects of repeated air blast exposures.¹⁻⁵ Up to the present time, biomedical criteria defining man's tolerance to multiple blasts were lacking. Such criteria would aid in assessing the hazards to crew members of modern weapon systems who are subjected to multiple short-duration blasts of relatively low intensities originating from the muzzle and breech of these weapons. In addition, these criteria would define the threat to persons receiving several long-duration blast waves associated with multiple detonations of modern warheads both conventional and nuclear.

The purpose of this report was, first, to review the results of past investigations dealing with the effects of repeated blasts on animals; second, to present the information gained from the present study on the effects of multiple blasts on sheep and swine; and, third, to estimate the blast overpressure levels required to produce mortality and injuries in man in relation to the number of blasts.

The findings of this study showed that the repeated application of sublethal blast overpressures resulted in early mortality. Multiple blasts increased the incidence and severity of lesions to the gastrointestinal tract and organs in the neck, including the larynx, pharynx, and trachea, at peak overpressures lower than those required to cause lung hemorrhage.

PREVIOUS INVESTIGATIONS

EARLY STUDIES

The earliest report on exposing animals to more than one blast dates to 1915.¹ Rabbits were placed in covered pits in the earth and subjected to several blasts from small charges at several-minute intervals. The results were difficult to interpret because the blast waves were of great intensity and were not of the same magnitudes since the distances from the charges to the animals were varied.

In the 1918-1919 period, dogs, cats, rabbits, and frogs were located directly beneath the muzzles of large-calibre cannons and mortars. In some of the tests, dogs were subjected to several muzzle blasts but the results obtained were unclear and therefore have not been included in this report.²

DOG EXPOSURE TO COMBINATIONS OF BLASTS FROM FOUR DETONATIONS

In 1943, dogs were exposed to multiple blasts at a very rapid rate by the method illustrated in Figure 1.³ The dogs were arranged in a square array to receive various combinations of shock waves from four 100-lb (50 kg) charges detonated simultaneously at each corner of the square. The dogs were at ranges from 36 to 55 ft (11 to 17 m) from the closest charge. The lethal range from a single charge was 17.4 ft (5.30 m); the no-injury range was about 23 ft (7.0 m). It was concluded from the experiment that four blasts of low intensity, delivered in rapid succession, did not produce mortality.

It was also reported in Reference 3 that two to six blasts of anticipated 40 to 50 percent of fatal intensity, delivered at 2- to 6-day intervals were not lethal. There were no deaths but the severity of lung hemorrhage from these repeated blasts was greater than that from a single one.

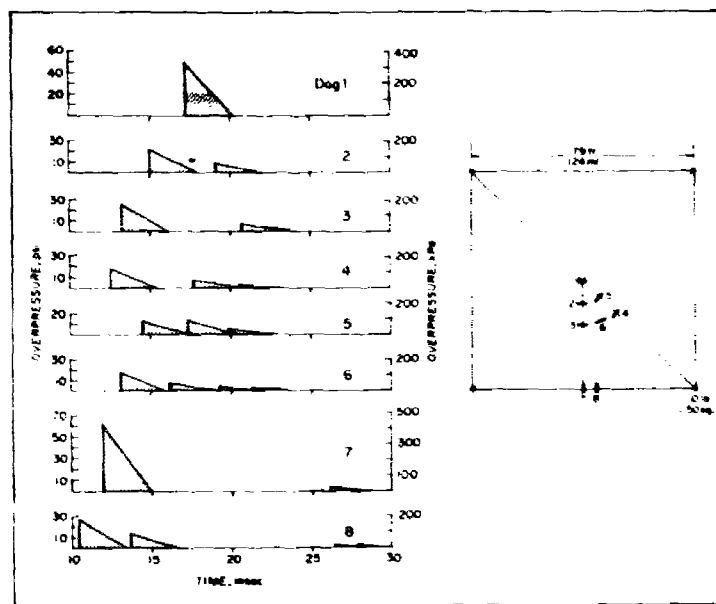


Figure 1. Test layout Used to Expose Dogs to Combinations of Four Blasts (Reference 3).

RESULTS FROM EXPOSING RABBITS TO COMPLEX BLAST WAVES

Rabbits were exposed to complex blast waves inside an enclosure from which two types of recoilless weapons were fired.⁴ The guns were fired either one, two, or three times with 1 minute between firings. The enclosure was 16x16x14 ft (4.9x4.9x4.3 m). The rabbits were 4 ft (1.2 m) above the floor. As seen in Figure 2, the pressure-time pattern was characterized by a series of reverberations.

The total duration of the overpressure was approximately 500 msec. Pulmonary hemorrhage, expressed as quotient of lung injury (i.e., the lung weight of the experimental animals divided by the lung weight of the control animal of equal body weight), varied from little or none (quotient <1.2) to severe amounts (quotient >1.5). It was suggested that the lung injury sustained by the rabbits at such low peak pressures of 5.4 psi (37 kPa) and less was associated with the frequency component of the complex blast wave matching a natural resonance of the rabbit's thorax-abdominal system, and repeated blasts increased the risk of lung injury in the animals. Bleeding was observed in the larynx of 60 percent of the rabbits.

RESPONSE OF RATS TO MULTIPLE SHORT-DURATION BLASTS

Figure 3 gives a 50-percent mortality curve for rats exposed in a prone position on a concrete surface to the reflected overpressure from small explosive charges

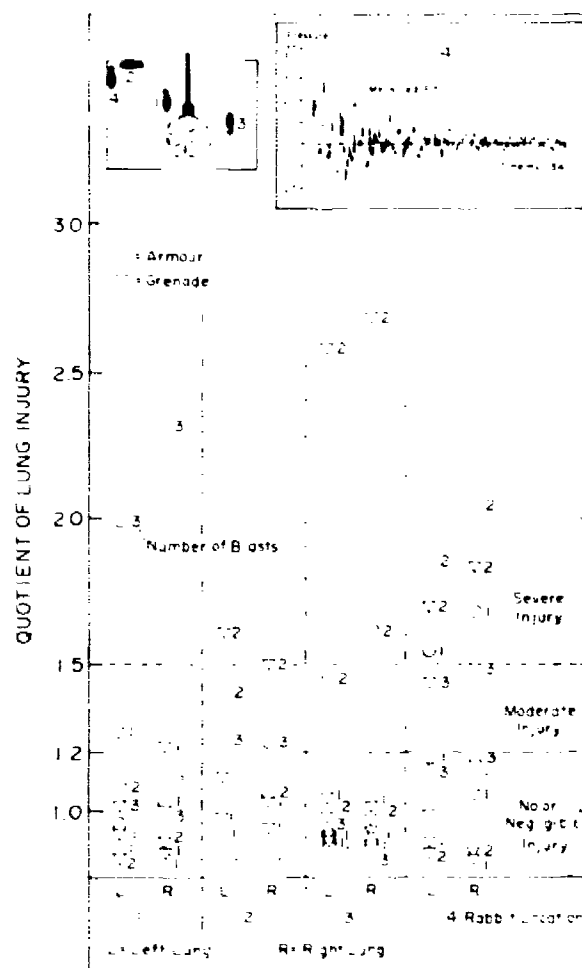


Figure 2. Lung Injury in Rabbits Subjected to One, Two, or Three Complex Blast Waves Within an Enclosure. There were no fatalities. (Reference 4)

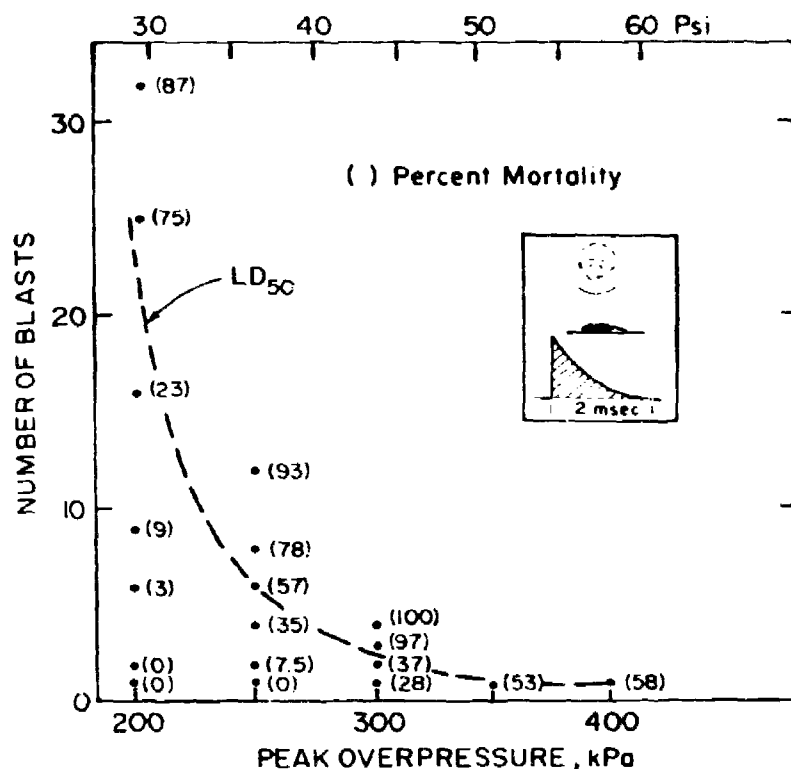


Figure 3. Twenty-Four-Hour Mortality in Rats Exposed to Blasts of 2-Msec Duration at 4-Minute Intervals. (Reference 5)

detonated above the surface.⁵ The blasts were delivered at a rate of one every 4 minutes. Each blast had a duration of approximately 2 msec. For a given animal, all of the blast waves it received had the same peak overpressure. The curve shows that the LD₅₀ overpressure for a single blast, 51 psi (352 kPa), was almost halved when the animals were exposed to 20 blasts.

Figure 4 shows the incidence of pulmonary lesions in the rats as a function of the peak pressure and number of blasts. The peak overpressure required for a 50-percent incidence of lung hemorrhage for a single blast, 7.3 psi (50 kPa), was reduced by a factor of four when the animals were given two blasts of 1.8 psi (12 kPa). A 9-percent incidence of lung lesions was observed for a single blast of 0.5 psi (3.4 kPa), an overpressure well below the previously reported threshold for lung injury.

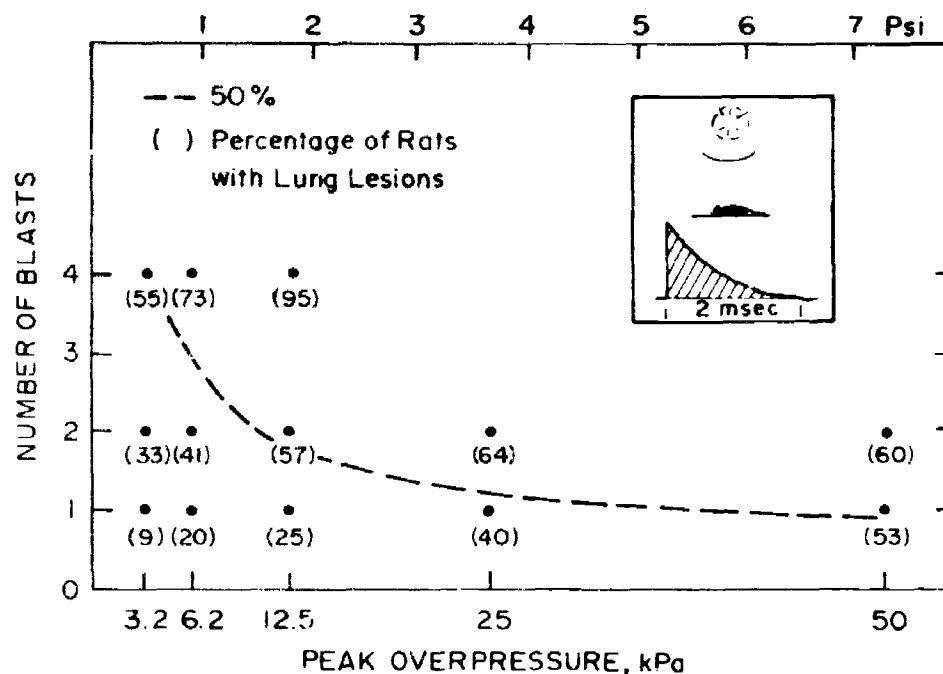


Figure 4. Incidence of Lung Lesions in Rats Exposed to Blasts of 2-Msec Duration at 4-Minute Intervals. (Reference 5)

EFFECTS OF THREE LONG-DURATION BLASTS IN SHEEP

Sheep were exposed to reflected overpressures of 100-msec duration while side-on against the endplate of a shocktube.⁶ The shocktube was air-driven, 3.5 ft (1.1 m) in diameter with a 15-ft-long (4.6 m) compression chamber separated from a 125-ft-long (38.1 m) expansion chamber by a Mylar[®] diaphragm. In this shocktube configuration, the LD₅₀ for single blasts was about 44 psi (303 kPa) and the LD₁, 30 psi (207 m). The ambient pressure for these experiments was 12 psia (83 kPa).

The sheep received one to three blasts separated by 30-minute intervals. The mortality, 17 percent, associated with a single blast of 35 psi (241 kPa) more than tripled, 60 percent, when it was applied twice (Figure 5).

Figures A-1 through A-3 in the appendix illustrate the extent of lung hemorrhage in sheep that received one, two, and three long-duration blasts of 26 psi (179 kPa). The visible increase in lung hemorrhage with number of blasts was confirmed by the lung weight

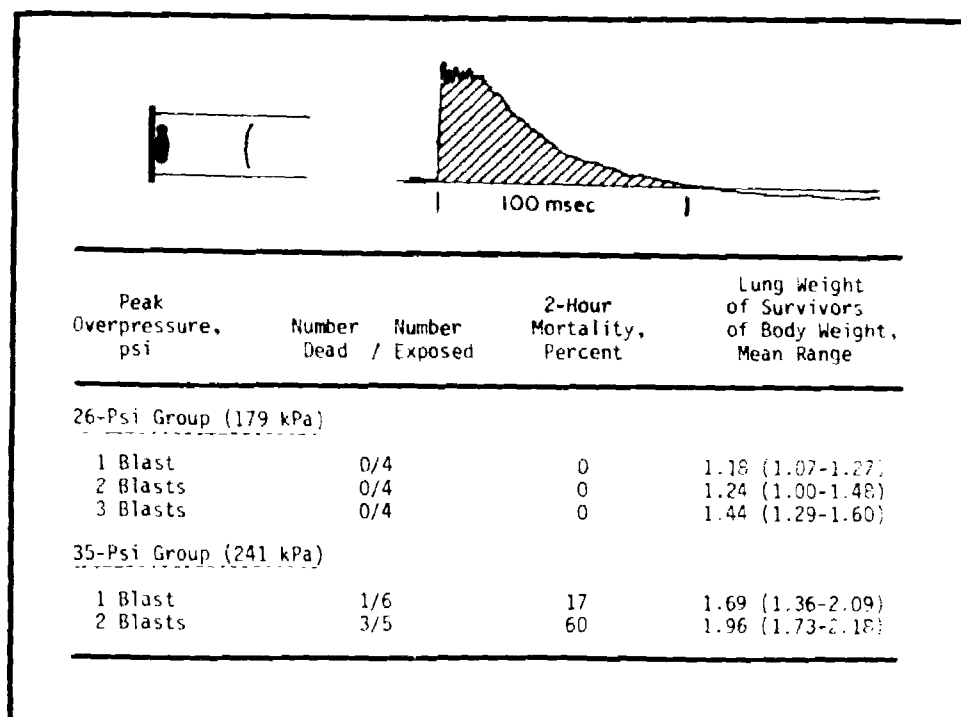


Figure 5. Mortality and Lung Weights of Sheep Subjected to Long-Duration Blasts at 0.5-Hour Intervals in a Shocktube. Ambient Pressure, 12 psia (83 kPa). (Reference 6)

data in Figure 5. In particular, the third blast produced a notable increase in the lung weights of the animals. This suggests that some larger number of blasts at this level would be lethal.

There was a significant increase in the severity of the gastrointestinal tract lesions with the increase in the number of blasts in these groups. At 14 psi (97 kPa), the gastrointestinal tract lesions were significantly more severe in animals blasted three times than in those that received single blasts. At this level, the lung hemorrhage was about threshold and did not appear to increase in intensity with repeated blasts.

RAT RESPONSE TO BLASTS APPLIED AT DIFFERENT RATES

The affect of varying the time between blasts on the 24-hr-mortality rate in rats appears in Figure 6.⁶ Groups of rats were given 26 psi (179 kPa) reflected pressures of

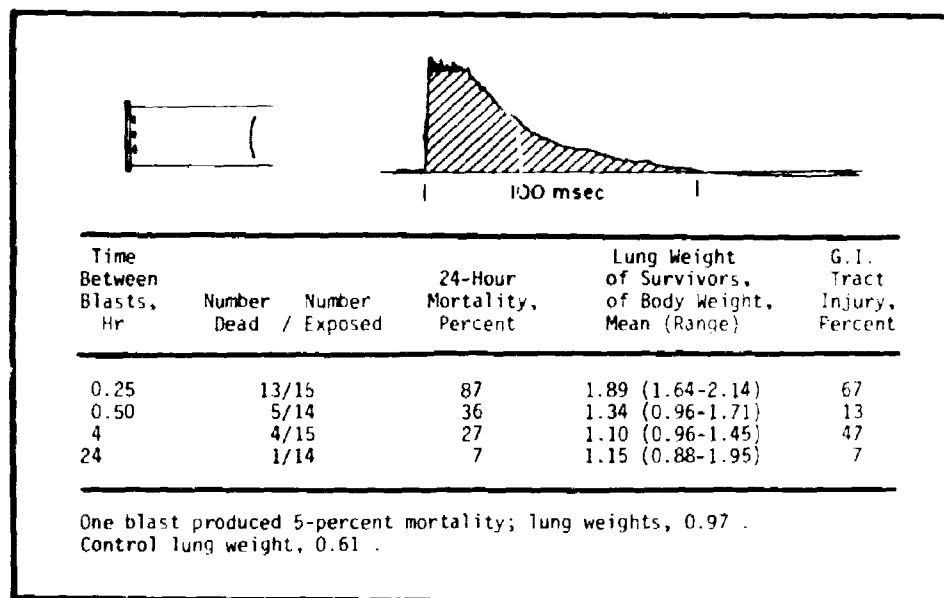


Figure 6. Mortality in Rats Given Three Blasts of Long Duration in Relation to the Time Between Blasts. Ambient Pressure, 12 psia (03 kPa). (Reference 6)

100-msec duration on the endplate of a 3.5-ft-diameter (1.1-m) air-driven shocktube. A single exposure to this blast wave produced a 5-percent mortality within 24 hr. Three blasts at 0.25-hr intervals resulted in 87-percent mortality. At longer time intervals, 0.5, 4, and 24 hr, the mortality declined to 36, 27, and 7 percent, respectively.

The mean lung weight was highest in 24-hr survivors subjected to blast at 0.25-hr intervals and decreased in the groups with longer times between exposure.

The incident of gastrointestinal tract injury was lowest in animals subjected to three blasts at 24-hr intervals.

SENSITIVITY OF SHEEP TO DOUBLE SHOCK WAVES

Figure 7 summarizes the results of a 1978 study conducted to detect any non-auditory blast injuries in sheep subjected to simulated muzzle blasts.⁷ The desired blast wave shape was one having a 4- to 5-msec duration and two shock fronts separated by a 2- to 3-msec time interval. It was generated by detonating two primacord charges simultaneously

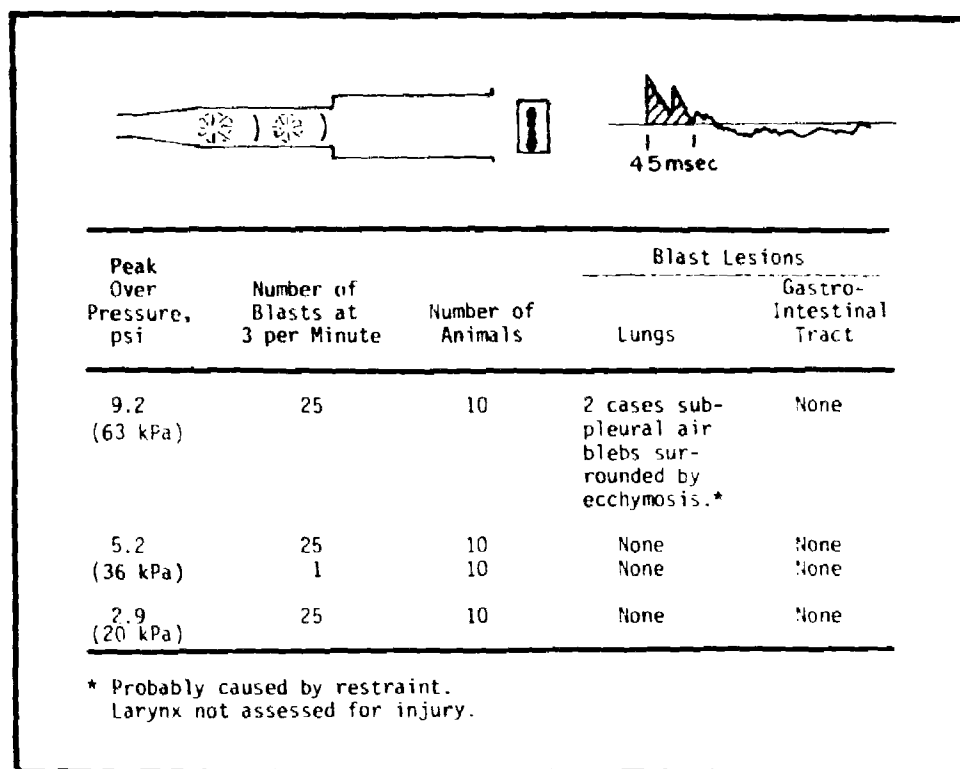


Figure 7. Effects on Sheep Exposed to Blasts Having Double Shock Fronts at Ambient Pressure of 12.0 Psia (83 kPa). (Reference 7)

inside a shocktube which was 120 ft long (36.6 m) and 6 ft (1.8 m) in diameter over the first 60-ft (18-m) section and 10 ft (3.0 m) wide over the distal 60-ft (18-m) portion. The peak pressures and time intervals between shocks were controlled by varying the weights of the charges and the distance between them. Two animals were tested at the same time; they were side-on to the blast, 6 ft (1.8 m) beyond the open end of the shocktube. The ambient pressure was 12 psia (83 kPa).

As seen in Figure 7, there were no direct air blast injuries to the lungs or gastrointestinal tract in sheep that received 25 blasts of 2.9, 5.2, or 9.2 psi (20, 36, or 63 kPa) applied at a rate of 3 per minute. There were two cases of minor lung lesions in the 9.2 (63 kPa) group that apparently were caused by the restraints abruptly stopping the animal's displacement associated with the abnormally high flow following the initial shock wave. This flow was not present at the lower pressures.

The larynges of these animals were not examined.

DETERMINATION OF LARYNGEAL LESIONS IN SHEEP FROM SHORT-DURATION BLASTS

The incidence and severity of laryngeal lesions was determined in sheep given 50 or 100 blasts with a single shock front of 2.6 or 5.2 psi (18 or 36 kPa) delivered at the rate of 1 per minute.⁷ The blasts were generated by detonating primacord charges near the endplate that closed the shocktube mentioned above. The animal station was 6 ft (1.8 m) beyond the open end of the tube. About one-third of the sheep that received 50 blasts of 2.6 psi (18 kPa) and two-thirds that received 5.2 psi (36 kPa) sustained slight laryngeal lesions in the form of petechial hemorrhages (Figure 8). The incidence of this lesion rose to about 83 percent in those that received 100 blasts but the severity of these lesions did not increase. There were no lung or gastrointestinal tract injuries detected in these animals. The laryngeal lesions sustained by animals at 2.6 and 5.2 psi (18 and 36 kPa) were of a trivial nature and no more severe than the petechial hemorrhages occasionally detected in the control animals.

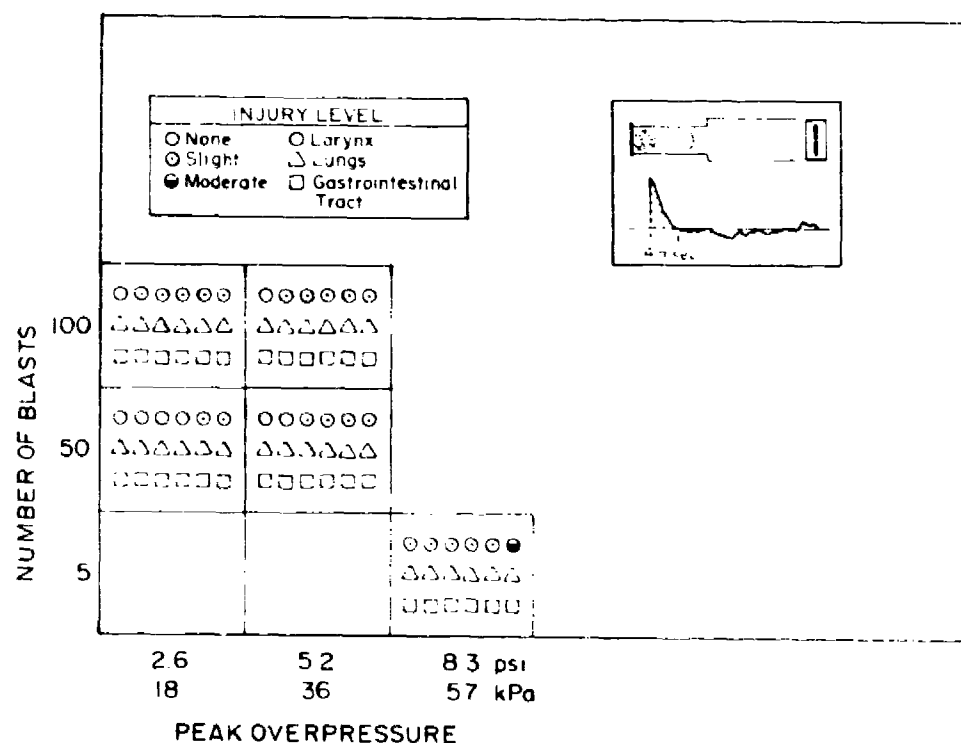


Figure 8. Incidence of Blast Lesions in Sheep Exposed to Blasts at 1-Minute Intervals. Ambient pressure, 12 psia (83 kPa). (Reference 7)

INJURY BUILD UP IN SHEEP AND SWINE FROM 50 SHORT-DURATION BLASTS

Sheep and swine were subjected to 50 blasts at five overpressure levels to determine injury to the lungs, larynx, and gastrointestinal tract.⁷ The animals were side-on against a reflecting surface inside the shocktube. Primacord charges were detonated at 1-min intervals at a 58-ft (18 m) standoff distance from the reflector.

Blast injury levels were graded as slight, moderate, and severe according to the scheme in Table 1.

TABLE 1
AIRBLAST INJURY LEVELS

INJURY LEVEL	GASTROINTESTINAL TRACT	LARYNX*	LUNGS
SLIGHT	Contusions, 1 cm ² or less, isolated.	Petechiae, hyperemic areas.	Ecchymosis.
MODERATE	Submucosal contusions, 1 to 5 cm ²	Ecchymosis, small, submucosal contusions.	Hemorrhages, isolated focal.
SEVERE	Submucosal contusions multiple, greater than 5 cm ² , hematomas, rupture.	Submucosal contusions, multiple, dark; edema and hematomas.	Extensive areas of confluent hemorrhage extending deep into parenchyma.

* Includes nasopharynx and upper trachea.

Examples of laryngeal blast lesions appear in Figures A-4 through A-7 in the appendix. As seen in Figure A-6, submucosal contusions and hematomas lined the larynx and surrounding portions of the nasopharynx. There were deep, concomitant, submucosal contusions and hematomas in the soft tissues of the tracheal wall. There were no lesions detected in the lining of the esophagus.

Figure 9 shows that 50 blasts of 2.6 or 5.3 psi (18 or 37 kPa) produced slight laryngeal lesions, 7.5 psi (52 kPa) produced moderate injury, and 12 or 16 psi (83 or 110 kPa) produced severe injury. Gastrointestinal tract injury was threshold at 7.5 psi (52 kPa), moderate at 12 psi (83 kPa), and severe at 16 psi (110 kPa). No lung hemorrhage was detected at these overpressure levels.

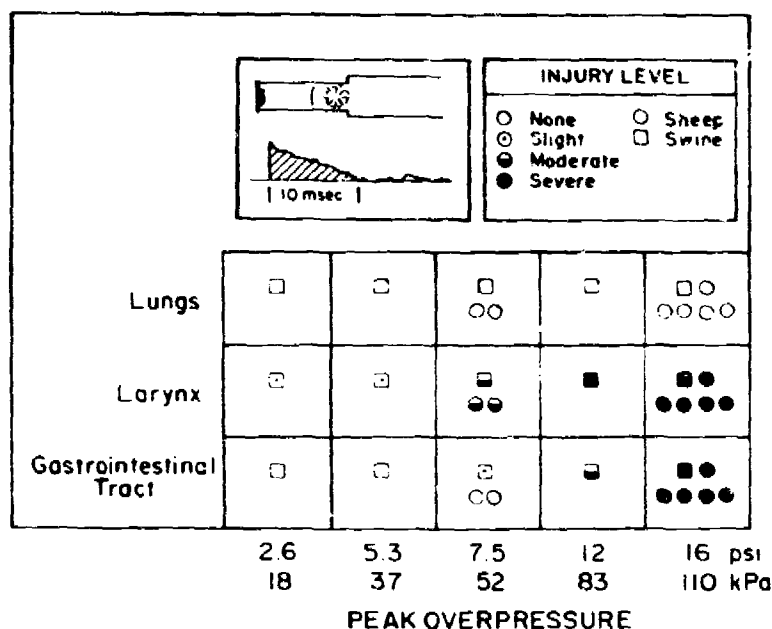


Figure 9. Injury Levels in Sheep and Swine Subjected to 50 Blasts at 1-Min Intervals. Ambient pressure, 12.0 psia (83 kPa). (Reference 7)

Figures A-8 through A-10 illustrate severe gut and laryngeal injuries, but an absence of lung hemorrhage in a swine subjected to 50 blasts of 16 psi (110 kPa).

PRESENT STUDY

BIOLOGICAL EFFECTS OF MULTIPLE BLASTS IN SHEEP AND SWINE

Mortality

The objective of the present study was to determine the mortality rate in large animal species from repeated blasts of low-level or high-sublethal intensities. The sheep used were Columbia-Rambouillet-cross ewes (mean body weight, 93 lb (42 kg)) and the swine were mixed breed of both sexes (mean body weight, 79 lb (36 kg)). The animals were given sedative levels of Rompun[®] (Xylazine), .01 to .02 cc per kg body weight I.M., 30 minutes prior to testing. They were restrained in a harness made of fish net material.

The subjects received reflected overpressures of 9-12 msec duration while side-on against a reflector plate in the shocktube. Primacord charges were detonated at 26- or 58-ft (8- or 18-m) standoffs from the reflector plate. The blasts were delivered at a rate of 1 per min. The ambient pressure was 12 psia (83 kPa). Figure 10 shows the

mortality data in relation to peak overpressure and number of blasts along with a 1-percent mortality curve that was fitted to the data. The 1-percent mortality overpressure from a single blast was approximately 50 psi (345 kPa). Two blasts of that magnitude produced 20-percent mortality and three blasts produced 100-percent mortality. Single sublethal blasts of 33 psi (228 kPa) generated 20-percent mortality when administered 15 times. The 1-percent mortality curve climbed steeply near 30 psi (207 kPa). Below 30 psi (207 kPa), lung hemorrhage did not increase significantly with the number of blasts, and lethality would not be expected from lung damage.

These data apply to mortality at 1 hr after the final blast, additional deaths from lung hemorrhage would probably occur beyond that time. In addition, delayed deaths from rupture of the digestive tract could occur at overpressures lower than 30 psi (207 kPa).

Injury Levels

Sheep and swine were subjected to a range of non-lethal, short-duration overpressures to determine threshold of injuries with emphasis on one and five blasts. Swine were added to the experiments to confirm that the gastrointestinal tract and laryngeal injuries observed were not specific to sheep that have a voluminous rumen and a relatively long neck.

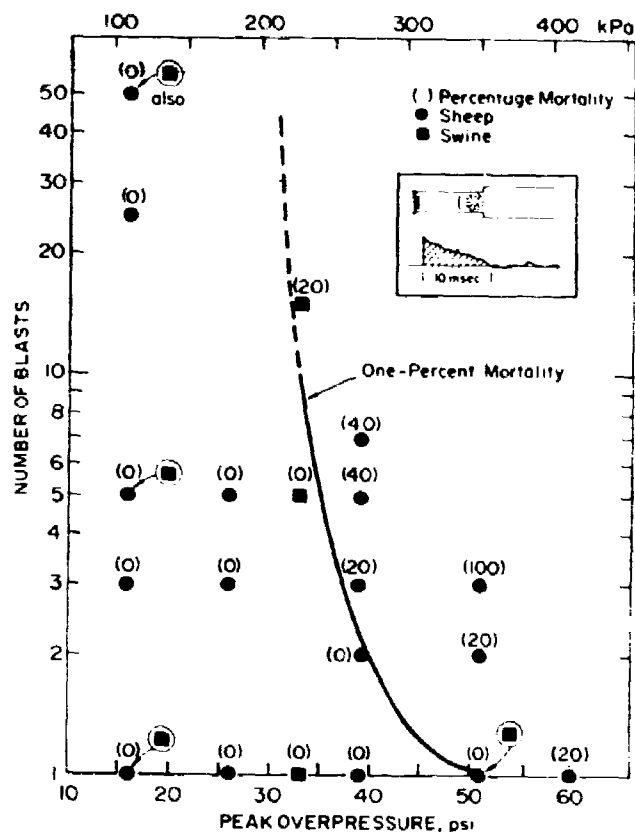


Figure 10. One-Hour Mortality in Sheep and Swine Subjected to Blasts of 9-12 Msec Duration at 1-Minute Intervals. Ambient pressure, 12 psia (83 kPa).

As seen in Figure 11, the threshold for submucosal contusions in the gastrointestinal tract of animals was 12 psi (83 kPa). Five blasts at that magnitude raised the incidence, and, to some extent, the severity of this lesion.

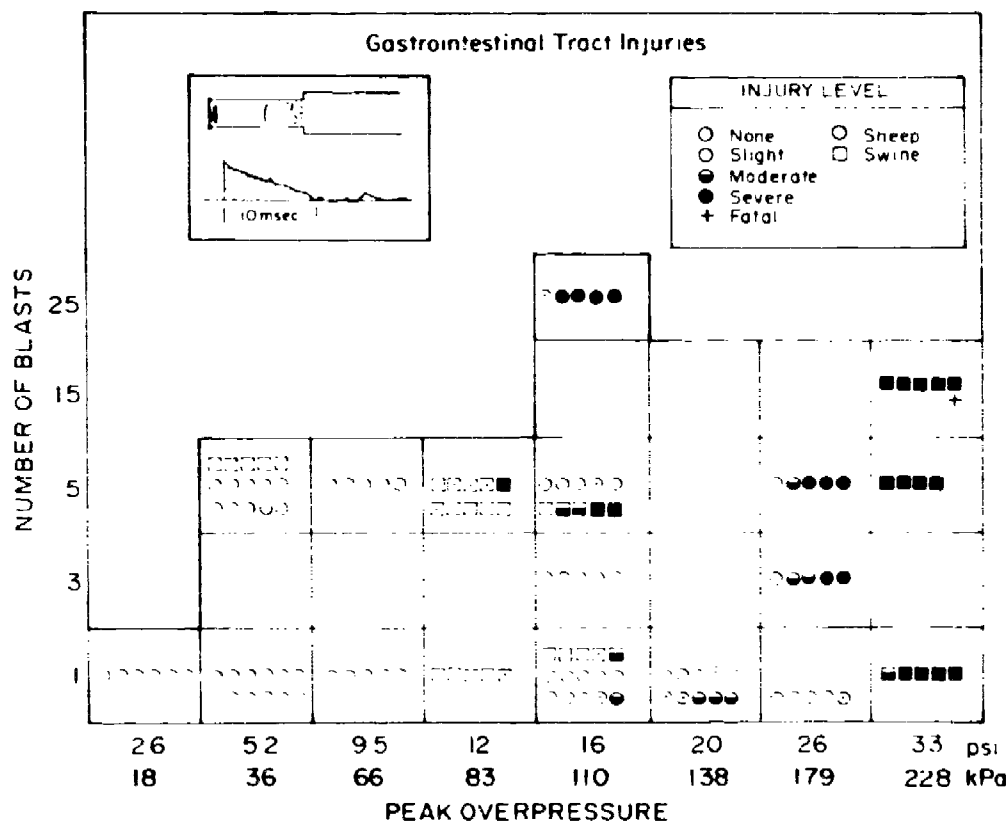


Figure 11. Gastrointestinal Tract Injuries in Sheep and Swine Subjected to Blasts Delivered at 1-Minute Intervals. Ambient pressure, 12 psia (83 kPa).

The threshold for injury to the larynx, including the nasopharynx and trachea, for single blasts was 9.5 psi (66 kPa) and for five blasts, 5.2 psi (36 kPa), Figure 12. Five blasts of 12 psi (83 kPa) resulted in a high incidence of laryngeal lesions of moderate to severe levels.

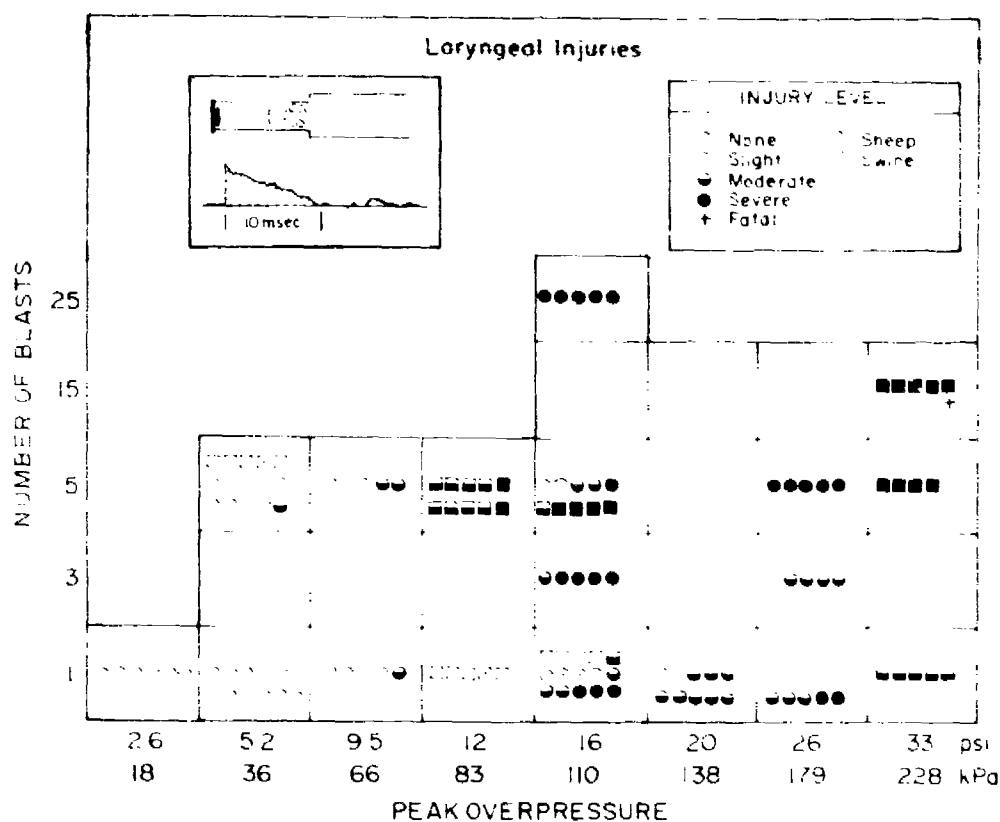


Figure 12. Laryngeal Injuries in Sheep and Swine Subjected to Blasts Delivered at 1-Minute Intervals. Ambient pressure, 12 psia (83 kPa).

As seen in Figure 13, the threshold for lung injury was at 16 to 20 psi (110 to 138 kPa). This lesion did not increase to severe levels until five successive blasts of 33 psi (228 kPa) were administered.

The presence of wax and ticks in the external ears of the sheep precluded accurate evaluation of the effects of repeated blasts on ear injury. About one-half the eardrums were ruptured in the sheep tested at 2.5 psi (17 kPa) for single exposures. At 5.2 and 9.5 psi (36 and 66 kPa), there were indications that repeated blast produced more

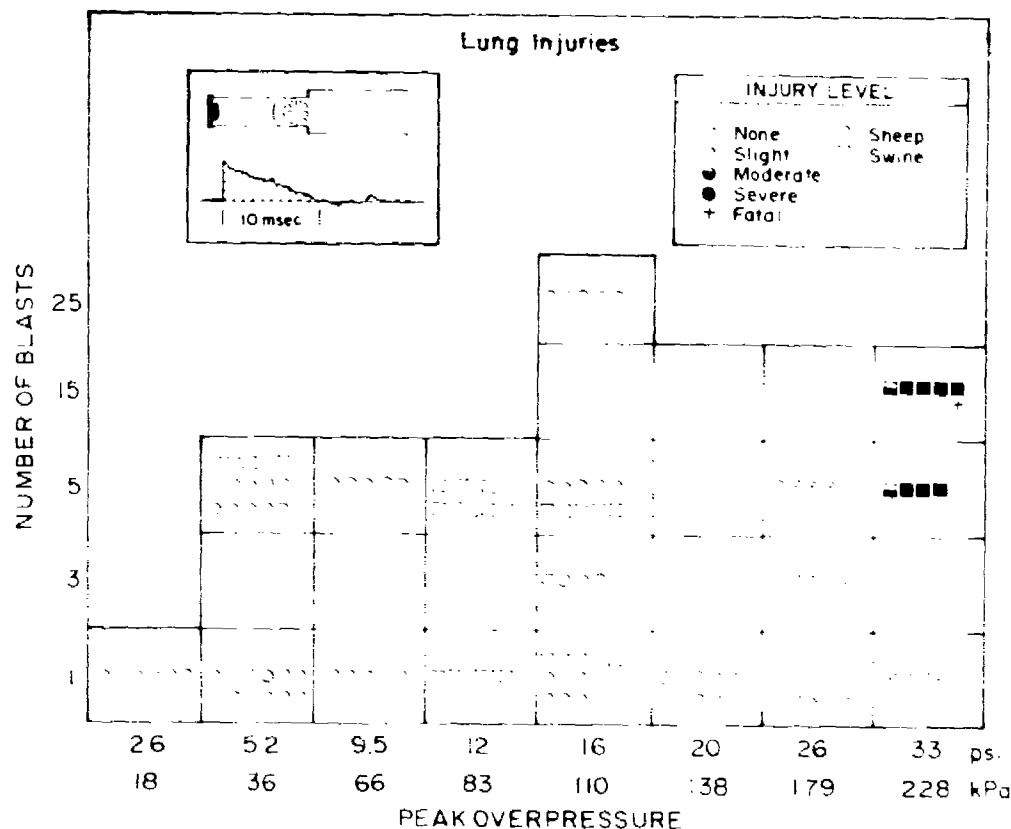


Figure 13. Lung Injuries in Sheep and Swine Subjected to Blasts Delivered at 1-Minute Intervals. Ambient pressure, 12 psia (83 kPa).

hemorrhaging than a single blast. At the higher overpressures, a single blast completely destroyed eardrums.

Sinus hemorrhages were not observed in animals subjected to multiple sublethal overpressures.

DISCUSSION

ESTIMATE OF MAN'S TOLERANCE TO REPEATED BLASTS

Mortality

Curves relating a 1-percent probability of mortality for man to the peak incident overpressure and number of blasts appear in Figures 14 through 16. The curves were

Figure 14. Estimated 1-Percent Mortality for Man Exposed End-On to Long-Duration Blasts as a Function of Incident Overpressure and Number of Blasts at Sea Level.

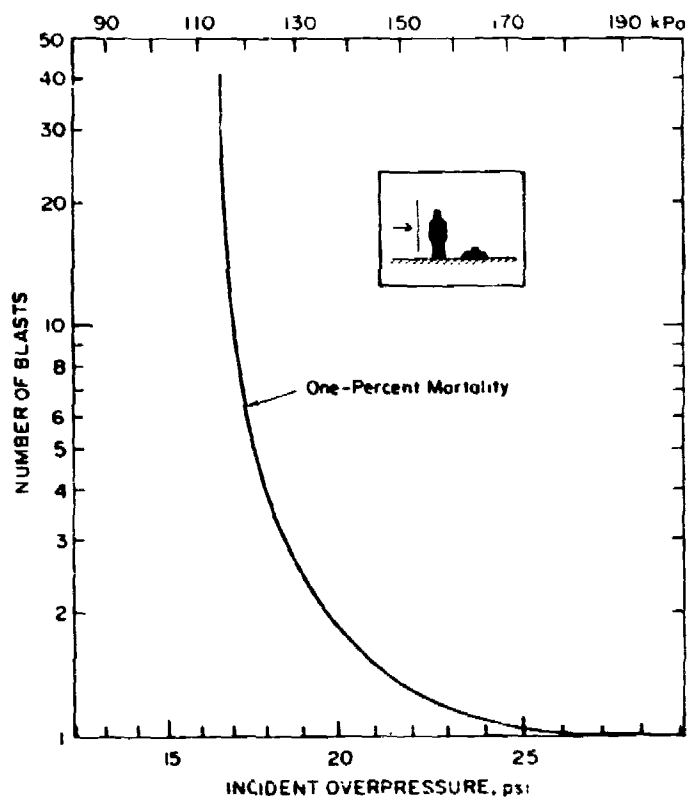
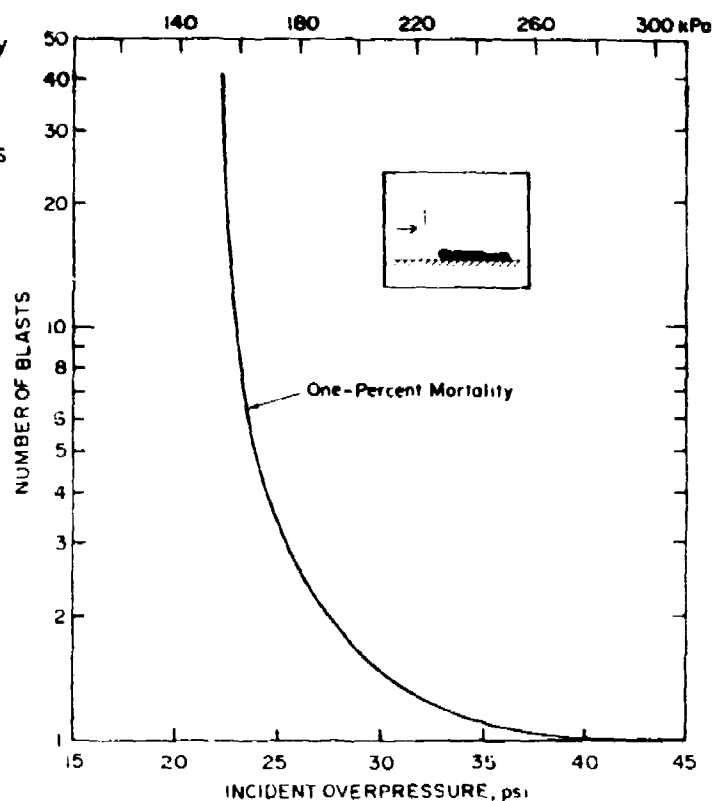
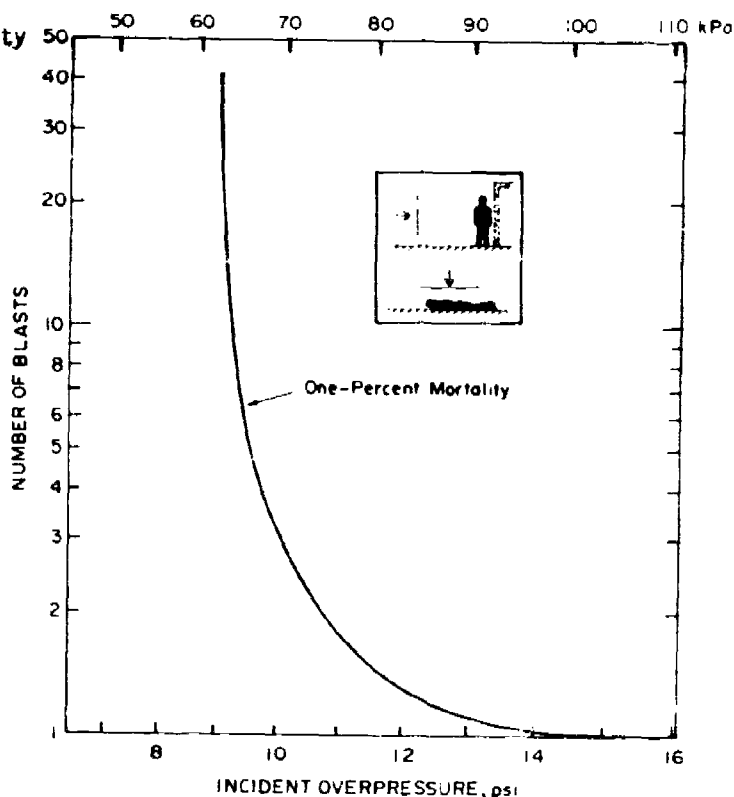


Figure 15. Estimated 1-Percent Mortality for Man Exposed Standing or Prone Side-On to Long-Duration Blasts as a Function of Incident Overpressure and Number of Blasts at Sea Level.

Figure 16. Estimated 1-Percent Mortality for Man Exposed to Long-Duration Reflected Blast Overpressures as a Function of Incident Overpressures and Number of Blasts at Sea Level.



derived by scaling the short-distance overpressures associated with the 1-hr mortality curve in Figure 10 for large animals at an ambient pressure of 12 psia (83 kPa) to man for long-duration overpressures at sea level using the equations in Reference 8. Each figure gives the incident overpressures necessary to generate man's effective air-blast dose for three conditions of exposure. For personnel prone end-on to the blast, the side-on incident overpressure constitutes the air-blast dose. A single blast of 40 psi (276 kPa) could be expected to produce 1-percent mortality (Figure 14). For personnel prone side-on to the blast or standing, the incident side-on overpressure plus the dynamic overpressure represents the air-blast dose and a total pressure of 40 psi (276 kPa) would be generated by an incident shock wave of 26.5 (183 kPa) plus a dynamic pressure of 13.5 psi (93 kPa), Figure 15. For personnel against or close to a large reflecting surface, the reflected pressure would be the damaging air-blast parameter and an incident shockwave of 14.6 (101 kPa) would reflect to 40 psi (276 kPa), Figure 16.

The 1-percent mortality for a single blast wave of near 40 psi (276 kPa) for man prone end-on to the blast found in this study was in agreement with previous estimates reported in Reference 8. Five blasts with incident overpressures of about 24 psi (166 kPa) would be predicted to produce 1-percent mortality among personnel in that orientation. For individuals against a reflecting surface, five blasts with incident overpressures of near 10 psi (69 kPa) could result in a 1-percent probability of lethality.

Injury Levels

Table 2 gives estimates of the effective overpressure doses for one and five blasts required to produce selected injuries in man. They were obtained by selecting equivalent injury levels from the sheep and swine data and scaling the corresponding overpressures to long-duration blast waves for man at sea level.

The procedures for scaling lung injury from animals to man was based on a considerable amount of data and mathematical modeling of the thorax. It was assumed that the scaling also applied to other forms of injuries.

The predicted threshold for lung hemorrhage in man from a single blast obtained by this method was 11 psi (76 kPa) which was in agreement with previous estimates of 10-12 psi (69-83 kPa).⁸ The threshold values from single blasts for laryngeal lesions, 6 psi (41 kPa), and gastrointestinal tract injury, 8 psi (55 kPa), were below that for lung hemorrhage. The overpressure required for given levels of laryngeal lesions from five blasts were on the order of half that from a single blast. A 50-percent incidence of moderate-severe injuries from five blasts could be expected to occur at overpressures of 8 psi (55 kPa) for the larynx, 14 psi (97 kPa) for the gastrointestinal tract, and 21 psi (145 kPa) for the lungs.

In the opinion of medical experts, stated in Reference 7, slight injuries of the larynx, gastrointestinal tract, and lungs would not be expected to impair human performance. They would be benign, asymptomatic, and probably produce no discomfort to the individual. They would be self-healing and not require treatment.

The information contained in this report provided a basis from which to estimate the consequences of repeated consecutive blasts of equal intensities to man. Information

relating to ear injury from multiple blasts remains to be determined. Obviously, there remain many other facets of the problem to be explored.

TABLE 2
OVERPRESSURE FROM ONE AND FIVE LONG-DURATION BLASTS
REQUIRED TO PRODUCE INJURY IN MAN

Injury Level	Effective Overpressure, psi (kPa)	
	One Blast	Five Blasts
<u>LARYNX:</u>		
Slight:		
Threshold	6 (41)	3 (21)
50% Incidence	10 (69)	5 (34)
Moderate-Severe:		
Threshold	10 (69)	5 (34)
50% Incidence	12 (83)	8 (55)
<u>GASTROINTESTINAL TRACT:</u>		
Slight:		
Threshold	8 (55)	7 (48)
50% Incidence	12 (83)	8 (55)
Moderate-Severe:		
Threshold	12 (83)	8 (55)
50% Incidence	18 (124)	14 (96)
<u>LUNGS:</u>		
Slight:		
Threshold	11 (76)	11 (76)
50% Incidence	16 (110)	16 (110)
Moderate-Severe:		
50% Incidence	27 (186)	21 (145)

Effective overpressure may be:

- (a) incident overpressure if end-on to the blast,
- (b) incident plus dynamic pressure if side-on to the blast, or
- (c) reflected overpressure if against a reflecting surface.

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APPENDIX

PATHOLOGY PHOTOGRAPHS



Figure A-1. Lungs of Sheep, One Long-Duration Blast of 26 psi (179 kPa); Lung Weight, 1.07 Percent of Body Weight.



Figure A-2. Lungs of Sheep, Two Long-Duration Blasts of 26 psi (179 kPa), Time Between Blasts, 0.5 Hour; Lung Weight, 1.00 Percent of Body Weight.



Figure A-3. Lungs of Sheep, Three Long-Duration Blasts of 26 psi (179 kPa), Time Between Blasts, 0.5 Hour; Lung Weight, 1.60 Percent of Body Weight.



Figure A-4. Larynx of Sheep, Slight Injury, One-Short Duration Blast of 9.5 psi (66 kPa).



Figure A-5. Larynx of Sheep. Moderate Injury, One-Short Duration Blast of 16 psi (110 kPa).



Figure A-6. Larynx of Sheep, Severe Injury, Fifty Short-Duration Blasts of 16 psi (110 kPa) at 1-Minute Intervals.



Figure A-7. Larynx of Swine, Fifty Short-Duration Blasts of 16 psi (110 kPa) at 1-Minute Intervals.



Figure A-2. Gastrointestinal Tract of Swine, Fifty Short-Duration Blasts of 16 psi (110 kPa) at 1-Minute Intervals.



Figure A-2. Stomach of Swine, Hematoma in Wall, Fifty Short-Duration Elasts of 16 psi
'110 kPa, at 1-Minute Intervals.



Figure A-10. Lungs of Swine, Fifty Short Duration Blasts of 16 psi (110 kPa) at 1-Minute Intervals.

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