Technical Memorandum 20-91

# FIRING RECOILLESS WEAPONS FROM ENCLOSURES



G. Richard Price

October 1991
AMCMS Code 611102.74A0011



U.S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*

**1a. REPORT SECURITY CLASSIFICATION:** Unclassified

**1b. RESTRICTIVE MARKINGS:**

**2a. SECURITY CLASSIFICATION AUTHORITY:**

**2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:**

**3. DISTRIBUTION/AVAILABILITY OF REPORT:** Approved for public release; distribution unlimited.

**4. PERFORMING ORGANIZATION REPORT NUMBER(S):** Technical Memorandum 20-91

**5. MONITORING ORGANIZATION REPORT NUMBER(S):**

**6a. NAME OF PERFORMING ORGANIZATION:** Human Engineering Laboratory

**6b. OFFICE SYMBOL** *(If applicable)***:** SLCHE

**6c. ADDRESS** *(City, State, and ZIP Code)***:** Aberdeen Proving Ground, MD 21005-5001

**7a. NAME OF MONITORING ORGANIZATION:**

**7b. ADDRESS** *(City, State, and ZIP Code)***:**

**8a. NAME OF FUNDING/SPONSORING ORGANIZATION:**

**8b. OFFICE SYMBOL** *(If applicable)***:**

**9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:**

**8c. ADDRESS** *(City, State, and ZIP Code)***:**

**10. SOURCE OF FUNDING NUMBERS**

| PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT ACCESSION NO. |
|---|---|---|---|
| 6.11.02 | 1L161102B74A | | |

**11. TITLE** *(Include Security Classification)***:** Firing Recoilless Weapons From Enclosures

**12. PERSONAL AUTHOR(S):** Price, G. R.

**13a. TYPE OF REPORT:** Final

**13b. TIME COVERED:** FROM ______ TO ______

**14. DATE OF REPORT** *(Year, Month, Day)***:** 1991, October

**15. PAGE COUNT:** 14

**16. SUPPLEMENTARY NOTATION:** affect of noise blast: Scandanavian archeology supplement 34 1991 pp 39-48 Hahns M Borchgrav

**17. COSATI CODES**

| FIELD | GROUP | SUB-GROUP |
|---|---|---|
| 23 | 02 | |
| | | |

**18. SUBJECT TERMS** *(Continue on reverse if necessary and identify by block number)***:**
blast overpressure; damage risk criterion; DRC; enclosures; hearing loss; impulse noise; noise hazard

**19. ABSTRACT** *(Continue on reverse if necessary and identify by block number)*

The problem. Recoilless weapons commonly release a great deal of energy rearward in the immediate vicinity of the crew. If such weapons are fired from within structures, there is concern that in addition to the acoustic hazard to the ear or other organs, there might be hazard associated with flying debris or even structural collapse.

Studies. Two studies were conducted to evaluate such hazards by remotely firing a total of 24 rounds from the 90mm recoilless rifle, LAW, TOW, and DRAGON weapons systems from within enclosures (Price, 1978; Shank & Garinther, 1975). The structures, selected from available buildings, were made of various materials (reinforced concrete masonry, sandbags, and wood) and ranged in volume from 14 $m^3$ to 161 $m^3$ with venting areas from 2.9 $m^2$ to 11 $m^2$. Data included pressure histories, motion pictures of the structures and small objects placed in the room, and physiological data from 32 goats (tissue/organ system damage) and 8 cats (hearing loss measures).

Results and conclusions. At the firer's locations, peak pressures ranged from 178 to 189 dB and B-durations ranged from 28 to 376 msec. Although the firings commonly produced some structural damage, none of the firings caused structural collapse or induced tissue damage to non-auditory organs. Ear drum rupture did occur in 5 goats, and the cat ears exposed with no hearing protection did show permanent hearing losses. Of the cat ears exposed with hearing protection (EAR plugs), only one showed a permanent loss.

**20. DISTRIBUTION/AVAILABILITY OF ABSTRACT:** ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS

**21. ABSTRACT SECURITY CLASSIFICATION:** Unclassified

**22a. NAME OF RESPONSIBLE INDIVIDUAL:** Technical Reports Office

**22b. TELEPHONE** *(Include Area Code)***:** (301) 278-4478

**22c. OFFICE SYMBOL:** SLCHE-SS-TSB

AMCMS Code 611102.74A0011 Technical Memorandum 20-91

# FIRING RECOILLESS WEAPONS FROM ENCLOSURES

G. Richard Price

October 1991

APPROVED: JOHN D. WEISZ
Director
Human Engineering Laboratory





U.S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

# FIRING RECOILLESS WEAPONS FROM ENCLOSURES

G.R. Price
U.S. Army Human Engineering Laboratory
Aberdeen Proving Ground, Maryland 21005-5001
USA

## ABSTRACT

The problem. Recoilless weapons commonly release a great deal of energy rearward in the immediate vicinity of the crew. If such weapons are fired from within structures, there is concern that in addition to the acoustic hazard to the ear or other organs, there might be hazard associated with flying debris or even structural collapse.

Studies. Two studies were conducted to evaluate such hazards by remotely firing a total of 24 rounds from the 90 mm recoilless rifle, LAW, TOW, and DRAGON weapons systems from within enclosures (Price, 1978; Shank & Garinther, 1975). The structures, selected from available buildings, were made of various materials (reinforced concrete, masonry, sandbags, and wood) and ranged in volume from $14m^3$ to 161 $m^3$ with venting areas from 2.9 $m^2$ to 11 $m^2$. Data included pressure histories, motion pictures of the structures and small objects placed in the room, and physiological data from 32 goats (tissue/organ system damage) and 8 cats (hearing loss measures).

Results and conclusions. At the firer's locations, peak pressures ranged from 178 to 189 dB and B-durations ranged from 28 to 376 msec. Although the firings commonly produced some structural damage, none of the firings caused structural collapse or induced tissue damage to non-auditory organs. Ear drum rupture did occur in 5 goats and the cat ears exposed with no hearing protection did show permanent hearing losses. Of the cat ears exposed with hearing protection (EAR plugs), only one showed a permanent loss.

## INTRODUCTION

There are a variety of tactical situations in which it would be desirable to fire a recoilless* weapon from within an enclosure. An enclosure, which would provide cover

---

* The term 'recoilless' is used in this paper in the most general sense to include rockets as well as recoilless rifles.

and/or concealment to the firer, might be a position specifically prepared for the purpose, such as a bunker, or it might be an adventitious position in a room in a traditional building. However, the launch of such weapons typically results in the release of a great quantity of energy to the rear and the production of an intense blast field with attendant acoustic overpressures. In such a situation, there is legitimate concern for the safety of the crew as well as for their ability to perform tracking operations that might be necessary for the operation of the weapon system. The hazards include the blast field immediately to the rear of the weapon, the intense sound field generated, as well as the possibility of secondary hazard from the structure itself, e.g., flying debris or even structural collapse. In addition, the impulse loading on the firer as well as possible obscuration might make tracking of a target less accurate or even impossible.

This paper summarizes two studies that were conducted at the Human Engineering Laboratory at Aberdeen Proving Ground which were intended to provide at least partial answers to questions about the safety and practicability of firing recoilless weapons from within enclosures (Price, 1978; Shank & Garinther, 1975). The study by Shank and Garinther (1975) concerned itself primarily with all the aspects of hazard and performance except hearing loss and the study by Price (1978) focussed primarily on the question of hearing loss. Because of the limited space available, this paper will cover the essential elements of these studies. The reader is referred to the original papers for additional details.

## METHODS

The enclosures. Because of time constraints, firings were conducted from three wooden frame buildings and two concrete block/reinforced concrete buildings that happened to be available on site and could be sacrificed in such tests. They were chosen to represent rooms that were clearly too small as well as those that were a clearly adequate size for such firings. They ranged in volume from 14 $m^3$ to 161 $m^3$ and had venting areas that ranged from 2.9 $m^2$ to 11 $m^2$. In general, they were thought to be representative of firing positions one might find in conflicts in an urban setting. A bunker, consisting primarily of overhead cover with sand bags stacked half way up the sides, was constructed specifically for the tests. The weapons were positioned so that they fired along the long axis of the rooms and across the short axis of the bunker.

The weapons. Tests were conducted with four different weapons: LAW (a light anti-tank rocket normally fired from a launcher on the shoulder) (9 rounds fired), DRAGON (a heavier anti-tank rocket normally fired from a bi-pod and tracked to the target) (7 rounds fired), TOW (a heavy anti-tank rocket normally fired from a mounted launcher which was also used to guide the missile to the target) (4 rounds fired), and the 90 mm recoilless rifle (normally fired from the shoulder) (2 rounds fired). In all cases the firer's head would normally be immediately adjacent to the launcher/barrel. In these experiments, all weapons were on stands and were remotely fired.

Instrumentation. Pressure measurements were made with gauges facing up and down at the operator's head position (to discriminate reflections from the floor and ceiling) and at several other locations to the rear of the weapon and within the enclosures. Pressure measurements made within reverberant environments inevitably suffer from an inability to control the angle(s) of incidence of the wave(s). In the worst case, wave lengths that are short, relative to the microphone diaphragm's size, and impinge directly on the diaphragm, will be up to 6 dB higher than they would have been had they arrived at grazing incidence.

Because of the possibility of hazard from flying debris from the weapon itself or from objects in the room that might be thrown about by the blast, the experiments were monitored visually by a high speed motion picture camera and several video cameras. The tests also deliberately included objects in the rooms in the form of ping pong balls, ball bearings, rubber balls or furniture. A camera facing along the firing axis was included to check for possible obscuration of the view for the firer who might need to track the target.

Physiological effects. Physiological effects were evaluated by two methods. For 16 shots with weapons other than the recoilless rifle, two goats were located at the gunner's position, one on either side of the weapon (a total of 32 animals). Prior to exposure they had been shorn, so that their skin was bare and would serve to check on possible penetrations, contusions, or abrasions resulting from the exposure. They were awake at the time of the exposure and twenty-four hours post exposure they were sacrificed and autopsied to determine any pathologies that might be visible in the internal organs.

In order to test specifically for auditory impairment, tests were conducted with rounds fired from the 90 mm recoilless rifle. Four cats were exposed at a time to one round (a total of 7 cats, 14 ears). They were awake at time of exposure and were restrained in a loose fitting canvas bag mounted on a stand. As a check to see whether or not hearing protection would be effective under such extreme conditions, each cat was fitted with an EAR plug in one of its ears while its opposite ear was unprotected. Hearing thresholds were measured electrophysiologically two months post exposure (after any recovery processes had run their course) and losses were established by comparison with laboratory norms for unexposed animals tested with the same procedures.

## RESULTS

Acoustic pressures. The peak sound pressures at the firer's position varied primarily as a function of the weapon rather than on the enclosure. The average peak pressures for the LAW and the TOW were 180 dB respectively, and for the DRAGON and the 90 mm recoilless rifle were 186 dB respectively. The size and the construction of the enclosure did affect the reverberant field produced by the weapons' impulses. The measure called "B-duration" (the time required for the envelope of oscillations to drop to 1/10 of the peak pressure) reflects this effect. For example, the B-duration for the DRAGON fired from the bunker was 38 msec, from the frame rooms 49 through 69 msec (as the rooms grew larger) and finally 254 msec in the masonry room (a medium sized room). In essence, larger, harder-walled rooms maintain the sound field longer. The implications for hazard will be discussed in a later section.

Effects on structures and resulting debris. The smallest room (2.8 m x 2.2 m), a wooden frame structure, was severely damaged by DRAGON. The 4.6 m x 4.7 m frame building was clearly but not severly damaged structurally and the 9.1 m x 5.9 m frame building was barely damaged structurally, even after firing one LAW, one DRAGON and two TOW rounds from it. Furthermore, none of the damage indicated a threat to the gunner, because the damage tended to occur on the ceiling, and on the wall or walls away from the gunner's position. The masonry buildings, because of their heavy construction, showed little damage.

Surprisingly, debris would have represented little hazard to a firer. In no case was anything observed flying toward the front of the room with sufficient velocity to be dangerous. In support of this conclusion, none of the goats experienced any skin penetrations during the tests, even though they were oriented with their long axes toward the rear wall. Furthermore, even the items placed to the rear of the weapon moved surprisingly little. However, personnel standing directly in the back blast would certainly have been injured by the ignition plugs of the LAW and TOW missiles or by the blast from DRAGON or the 90 mm recoilless rifle.

The camera recording the firer's field of view showed that obscuration of the target would not have been a problem. As one would expect, the particulate matter in the air within the room following firing depended on the room's structure and the amount of dust already present in the structure. In any event, it was not felt to be a significant issue for military operation.

In summary, although wooden frame structures suffered some structural damage, there was no collapse that would have harmed the firer. The walls behind the weapon did suffer damage; however, the firer at the front of the room would not have been injured by debris from the weapon or any entrained in the back blast. So long as personnel stay out of the flow field behind the weapon, injury from debris is unlikely.

Physiological injury. In the goats, no injury attributable to the exposure was seen in the heart and aorta, kidneys, bladder, trachea, epiglottis, skin, eyes, brain, ribs, lungs, gastrointestinal tract, spleen or liver. The goats did, however, experience 6 ruptured ear drums (out of 64 exposed). These occurred to LAW firings within the masonry building and DRAGON firings in the bunker, the small and the large frame buildings.

The cats were examined visually on the day of exposure and no injuries were evident. Two months later, at the time of the electrophysiological tests of hearing, the ear drums of the ears exposed without plugs showed signs of stress visible under an operating microscope; but had no scars that indicated a healed rupture from the time of the exposure.

It should be recognized that the foregoing data are not exhaustive, are not from the human, and lack a theoretical base; but the lack of injury to anything other than the ears suggests that if the ears can be protected, firing one round from an enclosure may not be a great risk for a soldier and given certain tactical sitations, may be a much smaller risk than remaining in the open.

Hazard to hearing. The pressure history of the 90 mm recoilless rifle fired within the room is presented in Fig. 1 and its spectrum appears in Fig. 2. The peak pressure of the impulse is largely a function of the weapon alone; however, the duration of the impulse as well as the frequency content of the pulse was a function of the interaction between the room and the weapon impulse. The reinforced concrete construction resulted in a highly reverberant environment. The B-duration of a 90 mm recoilless rifle fired in the open is about 18 msec; but the reverberant environment extended it to 275 msec. The effect of firing in a reverberant environment can also

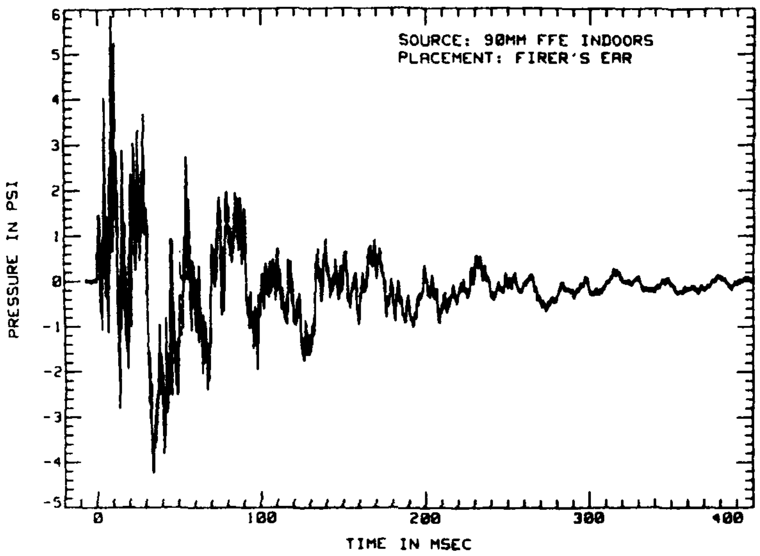


Fig. 1. Pressure history at the location of a firer's ear for a 90mm recoilless rifle fired within an enclosure.

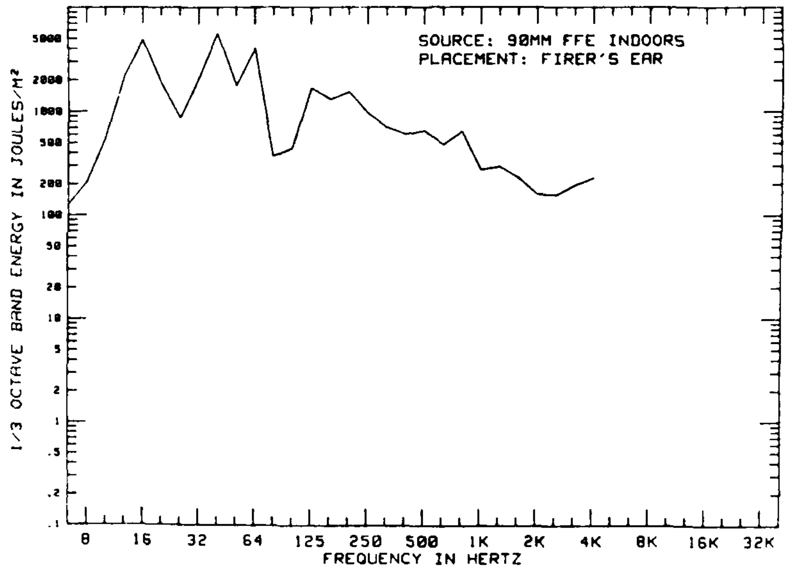


Fig. 2. 1/3 octave band energy spectrum of the recoilless rifle impulse in Fig. 1.

be seen in Fig. 2. The total energy in this exposure was about 36 kJ/m$^2$ with most of the energy appearing below 64 Hz. The same firing in the open would have resulted in about 2 kJ/m$^2$ and the spectral peak would have been nearer 125 Hz (Kalb, 1990). The increase of energy in the low frequency region was due to the fact that the dimensions of the room were such as to provide reflection paths suitable for the reinforcement of low frequencies.

The effect of a 90 mm recoilless rifle impulse on hearing sensitivity in the cat ears can be seen in Figs. 3 and 4. Fig. 3 shows individual thresholds for the ears exposed <u>with</u> ear protection. With one exception, it is apparent that they all fall in the normal range of sensitivity (shaded area). On the other hand, the ears exposed without protection showed permanent losses. The mean loss for this group is plotted in Fig. 4. On the basis of group means (either protected vs. unprotected ears in the same animal or unprotected ears vs. laboratory norms) the permanent losses were about 10-15 dB between 1 kHz and 10 kHz. It was interesting to note that the one animal that showed permanent losses in a protected ear also showed the largest losses in the group of unprotected ears as well; therefore, we speculate that that animal was either highly susceptible or it had the misfortune to be in a bad location during exposure.

On the basis of the foregoing data, it would seem that an EAR plug, known to be a good attenuator, is on the verge of being adequate protection for the cat ear for this particular exposure condition (one impulse at 186 dB peak level, 185 msec B-duration).

How might this finding in a cat ear relate to human exposure? The cat and human ears, like all mammalian ears, are highly similar in structure; however, they are not identical in all respects. In some noise exposure experiments (Miller, Watson & Covell, 1963) the cat ear has proved to be more susceptible than the human ear. It is probably fair to think of the average cat as a susceptible human being. Therefore, it is possible that a well protected human ear would have suffered no permanent effect from this exposure.

## IMPLICATIONS FOR DAMAGE-RISK CRITERIA

Given that the noise standard in use by the U.S. Army would not allow even one exposure to such an impulse, even with double hearing protection (MIL-STD 1474), the possibility that even a protected cat ear might survive such an exposure might be surprising. To provide another perspective, consider the fact that the energy in the single 90 mm recoilless rifle impulse was equivalent to the

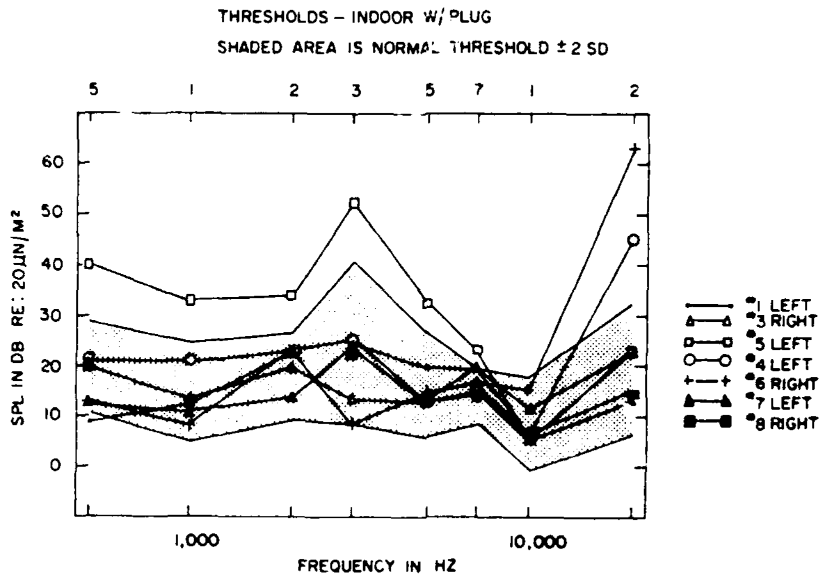


Fig. 3. Thresholds two months post exposure of the ears exposed, with hearing protection, to one 90 mm recoilless rifle impulse.

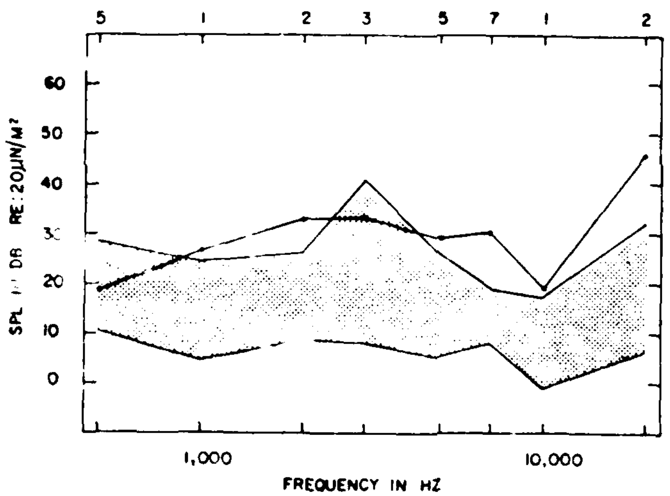


Fig. 4. Mean threshold two months post exposure for the group of ears exposed with no hearing protection to one 90 mm recoilless rifle impulse.

energy a worker would be exposed to in a 90 dB SPL sound field in about 5 years of daily employment! The basis for some of this apparent contradiction may lie in the methods used for rating hazard, a problem discussed in another paper in this symposium (Price & Kalb, 1990). At least two studies in which human subjects were exposed to low frequency impulses (howitzers) have shown that the ears showed much less threshold shift than the standards would have predicted (Hodge, Price, Dukes & Murff, 1979; Patterson & al., 1985). At this point, the data suggest that it may be possible to protect an ear from such an intense exposure with hearing protection that is properly fitted and worn. These exposures are properly viewed as hazardous and exposure to them should not be taken lightly.

REFERENCES

Hodge, D. C., Price, G. R., Dukes, N. L. & Murff, S. J. (1979) Effects of artillery noise on the hearing of protected crew personnel. Technical Memorandum 19-79, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, 37 pp.

Miller, J. D., Watson, C. S. & Covell, W. P. (1963) Deafening effects of noise on the cat. Acta-Otolaryngol. Suppl 176, 91 pp.

MIL-STD 1474(B) (1979) Noise limits for Army materiel. U.S. Army Missile Command, Redstone Arsenal, AL.

Patterson, J. H., Mozo, B. T., Marrow, R. H., McConnel, R. W., Lomba-Gautier, I., Curd, D. L., Phillips, Y., & Henderson, R. (1985) Direct determination of the adequacy of hearing protective devices for use with the M198, 155mm towed howitzer. USAARL Report No. 85-14, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL.

Price, G. R. (1978) Firing from enclosures with 90 mm recoilless rifle: Assessment of acoustic hazard. Technical Memorandum 11-78, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, 14 pp.

Price, G. R. & Kalb, J. T. (1990) A new approach to a damage risk criterion for weapons impulses. In Proceedings of XXI Nordic Congress of Military Medicine, Oslo, Norway.

Shank, E. B. & Garinther, G. R. (1975) Firing from enclosures with LAW, DRAGON and TOW. Technical Memorandum 16-75, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, 39 pp.