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Technical Memorandum 9-83

AN ACOUSTICAL ASSESSMENT OF THE IMPULSE NOISE OF GRENADE SIMULATORS EXPLODING IN ENCLOSURES

Georges R. Garinther
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July 1983

U. S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

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An assessment was made of the impulse noise produced when exploding grenade simulators both outdoors and at various locations and distances in two different shaped rooms with and without furnishings. The peak pressure level of the grenade simulator when measured outdoor was 178 dB and its B-duration was 6 msec.

The effect upon the impulse noise produced by a grenade simulator exploding at various locations with reference to the walls is described. The effect of

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ABSTRACT (Continued)

furnishings is given and equations are provided for computing peak pressure level and B-duration. A program is provided for producing idealized pressure time histories of the impulse noise with the explosive and transducer at various locations with reference to the walls. Proper instrumentation techniques are provided for measuring impulse noise in rooms.

The potential hazard for personnel who might undergo a once in a lifetime exposure is estimated for different impulse noise levels of exploding grenade simulators inside rooms Also, appropriate precautions for use in training, such as hearing protection, maximum number of exposures and maximum exposure level, are discussed.

AMCMS Code 611102.74A0011

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OF GRENADE SIMULATORS EXPLODING IN ENCLOSURES

INTRODUCTION

Considerable interest has been shown recently regarding the potential physiological hazard on personnel exposed to a single diversionary charge exploding in a room. Under consideration is the size of the explosive which might be used, the effect upon resultant impulse noise of exploding the device in a corner versus in the center of the room, the size of the room, the distance of personnel from the explosive, and the effect of a room with furnishings as opposed to an unfurnished room.

The potential hazard to hearing was assessed for various levels of impulse noise produced by a single exploding charge. Other less sensitive portions of the body such as the lungs and other gas filled organs were not considered since they would normally not be affected at the sound pressure levels being discussed in this report.

Since exposure to a diversionary charge would, hopefully, be a once in a lifetime experience, and since conventional impulse noise damage risk criteria (DRC) would not be applicable, the potential effects upon hearing for this application are based upon known single exposures or "case histories." It must be emphasized that this entire evaluation is based upon an exposure consisting of a single explosive. The conclusions drawn in this report regarding resultant hearing losses may not apply if the insulting impulse noise is followed by a second explosion or by other impulse noise such as that resulting from nearby gunfire. This evaluation is, of necessity, not based upon a large amount of data nor is it purported to be a medical assessment of a potentially hazardous situation. It is, however, based upon available scientific evidence.

In deciding that impulse noise level which might be used, consideration must be given to producing the least amount of potential damage to hostages while accomplishing the mission of a diversionary charge. "Actual" exposure of hostages to a diversionary charge, as opposed to a training situation, is one in which the potential risk to life must be balanced against the potential risk to hearing. This is comparable, in some degree, to the military situation where in actual combat many situations will arise where it is not possible to protect the hearing of soldiers, while in training every effort must be made to protect their hearing.

This report will address recommended hearing protection and other precautions required during training and familiarization exercises for those both near the explosive and in adjacent rooms.

In addition to assessing auditory hazard, the effect of explosive location upon pressure measured at different locations within the room was investigated. Finally, instrumentation techniques used to accurately measure impulse noise inside buildings are discussed.

PURPOSE

The purpose of this study is to provide information to estimate the potential physiological effects upon personnel when exposed to a single diversionary charge exploding in variously configured confined areas. More specifically, this study may be broken down into the following four tasks:

1. Assessment of the potential hearing hazard, based upon best scientific judgement, which may result if exposed to a single impulse produced by a grenade simulator exploding under a variety of room conditions and locations within rooms.

2. Recommending procedures for use in training situations to prevent hearing loss in instructor personnel who may be repeatedly exposed to the impulse noise of these grenade simulators.

3. Determination of the effect upon the free field pressure of exploding a grenade simulator in two different shape rooms with and without furnishings and of measuring the impulse waveshape at different locations within the room.

4. Description of proper instrumentation and proper techniques to be used when measuring high intensity impulse noise inside a room with its inherent reflective surfaces.

PROCEDURE

General

The impulse noise produced by 78 explosive devices was measured by personnel of the US Army Human Engineering Laboratory (HEL) in two rooms of a dwelling (Bldg 799) located at Aberdeen Proving Ground during the periods of 7-9 December 1981 and 12-15 January 1982. The following types of devices were exploded during these tests:

1. Simulator, hand grenade: M116A1 with modified fuse.
2. Simulator, hand grenade: M116A1 with modified fuse, and with soft epoxy ends.
3. QED
4. FFE (single base)
5. FFE (dual base)
6. Flash-Bang

Descriptive data for the M116A1 grenade simulator are given in Appendix E. The last four devices are items which were tested solely for comparative purposes: only items 1 and 2 are being considered for use as diversionary devices.

For most conditions, three or more devices were measured in order to provide valid statistical samples. In order to simulate a worst case situation for two locations within the room, the devices were exploded in the center and in the corner of the room with most measurements made 30" and 65" above the explosive. These two heights simulated a hostage at sitting height and standing height directly above the explosive. Measurements were made in a kitchen (Figure 1), in a bedroom (with and without furnishings, Figure 2) and outdoors. Furnishings were added to the bedroom for some of the tests to estimate the effect of adding absorption and diffusion to the room.

The furnishings for the room consisted of a 9 x 12 foot carpet, an upholstered couch, two upholstered chairs, a small desk, a television cabinet and sheer curtains on the two windows. The device was exploded on a sheet of 2 x 2 foot ballistic nylon placed over the carpet to prevent fire.

During the detonations, a Bruel & Kjaer type 2209 peak reading impulse sound level meter with a type 4136 condenser microphone was placed in an adjacent room near the door in order to determine the pressure at that location and to detect variations in pressure.

Instrumentation

The measurement procedures used for this study were those described in MIL-STD 1474B, 1979. This document specifies the method used for measuring the impluse noise waveshape produced at the operator's position of weapons such as guns, howitzers, and rifles. Although this document specifies that a minimum of three measurements be made per condition, due to limited availability only two devices were exploded for some conditions.

The transducer used for making the impulse noise measurements was a Piezotronics PCB Model 101M49, S.N. 2039, quartz pressure gauge. The sensitivity of this transducer was 127.5 mV/psi. It was connected by 100 feet of RG-59 coaxial cable to a Piezotronics Model 482A power supply. The signal was then connected to two Nicolet Explorer III digital oscilloscopes. The first oscilloscope was set for a total sweep time of 8 msec in order to accurately measure the peak pressure; the second oscilloscope was set at a slower sweep time in order to measure the B-duration of the pressure-time history (the time taken for the envelope of pressure fluctuations to decrease to 1/10 of the peak pressure). Each waveshape was then stored on a 5-1/4" floppy disk for subsequent analysis. The transducer was calibrated immediately following the study at the HEL shock tube facility.

ANALYSIS

When determining the potential hearing hazard of impulse noise, current DRC require peak pressure level and B-duration of the waveshape produced by the explosive. In analyzing the waveshapes for this study, peak pressure was obtained from the digital oscilloscope set at a sampling time interval of 2 microseconds per point (total sweep time was 8 msec). This sweep speed provided a sufficiently short sample time to accurately measure the peaks of high frequency short duration spikes. It is important when using a digital oscilloscope to ascertain that short spikes do not fall between discrete sampling points, thereby being underestimated.

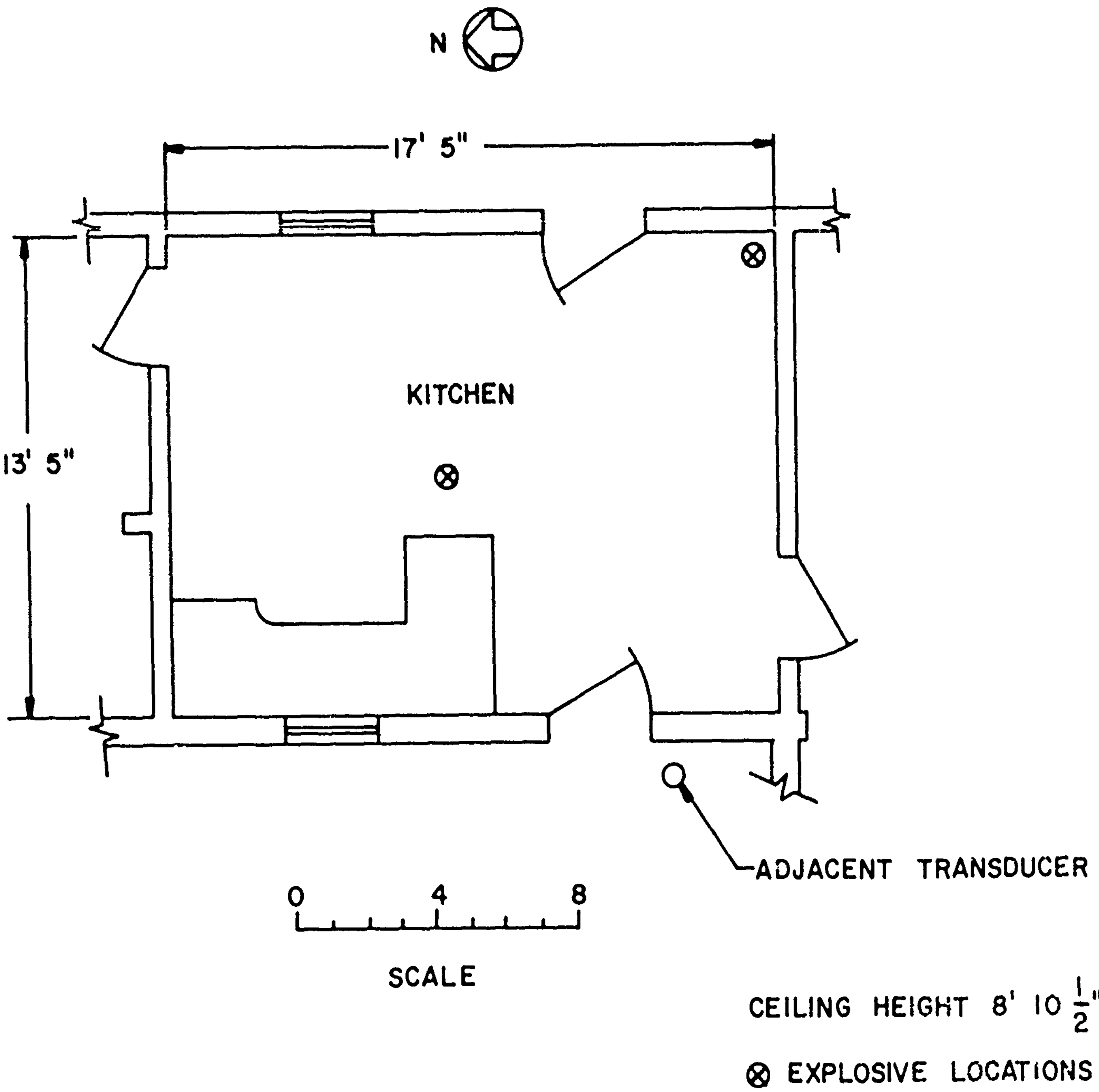

Figure 1. Plan view of kitchen.

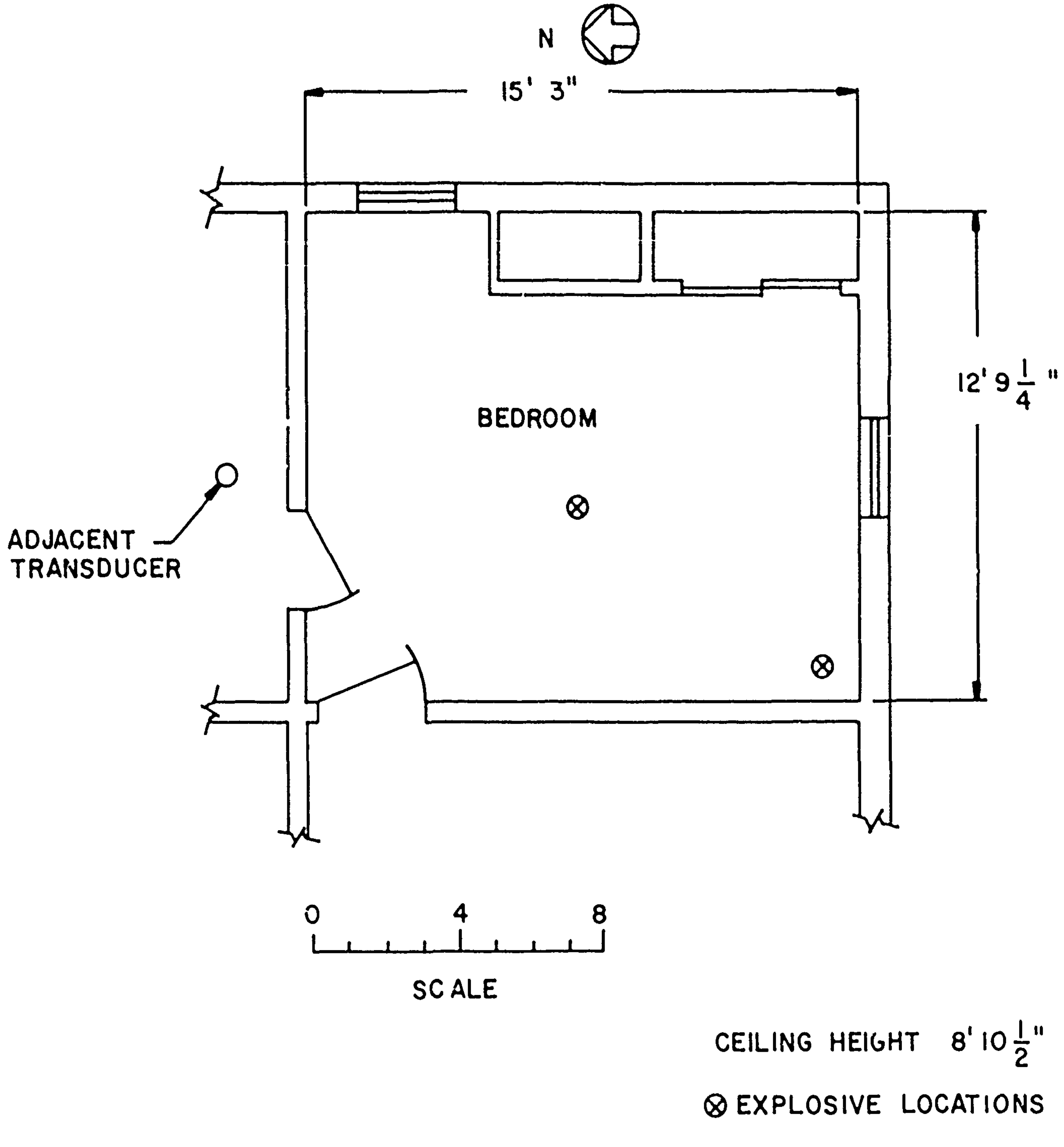

Figure 2. Plan view of bedroom.

B-duration was obtained from the second digital oscilloscope which was set at a much slower sweep speed varying from a total time of 40 msec to several hundred msec, depending on the duration of the pulse.

At approximately 40 msec after initiation of the pulse, the oscilloscope trace shifted downward due to the flash produced by the explosive. This shift was minimized somewhat by covering the sensing surface of the gauge with a layer of black electrical tape, but was still significant enough to affect determination of those B-durations which exceeded 40 msec. Because of this flash-produced shift, for waveshapes having a long duration, B-duration was determined by finding the time at which the peak-to-peak deflection decreased to one fifth of the maximum pressure level.

RESULTS

The results of the analysis for each detonation are shown in Appendix A, with peak pressure expressed both in decibels (dB) and pounds per square inch (psi). Tables 1 and 2 show the average peak pressure level and B-duration produced by each type of diversionary device for each measurement condition; range and number of measurements for each condition are shown in Appendix B.

Examination of the data of Tables 1 and 2 produces the following results:

The range of peak pressure levels produced by the M116A1 for all conditions tested was 171-190 dB.

Peak pressure levels are essentially the same (average difference of 1.5 dB) when measured at the same distance above a charge exploding outdoors or away from the walls of a room either with or without furniture.

Peak pressure levels are essentially the same (average difference of 0.8 dB), at the 30-inch microphone height, when measured at the center of the room or near the corner of the room: at the 65-inch microphone height, peak level is about 2 dB higher in the corner.

Peak pressure levels increase by approximately 7 dB when measured at 30" vs 65" above the explosive.

Enclosing the ends of the M116A1 with a soft epoxy reduces the peak pressure level by about 8 dB.

B-duration increases by a factor of about 20 when exploding a grenade simulator inside an unfurnished room vs outdoors.

B-duration decreases by a factor of about 4 when furniture is added to a room.

B-duration decreases by a factor of about 2 when a charge is exploded in a corner vs in the center of a room.

TABLE 1

Average Peak Pressure Level (dB) of Various Explosives Under Different Room Conditions and Outside

Explosive	Room Condition	Explosive in Center of Room		Explosive in Corner of Room			
		65" MIC	30" MIC	65" MIC	30" MIC	65" Above Floor Center[a]	65" MIC
M116A1 (Normal)	Outside (Over Grass)						178.4
M116A1 (Normal)	Kitchen (No Furniture)	178.7	187.6		187.6	172.5	
M116A1 (Normal)	Bedroom (w/Furniture)	175.7	187.9	186.8	190.0		
M116A1 (Normal)	Bedroom (No Furniture)	180.0	186.1	182.6	186.4	176.2	
4116A1 (w/Soft Epoxy Ends)	"	171.6				171.0	
QED	"	183.0					
FFE (Single Primer)		170.1					
FFE (Double Primer)	"	172.7					
Flash Bang	"	168.2					

[a]All microphone distances are above the explosive, except for this measurement which was made 65" above the center of the floor with the explosive in the corner.

TABLE 2

Average B-duration (msec) of Various Explosives Under Different Room Conditions and Outside

Explosive	Room Condition	Explosive in Center of Room		Explosive in Corner of Room			
		65" MIC	30" MIC	65" MIC	30" MIC	65" Above Floor Center[a]	65" MIC
M116A1 (Normal)	Outside (Over Grass)						6
M116A1 (Normal)	Kitchen (No Furniture)	136	21		31	178	
M116A1 (Normal)	Bedroom (w/Furniture)	69	10	17	7		
M116A1 (Normal)	Bedroom (No Furniture)	196	39	78	19	150	
M116A1 (w/Soft Epoxy Ends)	"	158				169	
QED	"	128					
FFE (Single Primer)		208					
FFE (Double Primer)	"	172					
Flash Bang	"	177					

[a] All microphone distances are above the explosive, except for this measurement which was made 65" above the center of the floor with the explosive in the corner.

An artifact may be noted on the peak levels obtained in the bedroom with furniture when measured 65" above the explosive detonated at the center of the room (Table 1). These levels are approximately 4 dB low when compared to the data obtained for the same condition in the kitchen or the unfurnished room. We believe the reason for this is that these were the first charges to be measured on the soft carpet which absorbed some of the energy, thereby producing a lower peak level. As subsequent charges were exploded, the carpet was compressed producing a harder reflective surface with inherently higher peak levels.

DISCUSSION

Hearing Loss Due to Single Unprotected Exposures

When investigating the potential physiological damage to an individual exposed to blast, we are normally concerned about effects upon hearing and upon the gas filled organs. The most sensitive of the gas filled organs are the lungs. Bowen et al., 1968, have shown that for single exposures at durations such as those obtained in this study the threshold for lung damage is 15 psi (194 dB) for the most hazardous body orientation; i.e., for the thorax near a reflecting surface which is perpendicular to the blast wave. Therefore, levels such as those produced by these grenade simulators should not produce lung damage.

Turning to the hearing mechanism, we need to deal with two considerations: eardrum rupture and hearing loss. The threshold for eardrum rupture is about 185 dB (5 psi). However, in most cases, with proper treatment a ruptured eardrum in which the bones of the middle ear remain intact will heal completely with no loss of hearing (Hodge & Garinther, 1973). For levels below 185 dB, potential hearing loss must be considered.

Cases of Accidental Exposure to Explosives

A number of documented cases have been reported which provide hearing loss data resulting from unexpected or accidental exposure to a single unprotected high level impulse noise. Ward & Glorig, 1961, have described the hearing loss resulting from an accidental exposure to a firecracker (2" long by 3/16" diameter) held 15" from a person's ear. For this individual, pre-exposure level was accurately known and the resultant permanent change in hearing level was 50 to 60 dB at 3,000 Hz and above.

Kerr & Byrne, 1975a, reported the results of a 5-pound bomb exploding in a 40' x 45' x 9' restaurant in Belfast in which two people were killed and in which five people lost limbs. In addition, there were serious injuries from head trauma, broken bones, burns, and lacerations. Of the 80 survivors examined, there were 60 ruptured eardrums and almost all of the individuals reported tinnitus. Almost all had some hearing loss which "recovered rapidly in most, more slowly in others, and did not recover in some." Thirty three percent incurred permanent losses averaging greater than 30 dB at 4,000 and 8,000 Hz, 11% of which had significant hearing loss that affected speech perception somewhat with 6% having a serious bilateral hearing loss. Pre-exposure hearing levels were unknown for these people and the reported hearing losses are based upon the assumption that hearing was normal prior to the blast. Also, unfortunately, the pressure characteristics of the explosives where neither available for this case nor the case reported by Ward.

Based upon these two explosions, significant permanent hearing loss can indeed occur from a single unprotected exposure to high level impulse noise and any exposure to such levels must be taken very seriously. Kerr & Byrne, 1975b, have reported, however, that fortunately even at the high levels produced by the Belfast bomb, in most cases "the ear has excellent properties of recovery after exposure to blast."

Conventional Damage Risk Criteria

The hearing hazard presented to personnel repeatedly exposed to high intensity impulse noise would normally be assessed by comparison to a generally accepted damage risk criterion such as the CHABA (NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics) Impulse Noise Damage Risk Criterion (NAS-NRC, 1968). However, this DRC, as well as others (Pfander, 1975; Smoorenberg, 1980), is not applicable to the situation presently being discussed for two reasons. First, these DRC are designed to protect exposures which are repeated each day for many years as would occur in a normal industrial and in some military situations. One may rightfully conclude that the situation presently being discussed should occur only once in a lifetime and certainly only once in a day. Secondly, a DRC is designed to limit hearing losses to a level which will not interfere with a person's normal social life even after exposure for many years. For example, adherence to the CHABA level is intended to limit impulse noise induced hearing loss obtained over a lifetime in 95% of the population to 10 dB at 500 Hz and below, 15 dB at 1,000 Hz, and 20 dB at 2,000 Hz and above. Obviously, an incident involving the use of a diversionary device should be considered critical, and hence, the potential hazard to hearing must be subordinated to the potential hazard to life.

For both these reasons, the CHABA limit which would restrict a single daily exposure to 152 dB for an exploding grenade simulator having a B-duration of approximately 50 msec would be inappropriate. Therefore, we must rely in this situation upon the effects of known single exposures or case histories which have been documented, and best scientific judgement in assessing risk from such exposures.

Current Research in Impluse Noise DRC

Recently CHABA has established an ad hoc working group to determine if there are sufficient new data to warrant a revision of the CHABA impulse noise DRC. The first meeting concluded that there was sufficient data to warrant a re-examination of the DRC, but that at the present time there was insufficient data to specify the changes which should be made. Basic research being conducted at HEL has produced evidence that a spectrally dependent critical level may prove to more accurately assess hearing damage than the present use of peak level and duration (Price, 1981; Price, 1982; Price 1983). This change would have wide implications in the assessement of impluse noise produced by weapons larger than small-arms (low frequency producing weapons) since it would permit exposure to higher levels than permitted by current DRC for low frequency impulse noise.

Succeeding Exposures

In addition to the characteristics of the noise, one must consider succeeding exposures in order to limit permanent hearing loss from high level impulse noise. Current DRC are based upon the tenet that impulse noise produces a temporary threshold shift (TTS) from which an individual may recover in anywhere from a few minutes to a number of days. If a permanent hearing loss is to be avoided, it must be ascertained that temporary hearing loss has completely recovered before succeeding exposures are permitted. If complete recovery has not yet taken place, and if due to an additional exposure on the same day or on a succeeding day a noise induced TTS occurs on top of the original one, there is an increased probability that permanent hearing loss may result. A single impulse must neither produce a hearing loss from which recovery never takes place, nor one where succeeding exposures add to the existing temporary hearing loss. Therefore, care must be taken that a person who has incurred a TTS from a diversionary device is not exposed to additional TTS producing noise prior to complete recovery.

Case Histories

Since there is no DRC which specifies that level which must not be exceeded for this type of "once in a lifetime" exposure, and since the accidental exposures previously cited provide data showing that permanent hearing loss does occur but do not provide data regarding the probability of its occurence at various levels, a suggested tolerable limit would of necessity be based upon our scientific judgement and a scant number of case histories. Three case histories which are described below in increasing order of severity are available to help describe the auditory hazard at varying levels.

Air Bag Exposures

The first study which has implications for single high level impulse noise exposures was the testing of the automobile personal restraint system employing a rapidly expanding air bag. This study which exposed 91 unprotected subjects to high level impulse noise was conducted in 1969 by the Air Force Biological Acoustics Branch (Nixon, 1969). It consisted of a single exposure to levels ranging from 167-170 dB with a B-duration of 21 msec. Figure 3 shows the resultant temporary threshold shifts from this exposure.

Immediately following each exposure, hearing levels were measured and repeat audiograms were given until complete recovery was achieved. About 65% of the individuals recovered to their pre-exposure levels within 24 hours, 95% within 1 week, and 99% within 2 weeks. One individual had a 10 dB TTS remaining at one frequency (600 Hz) after 6 months. This may have been an artifact caused by subsequent high level noise exposures encountered in this individual's normal work in which he operated a jackhammer (without hearing protection) and flew an airplane prior to complete recovery (Nixon, 1982).

From this study on 91 subjects, we can conclude that the hearing level of 90 of the subjects exposed to a single air bag explosion did return to normal within 2 weeks, while one individual may or may not have incurred a hearing loss from the air bag explosive. If we assume the worst case, that he did incur a hearing loss, we can state that 1% of those exposed had a hearing loss which was limited to 10 dB at 600 Hz. However, it must be stressed that 35% of those exposed did show some delay in the recovery process.

Rocket Launcher Exposures

In 1971, a study was conducted by HEL to determine the effect upon hearing when exposed to the firing of a single round from the M72 rocket launcher without hearing protection (Garinther & Hodge, 1971). Twenty-eight volunteers fired this weapon which has a peak pressure level of 180 dB and a B-duration of 12 msec. The temporary threshold shift resulting from a single firing without hearing protection is shown for the 95th percentile in Figure 4. This figure indicates that a temporary threshold shift occurred which is indeed above that which would "normally" be acceptable as shown by the curve labeled "CHABA limit." The word normally as used here refers to a TTS produced in a situation where more than one exposure would occur per day, and in which the exposure would be repeated several times per week for a number of years.

Immediately following each exposure to the rocket launcher, the hearing levels of the subjects were monitored to determine the length of time required for complete recovery, and to assure ourselves that their hearing did indeed return to its pre-exposure level. It is well known that recovery from high values of TTS can be very slow, being essentially linear in time rather than linear in log time as usually found for smaller values of TTS (Ward, 1960). Further, it has been shown (Luz & Hodge, 1971) that even for smaller values of impulse-noise induced TTS, recovery may not take place in a log-time fashion.

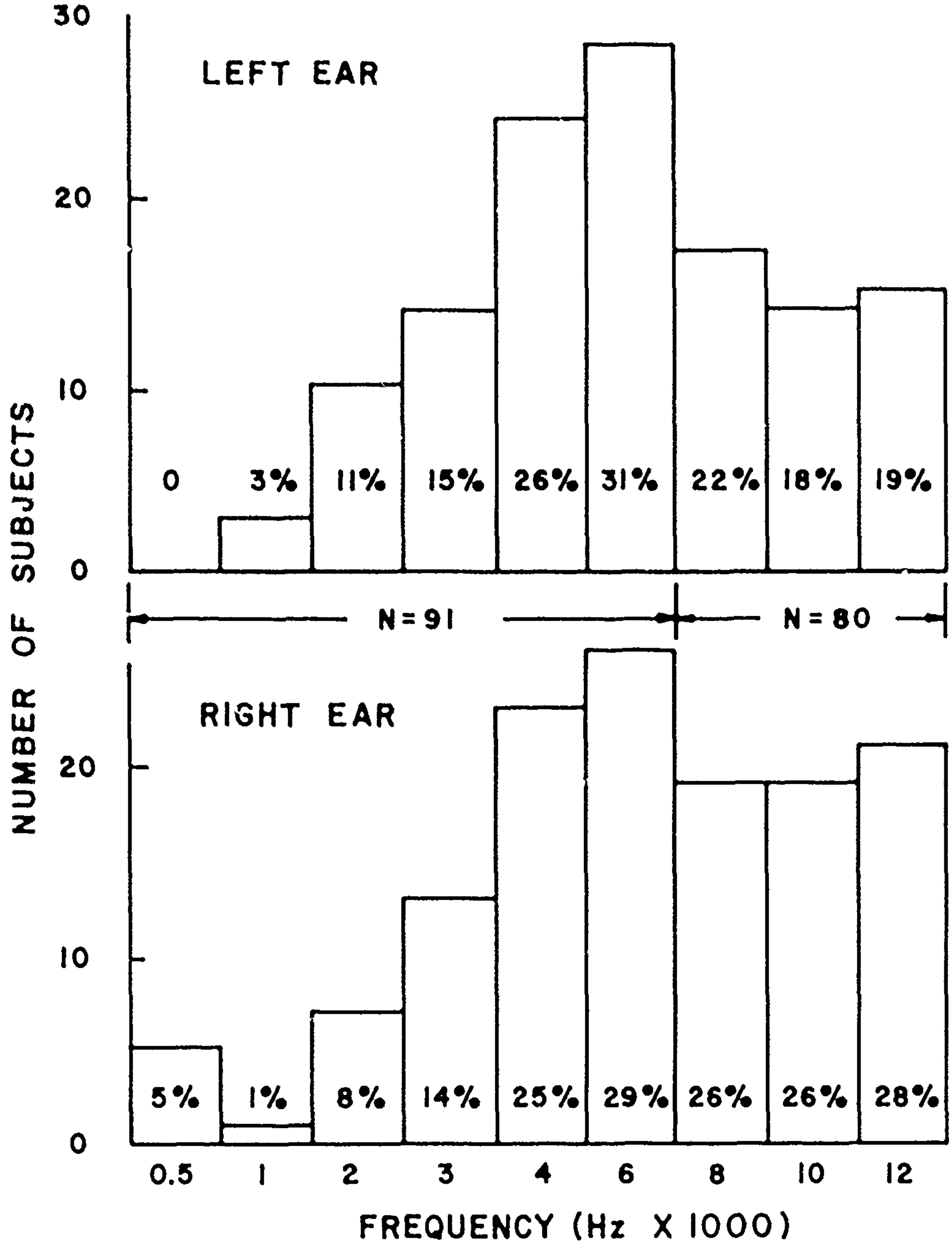

Figure 3. Incidence of TTS due to 167-170 dB exposure among ears of all subjects at each of the frequencies (from Nixon, 1969).

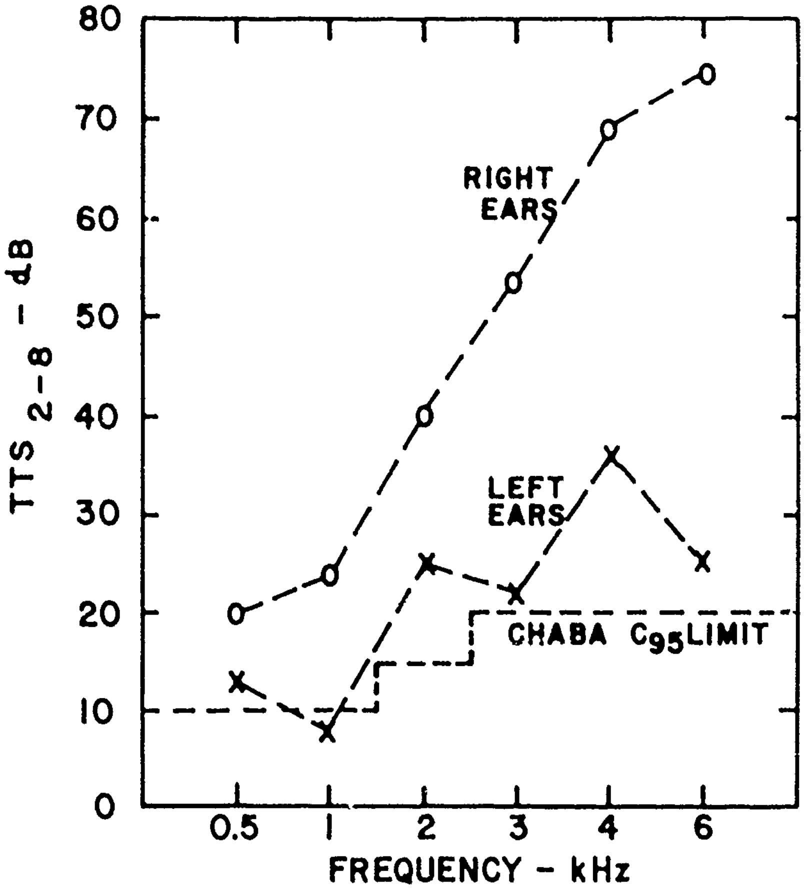

Figure 4. C_{95} TTS at operator's position of M72 law compared with CHABA C_{95} limits.

For this study most subjects recovered completely within 4 days, in several cases, however, recovery required up to 6 weeks. One individual who still had a small amount of hearing loss at the end of the 6-week period was released to his home station where he was to have his hearing level monitored; it is not known whether his hearing level completely returned to normal.

From these data on 28 subjects, we can conclude that 27 of the subjects exposed to a single shot from an M72 did return to normal within a period of 6 weeks, while the hearing level of one individual may or may not have returned to normal. If we assume the worst case, that he did not recover, we can state that 4% of those exposed had a hearing loss, which based upon this study was limited to less than 15 dB at frequencies above 2,000 Hz. Again, it must be stressed that recovery took place over a period of days or weeks for some individuals.

Artillery Exposures

The third set of information contributing to the determination of the potential effect of a single exposure to high level impulse noise is the exposures of Army personnel to artillery weapons used both in training and in combat. The highest impulse noise producing weapon which is standard in the Army is the 106mm recoilless rifle which produces a peak pressure level of 188 dB and an estimated B-duration of 20 msec at the operator's ear. This weapon has been in use since the beginning of the Korean War. Prior to the last 10 years, when less emphasis was placed on hearing conservation and the proper use of hearing protection, the 106mm RR was routinely fired without protection. Although it has been documented that artillerymen have incurred "clinically significant hearing losses" after several years in artillery (Walden et al, 1975), we have not been able to find documentation indicating that any single exposure at the operator's position of a weapon such as the 106mm RR was of itself sufficiently severe to have been reported as the cause of a known permanent hearing loss or acoustic trauma. This does not mean that acoustic trauma from single exposures has not occurred; we are sure it has, but it does indicate that this is probably not the prevailing condition when firing a single round. Those hearing losses, which were sufficient to have a noticeable auditory effect upon personnel, were in most cases caused by many firings per day over several years. Walden et al have shown that artillery crewmen who have been in the service for 1.5-2.4 years have mean hearing levels of 10.6, 10.2, and 9.9 dB at 500, 1,000 and 2,000 Hz, respectively, with corresponding standard deviations of 6.6, 6.2, and 8.3 dB, respectively.

Based upon these limited facts, there is insufficient data to quantify that percent of the population which might incur a hearing loss following a single unprotected exposure to levels between 180 and 188 dB. We can, however, infer that significant hearing loss will result in some individuals.

Estimates of Risk from Case Histories

These case histories which provide hearing loss data for single unprotected exposures at three different levels for impulse noise having B-durations ranging from 12-21 milliseconds may be summarized as follows:

1. Below 170 dB the probability of irreversible harm to personnel appears to be small (1% of exposed personnel). Also, persons exposed to this level have not complained of pain (pain is an indication that the eardrum may have been over-driven). However, exposure to this level will produce ringing or tinnitus in many persons for a short period of time.

2. Between levels of 170 and 180 dB, a single impulse may cause some degree of permanent hearing loss at frequencies above 2,000 Hz in up to 4% of personnel exposed. Also, tinnitus will occur in most persons for a number of hours or days.

3. Between levels of 180 and 188 dB, a single unprotected exposure will produce significant permanent hearing loss in some personnel, but due to the lack of data it is not possible to quantify the number of affected persons. In addition, the threshold for eardrum rupture occurs at 185 dB.

Estimates of Risk for Diversionary Devices

When assessing the hearing hazard of an impulse noise, duration must also be considered. Based upon the CHABA DRC, there is a trading relationship of 2 dB per doubling of duration between peak pressure level and B-duration. In other words, for each doubling of B-duration, peak pressure level must be reduced by 2 dB to produce an equal auditory hazard. Examination of the data of Table 2 indicates that B-duration ranges from 6-196 msec for the M116A1 grenade simulators under the conditions measured, while it ranges from 12-21 msec for the case histories. If we select the median B-duration of the M116A1 grenade simulators (54 msec) as being representative of the conditions being assessed and 20 msec as the median of the case histories, 3 dB must be subtracted from the peak levels obtained in the case histories to obtain the same degree of potential hazard. Therefore, in assessing the auditory hazard presented by a diversionary device exploded in an enclosure in which the B-duration is approximately 50 msec, 3 dB must be subtracted from the exposure levels given in the estimates of risk from case histories given above. Additionally, for rooms in which the reverberation time is known to be very long, such as churches with hard walls or buildings with marble interiors, the exposure levels should be reduced accordingly.

Variability of Impulse Noise Induced Hearing Loss

A final caveat must be made regarding the statistical probability of auditory damage due to impulse noise. Experiments in which personnel have been exposed to given levels of steady-state noise have shown a reasonably small variability. On the other hand, exposures to given levels of impulse noise have resulted in a very wide variation of hearing losses among personnel. Therefore, any predictions of impulse noise induced hearing loss are only applicable to reasonably large, statistically valid groups which may be representative of the population. The predictions may not apply to a single individual who may be ultra-sensitive to impulse noise and incur a large hearing loss when exposed to a relatively low level, i.e., less than 167 dB. Likewise, another individual may be exposed to a level above 177 dB with absolutely no detrimental effects. There is no way to predict the auditory effect upon a single individual who ultimately may be rescued using these explosive devices.

Hearing Loss Due to Training

Exposure to impulse noise from diversionary devices exploded in training may be in the form of three different situations:

1. Exposure to explosions occurring outdoors.

2. Exposure to explosions occurring in an adjacent room.

3. Exposure to explosions occurring in the same room.

In all of these training situations, hearing protection must be worn and in certain cases the number of daily exposures must be limited (Letter, HQDA). Appropriate hearing protection for these exposures is considered to be any good quality, properly fitted earplug, earmuff, or the use of fingers to occlude the ears (Holland, 1967).

For exposures to the M116A1 outside, where the peak level is approximately 140 dB at 100 feet, hearing protection is recommended within 100 feet of the explosive.

Occasional exposures to the M116A1 in an adjacent room should be conducted with hearing protection, particularly if the individual is near the door leading to the explosive. Repeated training exposures must be conducted with protection.

Exposures to the M116A1 (with soft epoxy ends) in the room itself must be conducted with well fitted hearing protectors at all times; the number of exposures limited to five per day and assurance must be made that the impulse noise level at the ear does not exceed Category Z of MIL-STD 1474B (See Figure 5).

Exposures to the normal M116A1 in the room itself should not be conducted. If it is necessary to expose personnel to this device, additional testing and evaluation (i.e., a walk-up study) of the normal M116A1 should be performed prior to exposing personnel.

IMPULSE NOISE LIMIT SELECTION CRITERIA

Maximum Expected Number of Exposures in a Single Day*	Impulse Noise Limit		
	No Protection	Either Plugs Or Muffs	Both Plugs and Muffs
1000	W	X	Y
100	W	Y	Z
5	W	Z	Z**

*A single exposure consists of either (a) a single pulse for non-repetitive systems (systems producing not more than one impulse per second; e.g., semiautomatic weapons), or (b) a burst for repetitive systems (systems normally producing more than one impulse per second; e.g., automatic weapons). (See 5.4.4.3)

**Higher levels than Curve Z not permitted due to possibility of other non-auditory physiological injury.

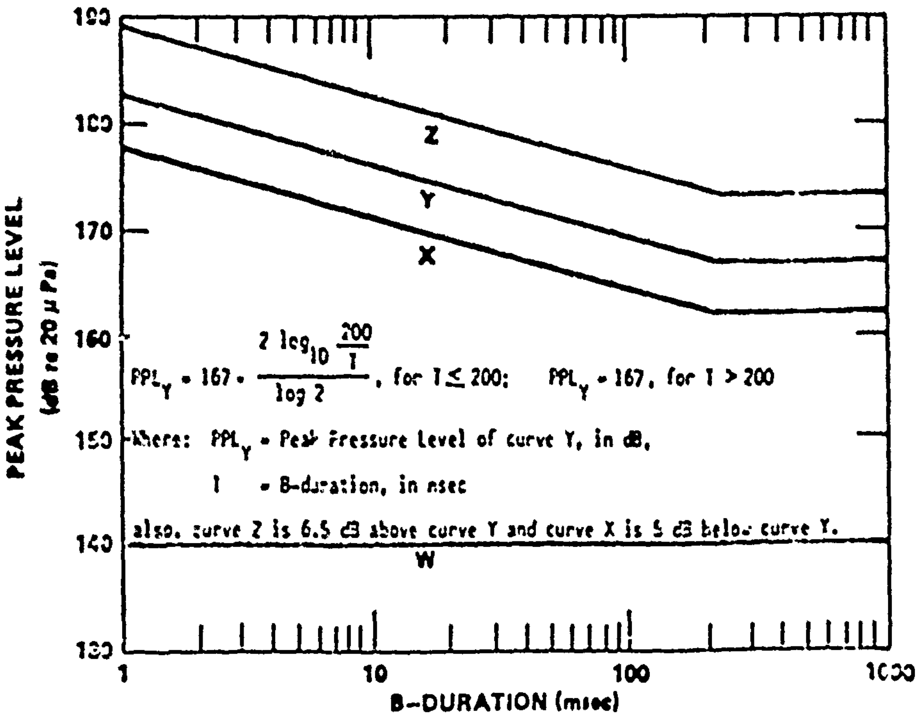

Figure 5. Peak pressure level and B-duration limits for impulse noise per MIL-STD 1474B.

Impulse Noise Waveshape Changes Due to Room Parameters

The energy released suddenly in an explosion produces a blast wave that travels predictably into the surrounding air. As shown in Figure 6, the blast wave arrives at a distance R after a time T_s, causing the pressure to increase to a peak value P_s and to decay back to ambient over a time interval T_s (also called the A-duration). Extensive measurements near explosives ranging in weight from an ounce to 500 tons have shown that a scale model can be formulated to describe these quantities as a function of distance from the source (Baker, 1973 & Goodman, 1960). The procedure known as Hopkinson scaling starts by dividing all distance and time quantities by $W^{1/3}$ (one-third power of the charge weight) to account for the amount of explosive present. All quantities with dimensions of pressure and velocity are left unchanged in the scaling. Empirical formulas and tabulated values then give the blast parameters which would occur for a free-air explosion (one with no reflecting surfaces nearby).

In those cases where the explosion occurs on a surface such as the ground or a floor, a stronger blast wave forms since the ground reflection merges with the direct-air wave. Part of the energy is lost (about 20% depending on the surface texture [Filippone, 1951]) in surface absorption while the remaining amount increases the energy of the free-air explosion by a factor of up to two. If, in addition, the explosive is both on the floor and directly against a wall, a further energy increase would occur, producing up to a quadrupling of the source energy. Finally, if the explosion took place in a corner, against two walls and the floor, another doubling would occur producing an eight-fold increase in yield. Figure 7 shows peak pressure versus distance for various charge weights both for an air burst and a ground burst, as given by equation 1 in Appendix C.

When considering multiple reflections of sound waves from a number of surfaces, the method of images is often applied. If the room surfaces were mirrors, then an array of mirror images of the real source inside the room could be seen behind each wall at increasing distances. If the walls (mirrors) were removed, then at the microphone the source distances and directions for each reflection could be calculated by considering transmission to occur directly from each image source. In this procedure, the assumption that the angle of incidence is equal to the angle of reflection at each wall is not entirely true for blast waves. Losses at each wall can be included by reducing the strength of each image source according to the number of reflections each wave underwent before reaching the microphone. Once the distances to the image sources are known, the peak pressures, arrival times (equation 2 in Appendix C), and positive phase durations can be calculated, and the waveform synthesized.

In actuality, a device would probably not land and explode exactly in the corner. In would, at worst, be a number of inches from the two walls. In such a situation, the pressure would be increased over the free-air pressure, due to the floor; however, any further increase would depend upon its proximity to the walls and the height of the microphone above the floor. The closer the explosive is to the wall, the more nearly equal in length will be the paths traveled by the reflective waves and the direct wave. If the difference between the arrival times of the shock waves is

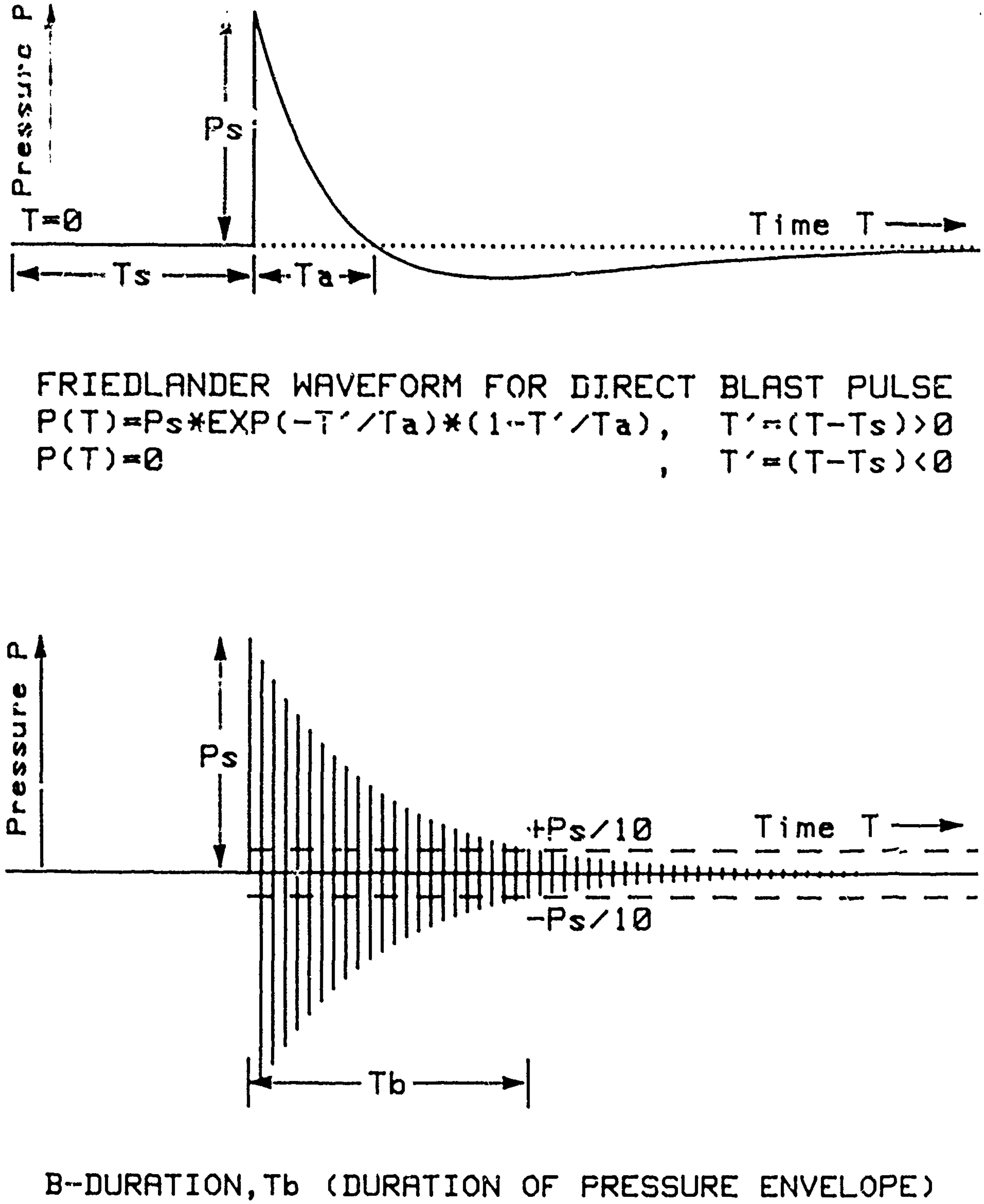

Figure 6. Idealized pressure time histories of blast pulses showing basic pressure and time quantities.

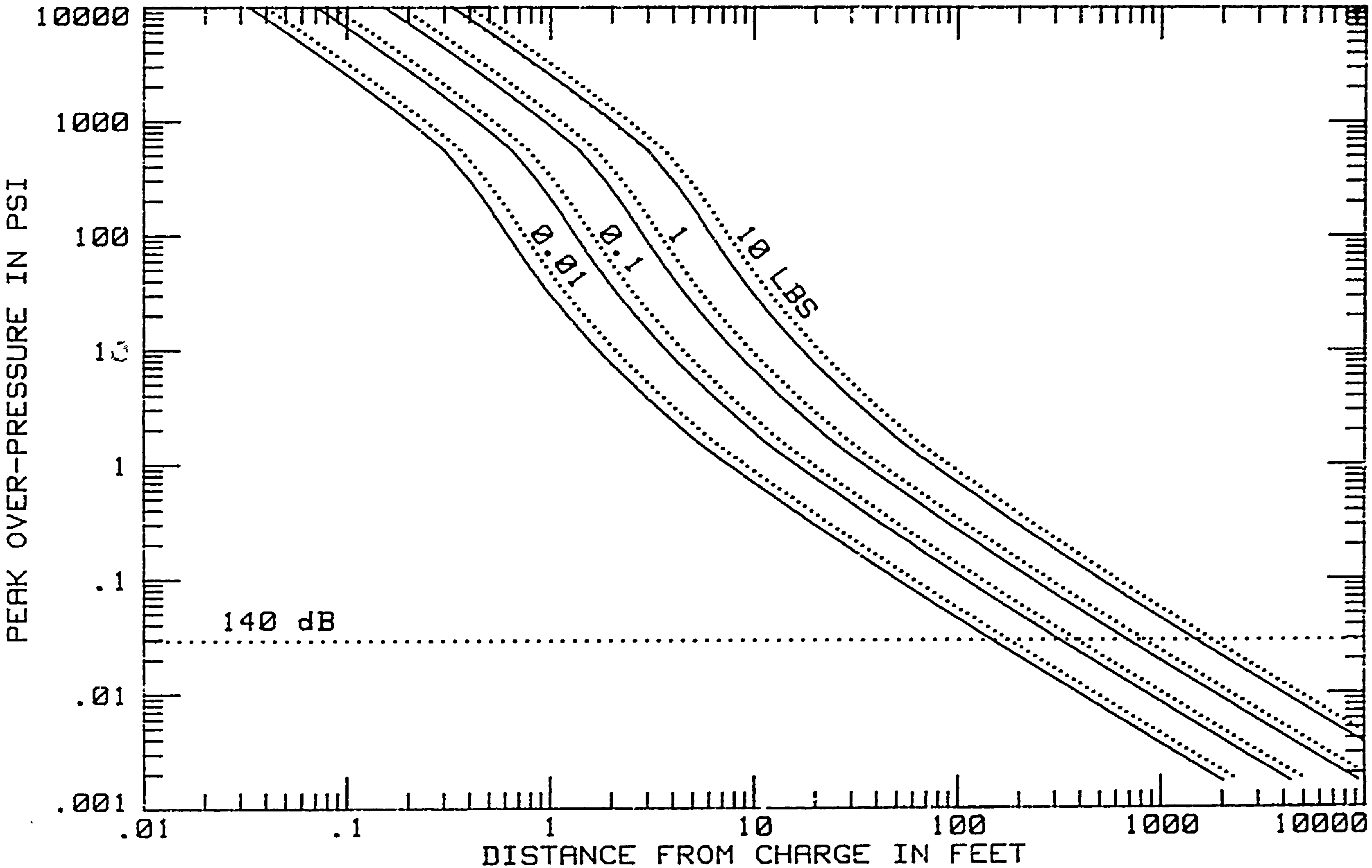

Figure 7. Peak pressure vs. distance from charge for various weights (pounds) of TNT (1 pound of TNT = 10 pounds of black powder). The solid line is for a free air burst, the dotted line is for a ground burst.

less than the positive phase duration of the direct wave, then the reflected waves will be partially superimposed onto the direct wave and produce a pressure higher than the initial direct wave value. This effect becomes more likely as the charge weight is increased because the positive phase is lengthened while the arrival times and their time differences are shortened. For example, in Table 1 we see that for the three room conditions there was no significant difference between the pressure measured 30" above the explosive in the room center and the pressure measured 30" above the explosive in the corner. However, at the 65" conditions there was an increase of a few decibels in the corner above that measured in the room center. This increase occurred because at 65" the path lengths of the direct wave and the reflections were of similar length, which allowed the waves to be superimposed onto each other, thereby increasing the peak pressure.

Both Figures 8a and 8b show typical waveshapes for the conditions measured in this study. Superimposed over the measured waveshapes are predicted waves, for a charge weight of 0.015 pounds (chosen to give a good all round estimate of peak pressure level) for each particular room configuration based upon the computer model provided in Appendix D. The lower portion of this figure shows the path taken by the direct and reflected shockwaves for each measured condition; these pathlengths are then used in the model to compute the time difference between reflections as shown in the predicted waveshapes.

Another consideration affecting the effective yield of the explosive is its chemical composition. High energy explosives such as TNT, RDX, and Pentolite all have essentially the same total energy release with peak pressures varying over a range of 1.5 (Baker, 1973), while slower burning black powder has 10% of the energy release compared to TNT (Kinney, 1962). The strength of the casing material can perhaps offset this slower burning rate of black powder by allowing the pressure to build up and then suddenly be released when the casing ruptures.

The values for A-duration given by Equation 3 in Appendix C needed to be multiplied by a factor of 1.5 in order to produce the fit shown in Figures 8a and 8b. This could have been a result of incorrectly assuming the photo-flash powder to burn as rapidly as high explosive. Another possible explanation is that the A-duration is imprecisely defined close to the explosive since multiple shock waves are produced in the expanding explosive gases.

A final problem with the explosive is that the case apparently didn't always rupture cleanly; in about half the instances the blast built up in stages when individual waves arrived from separate ruptures of the endcap and sidewall. This was also indicated by the fact that the peak pressure varied by about 2 dB from shot to shot.

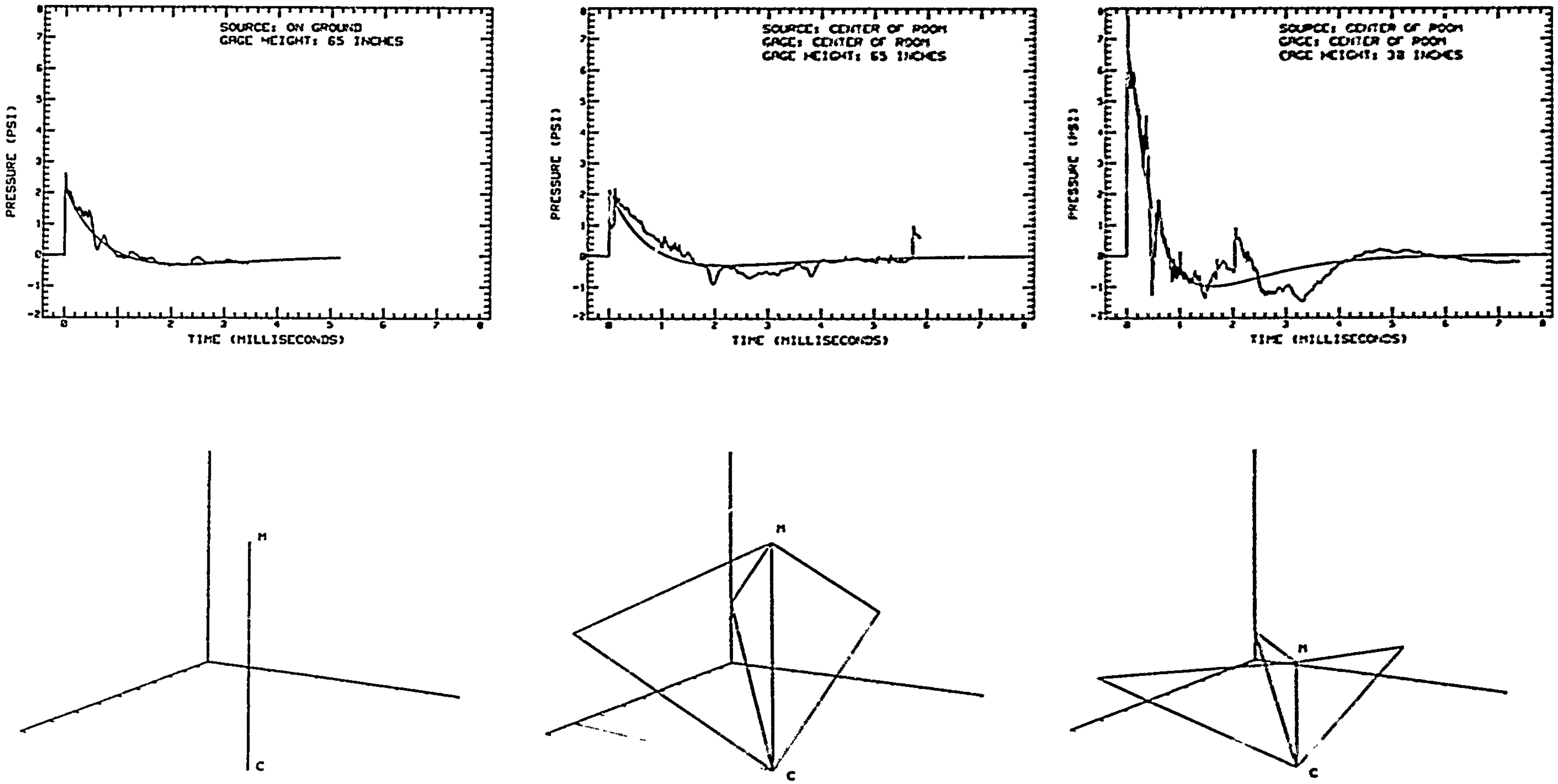

Figure 8a. Measured and predicted waveforms produced at three different microphone locations (M) by a charge (C) exploded on ground and in center of floor (lower figures show the shockwave paths for the three configurations, each tick mark equals 1 foot).

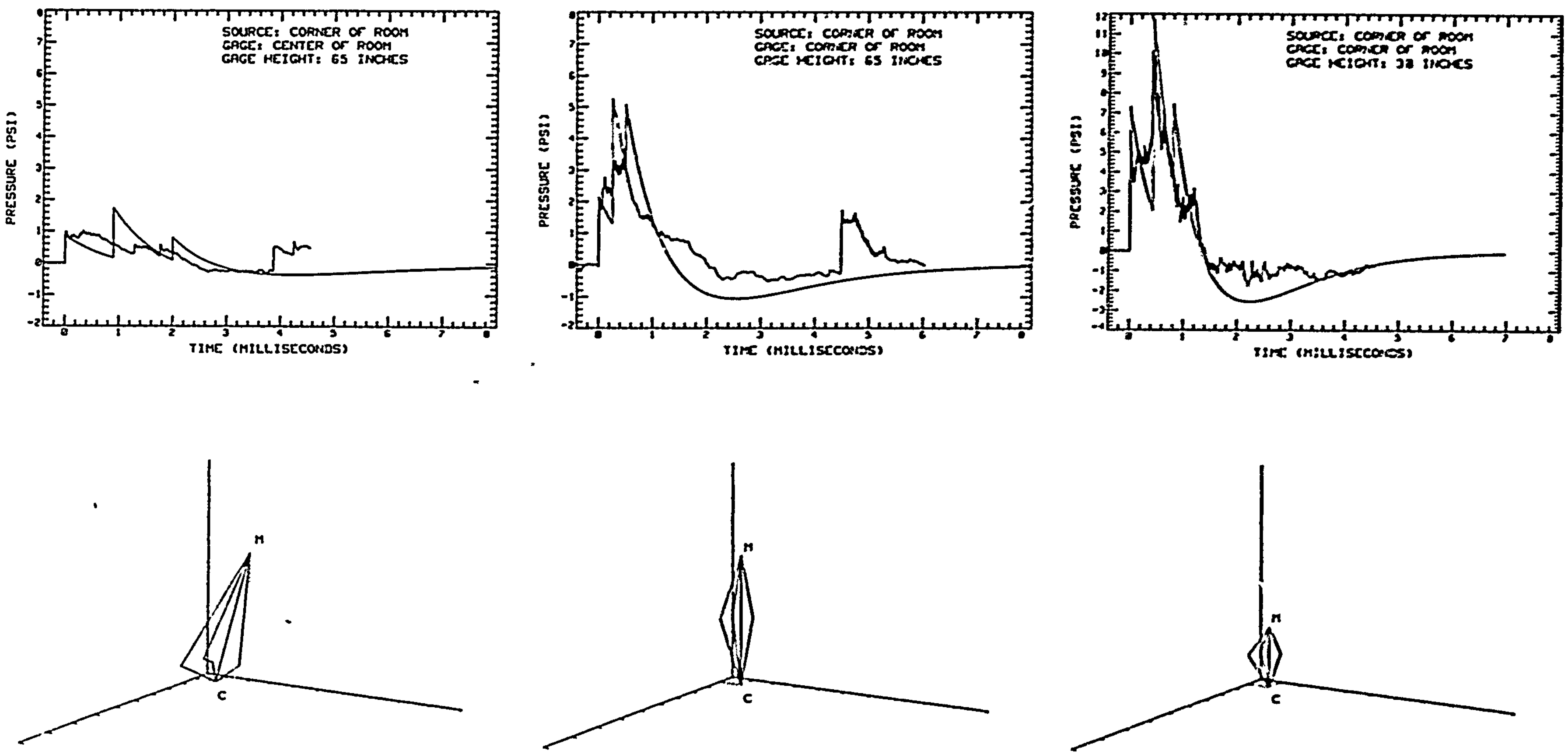

Figure 8b. Measured and predicted waveforms produced at different microphone locations by charges exploded on floor and in corner (lower figures show the shockwave paths for the three configurations, each tick mark equals 1 foot).

B-duration Prediction

The B-duration of a charge exploding in a room can be estimated using the Norris-Eyring reverberation time equation (Beranek, 1960). Assuming peak pressure decays just as the RMS average value of a sound wave decays, then the B-duration is 1/3 as long as the reverberation time of the room. Reverberation time being the time taken for the RMS sound pressure level to fall off by 60 dB after a steady sound is suddenly ended.

$$T_B = (1/3)T_{60} = \frac{2(4V/S)}{(-)C \log_{10}(1-a)}$$

where:

a = average absorption coefficient
C = speed of sound = 1.136 ft/msec at 77 degrees F.
S = surface area of the room in square feet
T_B = B-duration in msec
T_{60} = reverberation time in msec
V = room volume in cubic feet

Shown below are calculations for one of the rooms of the study for which the average absorption was varied by adding a rug and furniture. Assuming the room is average in absorption while empty and acoustically "dead" when furniture is added, and that the microphone is 65" above the center of the room, B-duration computations are close to the measured values.

Given that:

the room is 15.25 ft x 12.75 ft x 8.88 ft,
the surface area is 886 sq ft,
the volume is 1726 cu ft,
the mean free path, 4V/S, is 7.79 ft,

then:

Average Absorption Coefficient	B-duration	
	Calculated	Measured
0.40 (dead room)	62 msec	64-79 msec
0.15 (average room)	194 msec	149-236 msec
0.05 (live room)	616 msec	----

Note: Opening a window adds perfect absorption for that amount of surface area. Since windows are such a small percentage of the surface area of the room, an open window would have an insignificant effect upon B-duration.

Instrumentation Techniques

Of particular importance when measuring impulse noise in a room are the placement and orientation of the transducer with reference to the direction of travel of the incident shock wave produced by the noise source and those reflections caused by adjacent surfaces. It is important that the transducer be placed at grazing incidence (90°) to all noise sources and to as many of the reflections as possible (Garinther & Moreland, 1965). Care must be taken to assure that it is not oriented in a manner which would cause pressure waves to arrive at the transducer at face-on incidence (0°), thereby indicating an artificially high pressure. If it is not possible to orient the transducer at grazing incidence to certain reflections, it should be oriented so that the shock wave arrives at an angle greater than 90 degrees (i.e., from the rear of the transducer). Adherence to this procedure will prevent the shock wave from striking the transducer at angles between 0 and 90 degrees which produce reflections off the face of the transducer, causing an artificially high pressure and transducer ringing. For example, when measuring an explosive located on the floor near a single wall, the transducer should be placed horizontally such that the shockwave emanating from the source on the floor will cross the transducer face vertically at a grazing angle while the reflection off the wall will also cross the transducer face at grazing incidence.

Particular care must be taken when measuring above an explosive detonated in a corner as was done in this study. For this situation the transducer was placed horizontally with the face of the transducer pointer directly away from the corner. Other orientations would have produced resultant pressures either above or below the correct pressure. For example, placing the transducer vertically with the sensing surface up would have produced a lower than accurate pressure since the incident pressure wave from the explosive would have struck the transducer from the rear. Placing the transducer horizontally facing one of the corner walls would have produced a higher than accurate pressure since the pressure wave reflected off that wall would have struck the transducer at an incidence angle of about 60 degrees.

Transducers must have appropriate characteristics for the particular pressure being measured. HEL has selected the PCB 101M49 for measuring pressures at and above 171 dB and the B&K 4136 for measuring pressures below this level. The measurements reported herein conform to the procedures and instrumentation requirements of "Standardization of Muzzle Blast Overpressure Measurements" (Patterson et al, 1980).

SUMMARY AND CONCLUSIONS

Single Unprotected Exposures

Based upon Nixon, 1969, a single unprotected exposure to the impulse noise of a grenade simulator producing a level of 167 dB when exploding in a room may cause a small degree of permanent hearing loss in 1% of personnel exposed.

Based upon Garinther & Hodge, 1971, a single unprotected exposure to the impulse noise of a grenade simulator producing a level of 177 dB when exploding in a room may cause some degree of permanent hearing loss in about 4% of exposed personnel.

For a single unprotected exposure to the impulse noise of a grenade simulator producing a level above 177 dB when exploding in a room, significant permanent hearing loss will occur in some personnel. Since insufficient data are available to quantify the number of personnel, it would be inadvisable to expose personnel to such levels.

Personnel who have been exposed to a diversionary charge and have sustained a temporary threshold shift must not be exposed to subsequent hazardous noise until complete recovery has taken place.

Training Exposures

In most training situations using diversionary explosives, the use of hearing protection (including fingers to occlude the ears) must be used by all personnel, particularly instructors who may be repeatedly exposed.

In training situations using the M116A1 with soft epoxy ends, exposures in the room itself should be conducted only if it is ascertained that the parameters of Category Z of MIL-STD 1474B are not exceeded at all personnel locations.

In training situations using the normal M116A1 (without soft epoxy ends), exposures in the room itself should not be conducted until additional testing and evaluation of this device has been performed.

Variation in Waveshape Parameters

The range of peak pressure levels measured when exploding the M116A1 under the various conditions of this study was 171-190 dB; the range of B-durations was 6-196 msec.

Peak pressure level is not affected by room volume, type of wall surface, room furnishings, or window and door openings if the grenade simulator is exploded away from the wall for rooms the size of normal living quarters or larger; it is lowered, however, if exploded on a soft carpet.

Peak pressure level is essentially the same if a grenade simulator is exploded outside or in a room away from the wall.

Peak pressure level is lowered if a soft case or soft ends are used since the relatively slow burning photoflash powder does not build up in energy and produce a sudden and efficient release of blast.

Peak pressure level is increased if a grenade simulator is exploded within a few inches of a wall, and is additionally increased if it is exploded within a few inches of a corner.

Peak pressure level decreases by approximately 6 dB as the distance from the source is doubled.

The B-duration of an impulse noise produced in a room can be closely approximated through the use of the reverberation time equations.

The B-duration of an impulse noise increases by a factor of about 20 when exploding a grenade simulator inside an unfurnished room as opposed to outside.

The B-duration of an impulse noise decreases by a factor of about four when furniture is added to a room.

Instrumentation Techniques

When measuring impulse noise produced inside rooms, special instrumentation must be used and great care taken to properly orient the transducer; standard sound level meters are not acceptable.

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Nixon, C. W. Personnal communication, June 1982.

APPENDIX A

SUMMARY OF PARAMETERS OBTAINED FOR EACH EXPLODING CHARGE

Summary of Parameters Obtained for Each Exploding Charge

Date	Shot No.	Type Explosive	Room Condition	Peak Pressure (psi)	Peak Pressure Level (dB)	B-duration (msec)	Explosive Location	Transducer Location	Peak Pressure Level In Adjacent Room (dB)	Remarks
7 DEC 81	1	M116A1	Kitchen (No Furniture)	2.2	177.6	170	Center	65" above Explosive	163.0	
	2	-	-	2.3	178.1	110	-	-	162.5	
	3	-	-	1.5	174.0	170	Corner	65" above center of room	160.3	
	4	-	-	1.0	170.9	182	-	-	161.2	
	5	-	-	1.2	172.6	182	-		161.3	
8 DEC 81	6	-	-	7.1	187.8	10	-	30" above Explosive	-	Transducer facing corner caused inaccurate high reading.
	7	-	-	>10.1	>190.8	11	-	-	162.2	Same as Shot #6; oscilloscope overloaded.
	8	-	-	11.6	192.2	11	-	-	-	Same as Shot #6.
	9	-	-	6.7	187.2	50	-	-	165.0	For the remainder of all corner shots the transducer was facing directly away from the corner (Facing Northwest).
	10	-	-	7.3	188.0	11	-	-	162.5	
	11	-	-	4.5	183.8	46	Center	-	161.0	
	12	-	-	8.3	189.1	26	-	-	161.5	
	13	Misfire								
	14	-	Outside	1.9	176.2	3	On Ground	65" above Explosive	-	Peak pressure at 50' was greater than 147 dB.

(Continued)

Summary of Parameters Obtained for Each Exploding Charge

Date	Shot No.	Type Explosive	Room Condition	Peak Pressure (psi)	Peak Pressure Level (dB)	B-duration (msec)	Explosive Location	Transducer Location	Peak Pressure Level In Adjacent Room (dB)	Remarks
	15	-	-	2.6	179.2	5	-	-	-	Peak pressure at 90' was 142 dB.
	16	-	-	3	180.1	4	-	-	-	Peak pressure at 110' was 139.5 dB.
	17	-	-	2.4	178.2	8	-	-	-	Peak pressure at 110' was 143.0 dB.
	18	-	-	1.9	176.3	11	-	-	-	Peak pressure at 110' was 141.0 dB.
	19	-	-	3.1	180.5	7	-	-	-	Peak pressure at 110' was 141.0 dB.
9 DEC 81	20	-	Kitchen (No Furniture)	7.1	187.8	26	Center	30" above Explosive	161.5	
	21	-	-	2.4	178.0	103	-	-	159.9	Fuse malfunctioned; door to adjacent room open.
	22	-	-	6.2	186.5	49	-	-	161.5	
	23	-	-	8.6	189.5	3	-	-	164.5	
	24	-	-	8.0	188.8	3	-	-	162.2	
	25	-	-	6.4	186.9	17	-	-	158.5	
	25	-	-	9.7	188.5	2	-	-	157.8	
	27	-	-	2.6	179.2	146	-	65" above Explosive	156.0	
	28	-	-	2.5	178.7	133	-	-	157.5	

(Continued)

Summary of Parameters Obtained for Each Exploding Charge

Date	Shot No.	Type Explosive	Room Condition	Peak Pressure (psi)	Peak Pressure Level (dB)	B-duration (msec)	Explosive Location	Transducer Location	Peak Pressure Level In Adjacent Room (dB)	Remarks
	29	"	"	2.9	180.0	120	"	"	157.8	
	30	"	Bedroom (No Furniture)	3.2	180.9	156	Center	65" above Explosive	160.5	
	31	"	"	>4.0	>182.8	>89	"	"	161.0	Oscilloscope overloaded.
	32	"	"	1.9	176.3	236	"	"	157.5	
	33	"	"	5.1	184.9	54	"	30" above Explosive	159.2	
	34	"	"	6.7	187.3	23	"	"	157.5	
2 JAN 82	35	"	"	1.9	176.4	149	Corner	65" above center of room	157.0	
	36	"	"	1.8	176.0	150	"	"	155.5	
	37	M116A1 (With Soft Epoxy Ends)	"	0.7	168.1	>150	"	"	150.0	
	38	"	"	1.4	173.9	188	"	"	150.5	
	39	"	"	1.7	175.4	129	Center	65" above Explosive	150.0	
3 JAN 82	40	"	"	1.0	170.9	210	"	"	144.5	
	41	"	"	0.8	168.4	136	"	"	143.5	
	42	QED	"	3.4	182.4	136	Unknown	"	152.5	This grenade shot away from center of bedroom and exploded at the south end of the room at a microphone incidence of about 45°.

(Continued)

Summary of Parameters Obtained for Each Exploding Charge

Date	Shot No.	Type Explosive	Room Condition	Peak Pressure (psi)	Peak Pressure Level (dB)	B-duration (msec)	Explosive Location	Transducer Location	Peak Pressure Level In Adjacent Room (dB)	Remarks
	43	"	"	4.4	183.6	120	"	"	154.8	Same as Shot #42.
	44	FFE (Single Primed)	"	0.6	166.4	-	Center	"	143.5	Electrically set off.
	45	"	"	1.0	171.0	185	"	"	145.5	
	46	"	"	0.8	168.6	300	"	"	150.0	
	47	"	Misfired				"	"		
	48	"	Misfired				"	"		
	49	FFE	"	1.0	170.7	140	"	"	148.0	
	50	Flashed-Bang	"	0.6	166.2	224	Unknown	65" above center of room	151.0	This grenade shoots out from container and explodes somewhere in room.
	51	"	"	0.8	168.5	174	"	"	-	Same as Shot #50.
	52	"	"	0.9	169.8	133	"	"	143.5	Same as Shot #50.
	53	M116A1	"	3.4	181.3	77	Corner	65" above Explosive	-	
4 JAN 83	54	"	"	4.1	183.0	76	"	"	-	
	55	"	"	3.6	182.0	80	"	"	150.5	
	56	"	"	4.6	183.9	77	"	"	151.5	
	57	FFE (Dual Primed)	"	1.1	171.8	137	Unknown	65" above center of room	150.0	Mechanical primer used.

(Continued)

Summary of Parameters Obtained for Each Exploding Charge

Date	Shot No.	Type Explosive	Room Condition	Peak Pressure (psi)	Peak Pressure Level (dB)	B-duration (msec)	Explosive Location	Transudcer Location	Peak Pressure Level In Adjacent Room (dB)	Remarks
	58	"	"	1.4	173.4	198	"	"	147.0	Same as Shot #57.
	59	"	"	1.3	173.0	180	"	"		Same as Shot #57.
	60, 61, 62, 63 fired without noise measurements									
	64	M116A1	Bedroom (With Furniture)	1.6	175.0	64	Center	65" above Explosive	147.0	
	65	"	"	1.7	175.5	65	"	"	152.0	
15 JAN 83	66	"	"	2.0	176.8	79	"	"	146.5	
	67	"	"	5.4	185.4	10	"	30" above Explosive	148.0	
	68	"	"	9.0	189.8	15	"	"	148.5	
	69	"	"	7.6	188.4	6	"	"	156.8	At this point a 6" wide section of the door was blown off between the bedroom and the adjacent room in which measurements were made.
	70	"	"	10.7	191.4	7	Corner	"	157.0	
	71	"	"	8.7	189.6	7	"	"	153.5	
	72	"	"	8.3	189.1	8	"	"	155.0	
	73	"	"	6.9	187.5	16	"	65" above Explosive	154.8	
	74	"	"	5.2	185.1	19	"	"	153.5	
	75	"	"	7.0	187.7	16	"	"	156.0	

(Continued)

Summary of Parameters Obtained for Each Exploding Charge

Date	Shot No.	Type Explosive	Room Condition	Peak Pressure (psi)	Peak Pressure Level (dB)	B-duration (msec)	Explosive Location	Transducer Location	Peak Pressure Level In Adjacent Room (dB)	Remarks
	76	"	Bedroom (No Furniture)	6.4	186.9	10	"	30" above Explosive	156.7	
	77	"	"	5.3	185.2	36	"	"	158.5	
	78	"	"	6.6	187.2	10	"	"	158.0	

APPENDIX B

RANGE AND NUMBER OF MEASUREMENTS FOR EACH CONDITION

Peak Pressure Level Extremes (dB) and Number of Devices Exploded for Each Measurment Condition

Explosive	Room Condition	Explosive in Center of Room		Explosive in Corner of Room			
		65" MIC	30" MIC	65" MIC	30" MIC	65" Above Floor Center[a]	65" MIC
M116A1 (Normal)	Outside (Over Grass)						176.2-180.5 6
M116A1 (Normal)	Kitchen (No Furniture)	177.6-180.0 5	183.8-189.5 8		187.2-188.0 2	170.9-174.0 3	
M116A1 (Normal)	Bedroom (w/Furniture)	175.0-176.8 3	185.4-189.8 3	185.1-187.7 3	189.1-191.4 3		
M116A1 (Normal)	Bedroom (No Furniture)	176.3-182.8 3	184.9-187.3 2	181.3-183.9 4	185.2-187.2 3	176.0-176.4 2	
M116A1 (w/Soft Epoxy Ends)		168.4-175.4 3				168.1-173.9 2	
QED		182.4-183.6 2					
FFE (Single Primer)		168.6-171.0 3					
FFE (Double Primer)		171.8-173.4 3					
Flash Bang		166.2-169.8 3					

[a] All microphone distances are above the explosive, except for this measurement which was made 65" above the center of the floor with the explosive in the corner.

B-duration Extremes (msec) for Each Measurement Condition

Explosive	Room Condition	Explosive in Center of Room		Explosive in Corner of Room			
		65" MIC	30" MIC	65" MIC	30" MIC	65" Above Floor Center[a]	65" MIC
M116A1 (Normal)	Outside (Over Grass)						3-11
M116A1 (Normal)	Kitchen (No Furniture)	110-170	2-49		11-50	170-182	
M116A1 (Normal)	Bedroom (w/Furniture)	64-79	6-15	16-19	7-8		
M116A1 (Normal)	Bedroom (No Furniture)	89-236	23-54	76-80	10-36	149-150	
M116A1 (w/Soft Epoxy Ends)		129-210				150-188	
QED		120-136					
FFE (Single Primer)		140-300					
FFE (Double Primer)		137-198					
Flash Bang		133-224					

[a]All microphone distances are above the explosive, except for this measurement which was made 65" above the center of the floor with the explosive in the corner.

APPENDIX C

EQUATIONS FOR PREDICTING BLAST QUANTITIES

Equations for Predicting Blast Quantities

1. Goodman's equation for peak side-on pressure p_s:

$$p_s = \frac{93.66 + \dfrac{1498}{1 + 0.2309(Z-a)^2}}{Z \sqrt{Z \ln(Z/a)/(Z-a)}}$$

for $a < Z < 68 \text{ ft/lb}^{1/3}$

2. Arrival time T_s for shock wave:

$$T_s = W^{1/3} \cdot \left(1 - \frac{0.96}{1 + 0.08(Z-a)} \right) \cdot (Z - a)/c_o$$

for $a < Z < 1000 \text{ ft/lb}^{1/3}$

3. Positive phase duration (A-duration) T_a:

$$T_a = W^{1/3} \cdot 10^{(-0.1222789 + 0.5261483 \cdot X - 0.0605408 \cdot X^2)}$$

where:

$$X = \log_{10}(Z - 2.7 \cdot a)$$

where:

$Z = R/W^{1/3}$ = scaled distance

R = radial distance from center of charge in ft

$a = 0.1321 \text{ ft/lb}^{1/3}$ = scaled radius of 1 lb of Pentolite

W = weight of charge in lbs

p_s = side-on pressure in psi

c_o = speed of sound in ft/sec = 1139.4 ft/sec @ 300°K

T_s = Arrival time in sec

T_a = Positive phase duration in sec

APPENDIX D

BLAST PREDICTION MODEL FOR CHARGES EXPLODING IN A ROOM

Blast Prediction Model for Charges Exploding in a Room

```
10     REM **** BLAST PREDICTION INSIDE ENCLOSURES ****
20     OPTION BASE 0
30     DIM Pk(5),Ts(5),Td(5)
40     LET Ts(0)=0  ! Beginning time
50     LET Ts(5)=10 ! End time in milliseconds
60     PLOTTER IS 13,"GRAPHICS"
70     LIMIT 0,184,0,140
80     LOCATE 0,100*RATIO,0,100
90     LET Aa=.1323     !ft radius of 1lbm of Pentolite (50/50)
100    LET Ao=1.11644   !ft/msec ,speed of sound at 59 deg F
110    LET Rscale=9.3111675 !ft scale factor
120 A: !
130    LET W=.015! lbm, weight of charge
140    LET W3=W^(1/3)
150    LET Xc=1    ! ft charge location relative to walls & floor
160    LET Yc=1
170    LET Zc=0
180    LET Xm=1   ! ft microphone location relative to walls & floor
190    LET Ym=1
200    LET Zm=5
210  ! Direct wave #1
220    LET X=Xc
230    LET Y=Yc
240    LET Z=Zc
250    GOSUB Distance
260    GOSUB Theory
270    LET Pk(1)=Pk
280    LET Ts(1)=Ts
290    LET Td(1)=Td
300    IF Xc>Yc THEN 340
310      LET Temp=Xc
320      LET Xc=Yc
330      LET Yc=Temp
340    LET Gain=1
350    IF Xc=Yc THEN Gain=2
360 ! Reflection off nearer wall
370    LET X=Xc
380    LET Y=-Yc
390    GOSUB Distance
400    GOSUB Theory
410    LET Pk(2)=Pk*Gain
420    LET Ts(2)=Ts
430    LET Td(2)=Td
440    LET K=Kmax=3
450    IF Gain=2 THEN 570
460      LET Kmax=4
470      LET K=3
480    ! Reflection off further wall
490      LET X=-Xc
500      LET Y=Yc
510      GOSUB Distance
520      GOSUB Theory
530      LET Pk(K)=Pk
```

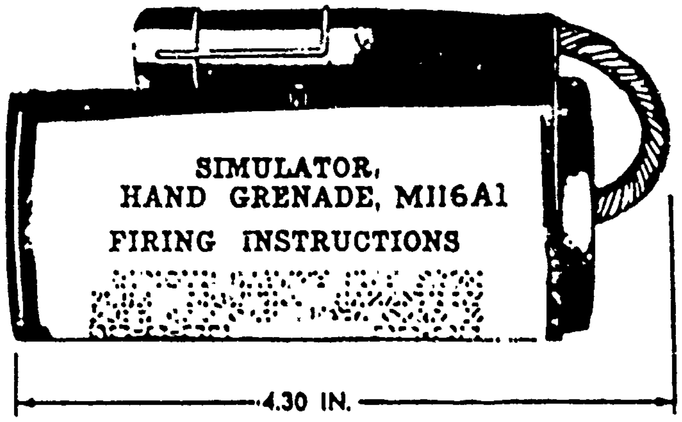
```
540     LET Ts(K)=Ts
550     LET Td(K)=Td
560     LET K=4
570 ! Reflection off both walls
580   LET X=-Xc
590   LET Y=-Yc
600   GOSUB Distance
610   GOSUB Theory
620   LET Pk(K)=Pk
630   LET Ts(K)=Ts
640   LET Td(K)=Td
650   GOSUB Plot
660   STOP
670 Distance:!
680   LET R=SQR((X-Xm)^2+(Y-Ym)^2+(Z-Zm)^2)
690 RETURN
700 Theory:! Blast predictions
710   LET Zz=R/W3
720   LET Za=Zz-Aa
730   LET Pk=(93.66+1498/(1+.2309*Za*Za))/(Zz*SQR(Zz*LOG(Zz/Aa)/Za))
740   LET Ts=W3*(1-.96/(1+.08*Za))*Za/Ao
750   LET Xx=LGT(Zz-2.7*Aa)
760   LET Td=W3*10^(-.1222789+(.5261483-.0605408*Xx)*Xx)
770 RETURN
780 P:!
790   LET Ttd=-T/Td(K)
800   LET P=P+Pk(K)*(1+Ttd)*EXP(Ttd)
810 RETURN
820 Plot:!
830   SCALE Ts(0),Ts(5),-2,10
840   GRAPHICS
850   MOVE 0,0
860   DRAW Ts(1),0
870   DRAW Ts(1),Pk(1)
880   LET N12=50
890   LET Dt=(Ts(2)-Ts(1))/N12
900   LET K=1
910   FOR I=1 TO N12
920     LET P=0
930     LET T=I*Dt
940     GOSUB P
950     LET T=T+Ts(1)
960     DRAW T,P
970   NEXT I
980   DRAW Ts(2),P+Pk(2)
990   LET N23=10
1000  LET Dt=(Ts(3)-Ts(2))/N23
1010  FOR I=1 TO N23
1020    LET P=0
1030    LET T=I*Dt
1040    FOR K=2 TO 1 STEP -1
1050      GOSUB P
1060      LET T=T+Ts(K)-Ts(K-1)
1070    NEXT K
```

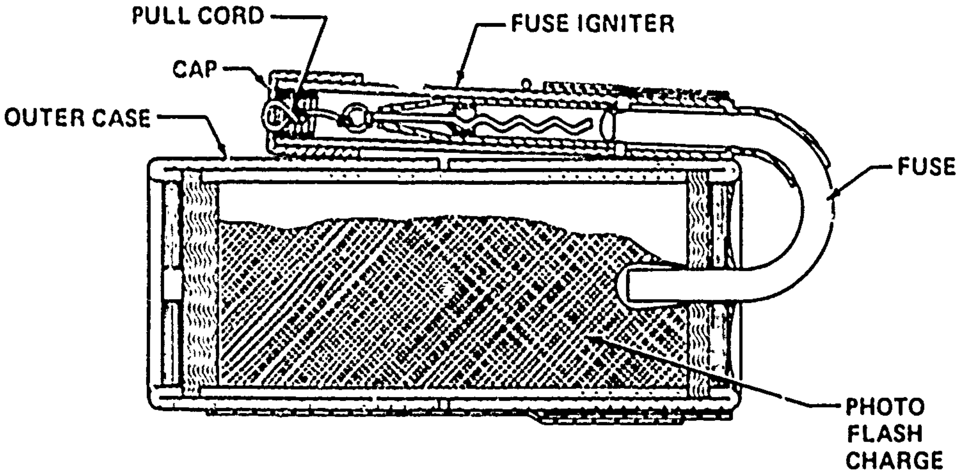
```
1080    DRAW T,P
1090  NEXT I
1100  DRAW Ts(3),P+Pk(3)
1110  LET N34=10
1120  LET Dt=(Ts(4)-Ts(3))/N34
1130  IF Gain=1 THEN 1170
1140    LET N35=100
1150    LET Dt=(Ts(5)-Ts(3))/N35
1160    LET N34=N35
1170  FOR I=1 TO N34
1180    LET P=0
1190    LET T=I*Dt
1200    FOR K=3 TO 1 STEP -1
1210      GOSUB P
1220      LET T=T+Ts(K)-Ts(K-1)
1230    NEXT K
1240    DRAW T,P
1250  NEXT I
1260  IF Gain=2 THEN 1390
1270  DRAW Ts(4),P+Pk(4)
1280  LET N4end=100
1290  LET Dt=(Ts(5)-Ts(4))/N4end
1300  FOR I=1 TO N4end
1310    LET P=0
1320    LET T=I*Dt
1330    FOR K=4 TO 1 STEP -1
1340      GOSUB P
1350      LET T=T+Ts(K)-Ts(K-1)
1360    NEXT K
1370    DRAW T,P
1380  NEXT I
1390  RETURN
```

APPENDIX E

DESCRIPTION OF THE M116A1 HAND GRENADE SIMULATOR

Description of the M116A1 Hand Grenade Simulator





<u>Type Classification:</u>

Std OTCM 37524

<u>Use:</u>

To simulate battle noises and effects during troop maneuvers. (On land only).

<u>Description:</u>

The body of this simulator consists of a cylindrical paper tube containing a sealed charge of photoflash powder. A fuse igniter, Type M3A1, is taped to the outside of the tube, and is joined to the photoflash charge by a safety fuse. A safety clip through the cap of the fuse igniter prevents accidental detonation. A label giving firing instructions is attached to the outside of each simulator.

<u>Functioning:</u>

This simulator is hand-thrown device. The pull cord-actuated igniter is of the friction type and ignites the safety fuse. The burning of the safety fuse provides a 5 to 10 second delay after igniting by jerking the pull cord and throwing the simulator. The safety fuse ignites the photoflash charge which explodes, producing a flash and a loud report.

Tabulated Data:

NSN	1370-00-752-8124
Weight loaded	0.2 lb.
Length	4.30 in.
Diameter	2.18 in.
Method of actuation	Manual pull cord
Body material	Kraft paper
Color	White w/white label w/black markings
Pyrotechnic charge:	
Type	Photoflash powder
Weight	1.3 oz.
Igniter	Blasting Fuse M3A1
Performance:	
Delay	5 to 10 sec.
Photoflash powder	Instantaneous

*Packing—150 per box; 5 per inner pack

*Packing Box:

Weight	65 lbs.
Dimensions	23-1/4 x 13-5/8 x 15-25/32 in.
Cube	3.1 cu. ft.

*NOTE: See SC 1340/98 IL for complete packing data including NSN's.

Shipping and Storage Data:

Quantity-distance class	3
Storage compatibility group	B & Q
DOT shipping class	EXPLOSIVE B
DOT designation	SPECIAL FIREWORKS HANDLE CAREFULLY KEEP FIRE AWAY
DODAC	1370-L601
Drawing number	8835109

References:

AMCP 700-3-5
TM 9-1370-203-12

TM 9-1370-203-34