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Feasibility of Using an Artillery Piece
in an Indoor Facility to Test Electronic Fuzes

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U.S. Army Materiel Development
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HARRY DIAMOND LABORATORIES
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TR-1812—Feasibility of Using an Artillery Piece in an Indoor Facility to Test Electronic Fuzes, by Harry J. Davis

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CONTENTS

1.	INTRODUCTION	5
2.	CURRENT FUZE TESTING PRACTICES	6
3.	PROPOSED FACILITY	7
4.	DESIGN CONSIDERATIONS	8
	4.1 Site Location	8
	4.2 Test Requirements	8
	4.3 Cannon	10
	4.4 Control of Blast, Noise, and Propellant Gas	16
	4.5 Control of Projectile Motion	16
	4.6 Measurement and Control	18
	4.7 Storage and Operating Procedures	19
5.	SUMMARY AND CONCLUSIONS	20
	LITERATURE CITED	21
	DISTRIBUTION	49

APPENDICES

A.	ELECTRONIC FUZE TESTS PERFORMED IN THE FIELD	23
B.	CHARACTERISTICS OF ARTILLERY FIRING RANGES	25
C.	NAVAL SURFACE WEAPONS CENTER (WHITE OAK) HYPERVELOCITY FACILITIES	31
D.	BIBLIOGRAPHY OF MEASUREMENT INSTRUMENTS AND TECHNIQUES USED IN INTERIOR BALLISTICS	35
E.	U.S. ARMY ARTILLERY WEAPON, PROJECTILE, AND CHARGE CHARACTERISTICS	43

FIGURES

1.	Amplitude and duration of mortar and howitzer firing pulses	12
2.	Amplitude and duration of gun firing pulses	13
3.	Artillery sleigh developed at Rock Island Arsenal	14
4.	XM153 artillery carriage	14
5.	XM158 artillery carriage used as universal test mount	15
6.	Penetration of bombs and projectiles into soil	17

TABLES

I.	Characteristics of Potential Locations for the Fuze Environment Simulation Facility	9
II.	Characteristics of Selected Army Ammunition	11
III.	Aberdeen Proving Ground Standard Operating Procedures (SOP's)	19

1. INTRODUCTION

The performance of ordnance electronic fuzes is determined by testing in the laboratory and in the field. Unfortunately however, existing techniques limit both the meaningfulness and timeliness of the test results. The Harry Diamond Laboratories (HDL) has been aware of this problem for some time and has devoted considerable effort to solving it.¹⁻⁶ In the past few years, experience and reason have led to the conclusion that building an indoor artillery firing range near the development center would significantly improve the testing of electronic fuzes.

The concept and earliest plans for firing artillery-type guns indoors at HDL dates back to work done in 1969 by HDL staff members H. D. Curchack and F. L. Tevelow. Planning was based on a logical continued development of the artillery simulator, invented by H. Curchack, and on the fuze engineer's need to have access to guns to test fuzes and fuze components in a controlled laboratory environment. In this environment, fuze engineers could measure, compare, evaluate, and correlate pertinent parameters as they exist in simulation testing and in field-gun firing tests.

The original documents for advanced operations were drawn up with the plans for the relocation of HDL. Subsequent cutbacks in allocated space prevented inclusion of the pressure-driven, high-velocity 915-m/s (3000-ft/s) artillery simulators and the artillery-type guns in the Research and Engineering Laboratory Support Building (REL).

The problem of housing atmospheric-vacuum-driven (AVD) artillery simulators in the REL, following the space curtailment, was overcome by putting most of the seldom-accessed long tube sections in covered trenches. In fact, despite building space reduction, this concept has even permitted the addition of two much-needed simulators to test larger components. Whereas, in 1970, the former HDL site housed only a 2-in. i.d., 34-ft simulator and a 4-in. i.d., 96-ft AVD gun, two more systems are now in service in the REL, namely, a 3-in. i.d., 100-ft artillery simulator and a 7-in. i.d., 314-ft AVD gun.

However, even while heavily involved with the details of the design of the REL building and its facilities, HDL staff continued uninterrupted to work on plans and designs for development of the advanced artillery simulators, an indoor firing range, and a structure to house these operations. The proposed facility, the Fuze Environment Simulation Facility (FESF), became part of the HDL Military Construction Army (MCA) long-range planning program in 1972.

Technical Planning for facilities, equipment, and operations for both REL and FESF was performed by and under the supervision of H. D. Curchack. Incorporation of operations into building layout and design has been the responsibility of F. L. Tevelow, who authored most of the documentation needed to enter the MCA program and to satisfy its requirements.

¹H. Curchack, *Artillery Simulator for Fuze Evaluation*, Harry Diamond Laboratories TR-1330 (1966). See also Shock and Vibration Bulletin 47, Part 3 (1970), 155.

²M. Otten, *Development of a 7-in. Air Gun for Use in Interior Ballistics Simulation*, Harry Diamond Laboratories TM-75-13 (1975).

³W. P. Morrow, *Hard Wire Technique for Extracting Data from a Projectile During In-Bore Environments*, Harry Diamond Laboratories TM-72-27 (1972).

⁴T. Liss and J. Richardson, *Ruggedized Quartz Oscillator Crystal for Gun Launched Vehicles*, Harry Diamond Laboratories TM-68-23 (1968).

⁵J. Richardson, *Preliminary Report on Development of a Crystal Controlled L Band Artillery Telemetry Transmitter*, Harry Diamond Laboratories TR-1564 (1971).

⁶H. J. Davis et al, *Dynamic Response of a Fuze/Projectile System to Propellant Pressure Waves in the M199 155mm Howitzer*, Proceedings of the Fuze/Munitions Environment Characterization Symposium II, Picatinny Arsenal (1975).

It is the purpose of this report to consider various aspects of fuze testing, to propose solutions to the problems involved and to consider the implementation of these solutions. Background data gathered in the course of the investigation are presented in the appendices. Thus, field tests usually performed on electronic fuzes are discussed in appendix A. Characteristics of existing ranges were studied for potential application to the fuze test facility and are described in appendix B. In particular, an attempt was made to define the state of the art of various field-testing techniques so that those suitable to the proposed application could be used. Using existing techniques would cut down both on the risks and on the costs involved in new development. In particular, the indoor hypervelocity launcher facilities at the Naval Surface Weapons Center (NSWC) at White Oak were considered (discussed in app C). Appendix D includes a bibliography describing ballistic instrumentation. Pertinent characteristics of U.S. Army weapons, projectiles, and propellant charges are presented in appendix E.

2. CURRENT FUZE TESTING PRACTICES

Most artillery firings currently used by HDL to test electronic fuzes are carried out at the various Army Test and Evaluation Command (TECOM) Proving Grounds; some testing is also carried out at the recently reactivated HDL Test Site at Blossom Point, MD. Tests at all these locations are set up at the request of the fuze-development project concerned, which also provides the fuzes to be tested. The range, weapon, rounds, and operating personnel are provided by the test facility. The test facility arranges scheduling according to priorities, work load, availability of equipment and personnel, traffic through the range space (air, water, and vehicular), and the weather and travel conditions at the time of test. At all facilities, most tests are functional; i.e., the fuze (or fuze subsystem — power supply, safety and arming mechanism, impact element, etc) either causes a visible function after being fired or it does not. Therefore, these tests must be performed during the external or terminal ballistic phase of the projectile's flight. Specialized electronic equipment such as transducers and telemeters are not routinely used during this testing. Many test results are not useful to the general fuzing community, because the information obtained is usually specific to the hardware project involved, not all prevailing conditions are recorded, and the data collected are generally stored in project files which are not available to other potential users.

The field testing system just described causes hardship and expense to developers of modern electronic fuzes. Long lead times, with large slack periods, must be planned to compensate for delays at the proving grounds. Range personnel, though competent and willing, are not necessarily trained for fuze-development projects. Fuze-development personnel who are detailed to a range test may not necessarily be skilled in range or weapon procedures. Insight and understanding of the effects of ballistic phenomena on fuze performance are thereby lost. This is particularly true of information on the internal ballistic regime, which must be deduced from the results of the functional tests performed during the external or terminal ballistic regimes. This loss is unfortunate since internal ballistic phenomena vitally affect fuze survival and performance. Testing under these conditions requires considerable deduction and judgement to determine just what has happened if the fuze does not function.

The compressed air and vacuum guns¹ currently used at HDL provide means of laboratory testing electronic ordnance fuzes over a wide range of linear and angular accelerations. These tests can be carried out accurately, repeatably, and at less cost than comparable field tests since they are performed

¹H. Curchack, *Artillery Simulator for Fuze Evaluation*, Harry Diamond Laboratories TR-1330 (1966). See also Shock and Vibration Bulletin 41, Part 3 (1970), 155.

indoors, with equipment that can be kept in place over a long time, using permanently assigned and highly trained personnel. It is impossible to simulate gun firings completely in the laboratory, however, since phenomena occur while firing that are not fully defined. For example, the effect on fuzes of the amplitudes, durations, and frequency of occurrence of balloting, side slap, and muzzle jump forces is not well understood. Actual gun firings are needed, and will continue to be needed, to study and characterize fuze performance.

3. PROPOSED FACILITY

Propellant-driven projectiles must be fired at the proposed test facility so that the effects of anomalous ballistic phenomena on fuzes may be studied. The facility should also make use of the ease, low expense, and accuracy of experimental simulation techniques and of the power and understanding afforded by modern instrumentation and data-processing techniques. The facility should be under the control of a fuze development agency (HDL for Army electronic fuzes). Such a facility should be able to handle relatively large weapons and contain apparatus and instruments suitable for use in all ballistic regimes. Range personnel should be intimately associated with the development of fuzes to ensure that all lessons learned are fed back into the development cycle. Continuous control over the fuzes' ballistic environment should be maintained. This can be done if the facility consists of a building enclosing the artillery piece, a short portion of flight range, and a projectile-stopping or -catching mechanism. Tests would then be performed independently of temperature, weather, wind, and local traffic conditions. Under these circumstances, calibrated instrumentation could be set up and left permanently in place, and sophisticated techniques developed and applied which would not otherwise be practicable. Besides increasing the precision and accuracy of the testing operation, the improved instrumentation would permit testing with fewer personnel than on a range, resulting in long range cost savings to the Government. Firings could be carried out not only as development tests of specific hardware designs, but also as generalized studies of the effect of ballistic environments on fuzes. Increased understanding of such effects will greatly expedite the present evolutionary procedures followed in fuze design, optimization, and standardization, at the same time maintaining high levels of reliability and cost effectiveness. The information gathered would permit greater use of simulation and modeling techniques.

When a shell is launched from a cannon and later recovered it will generally undergo two major axial accelerations: one on launch and the other on stopping. If the stopping acceleration is small (10 percent or less) compared to that of launch, it is termed *soft* and a *soft catch* is made. If the stopping acceleration is similar to that of launch, it is termed a *moderate catch*, and if it is larger, a *hard catch*. Obviously, it is best to soft catch a shell to evaluate the effects of the launch on the fuze. A soft catch, however, requires distances greater than 10 gun-barrel lengths to decelerate. Moderate catch results after about one barrel length of travel. A hard catch is achieved after a fraction of a barrel length of travel.

In this report, the proposed facility is referred to as the Fuze Environmental Simulation Facility (FESF). The building housing the test facility (the Fuze Environmental Simulation Building — FESB) would comprise a simulation area, containing air and vacuum guns, and a weapon firing area. The concern of this report is the weapon firing area. This area would incorporate two recovery systems, a 105-mm howitzer, which fires projectiles into a soft-catch recovery device, and a free-flight weapon-firing area, approximately 400 calibers long, in which projectiles will be fired into a moderate-catch recovery area. The choice of the 105-mm howitzer for the soft catch area is based (as will be seen) on the wide range

of launch environments available with a small propellant charge. The minimum required recovery distance is 37 m. The free-flight range will be used to fire various weapons, up to a 155-mm howitzer. The associated moderate-recovery stopping distance would have to be at least 4.6 m.

4. DESIGN CONSIDERATIONS

The information contained in the appendices indicates that the techniques and apparatus needed to operate an artillery piece in the FESB have already been developed. The use of the artillery piece and the application of developed procedures to the FESB is discussed in the following section.

4.1 Site Location

Table I lists potential sites for the FESF. The list is limited to existing test or fuze-development facilities on the northeast coast. More information on these sites is given in appendix B. Table I lists factors arguing for and against placing the facility at various sites. These include distance from HDL, availability of fuzing experience and personnel at the site, the administrative structure of the organization controlling the site, and the characteristics of the site itself. The factors are judged positive or negative according to the way they might affect HDL's fuze-development operations.

4.2 Test Requirements

Tests of electronic-fuze power supplies, safety and arming mechanisms (S&A's), impact elements, and electronic circuitry, as well as tests of complete fuzes, could be carried out in the FESB if a free-flight range is provided. The main criterion determining the necessary length of the free-flight range is the distance it takes the S&A to arm. Standard artillery fuzes generally arm in less than 800 calibers of flight. This is approximately 124 m for a 155-mm projectile.

The functioning of a fuze subsystem is sometimes determined on a test range by the test item setting off a pyrotechnic booster. This same testing technique could be used in the FESB using pyrotechnics or telemeters instead of explosives. The pyrotechnic development group at Picatinny Arsenal states that standard units are probably suitable but, if not, others can be developed for the purpose. In the same way, it would be possible either to use standard proximity fuzes to indicate functioning⁷ or to develop telemeters for the purpose. The level of interference created by metal in the walls of the building interacting with the proximity fuzes' oscillators would determine which course should be followed. The functioning or nonfunctioning of mechanical impact elements upon striking raindrops, different thicknesses of plywood, or standard target materials (earth, sand, water, etc) can be determined by similar techniques.

If the result of the free-flight functional tests is positive, the fuze designer has the desired information. If the test result is negative, however, the fuze designer usually wants to recover the fuze to find out what happened. The usual practice when testing a new mechanism or when investigating a malfunction is to recover the fuze from the earth after firing. (Parachute recovery vehicles are also used, but infrequently, because (1) special hardware is required for each test, (2) the projectile must be modified from its standard configuration, and (3) the complete test is relatively expensive.) Firing into earth constitutes, under normal conditions, a moderate catch of the projectile. This less-than-

⁷F. Blodgett, *Switch Telemetry for M514A1E1 Fuze*, Harry Diamond Laboratories TM-71-10 (1971).

TABLE I. CHARACTERISTICS OF POTENTIAL LOCATIONS
FOR THE FUZE ENVIRONMENT SIMULATION FACILITY

Location	Positive factors	Negative factors
Aberdeen Proving Ground, MD		
Ballistic Research Laboratories	Ballistic experience Existing resources	Distance from Harry Diamond Laboratories (HDL) Different administrative structure Different emphasis in operations
Materiel Testing Directorate	Testing experience Existing resources	Same as above
Adelphi, MD		
Harry Diamond Laboratories	Location Fuze-development experience Intimate development/testing relationship Unified administrative structure	Limited space Residential nature of community
Naval Surface Weapons Center (White Oak)	Location Existing facility	Same as above plus different military service Existing facility requires modification
Blossom Point, MD		
Harry Diamond Laboratories	Fuze-testing experience Unified administrative structure	Distance from HDL fuze-development resources Limited space
Dahlgren, VA		
Naval Surface Weapons Center (Dahlgren)	Testing experience Available facilities	Distance from HDL Different military service
Dover, NJ		
Picatinny Arsenal	Fuze-development experience	Distance from HDL Different administrative structure
Philadelphia, PA		
Frankford Arsenal	—	Arsenal closing down

satisfactory technique can be duplicated in the FESB by firing into an earth-filled pit at the end of the range. A number of firings are often required during a test, not only because of the difficulties of finding the projectile and recovering it reasonably intact but also because the phenomena causing the failure may be random and not occur on every shot. Shell will therefore have to be recovered relatively rapidly from the earth in the FESB so that new projectiles do not strike those previously implanted.

Techniques exist to catch free-flying, lightweight (a few kilograms) or low-velocity (30 m/s or less) projectiles without damage (see app B). Outside these limits, there are no universal techniques for soft recovery of free-flying shell in existence today (see sect. 4.5 for methods of improving this situation). Soft recovery of the shell to study the effects of the internal ballistic regime can be accomplished, however, by using one of the already developed guided shell recovery techniques: the water-trough or air-tube technique (see app B).

The use of transducers and telemeters to study component performance would not only compensate for the lack of well-developed mechanisms to soft-catch free-flying shell, but would also measure the component's performance in flight. Considerably more data would therefore be available to characterize a specific component than can be obtained by examining the entire mechanism after recovery. In addition, these time-dependent measurements could be used to validate mathematical models and improve the entire simulation process.

4.3 Cannon

Consideration of the characteristics of U.S. Army weapons, projectiles, and charges (app D) gives information on cannon that should be used in the FESB. Recoilless rifles and antitank guns primarily fire kinetic-energy contact-fuzed shell; thus, proximity fuzes are not widely used with ammunition for these types of weapons. Small-caliber weapons have not seen much service recently, which tends to eliminate the need for these weapons in the FESB. Shell fired from guns (as opposed to howitzers) are high velocity, as seen from the 175-mm entry in table II, and require the use of large amounts of propellant. The other entries in table II are for high-explosive (HE) shell fired from mortars and howitzers.⁸ The velocities shown are the maximum velocities attained with each weapon.

Figure 1 presents envelopes of the peak accelerations and pulse durations experienced by mortars and howitzer projectiles while being fired. It can be seen that mortar pressures have small amplitudes and durations compared to those of howitzers. In addition, the many varieties of 105-mm shell cause their envelope to cover much the same space as that of the other size weapons. Figure 2 presents the same kind of data as figure 1 for guns. Narrower envelopes with much higher amplitudes than that of howitzers are apparent.

Many artillery cannon show anomalies; for example, shell in the XM198 155-mm howitzer show marked decelerations before leaving the gun tube during low zone firings. These weapons, if possible, should be used in the FESB, within the size restrictions imposed by the building design. One problem in selecting these weapons, however, is that sometimes the anomalies are not known to the entire ordnance community. Another factor to be considered in choosing a cannon is that there are special-purpose fuzes whose diameter is the same as that of the projectile. A number of such fuzes have been designed for 155-mm shell.

⁸L. Heppner, *Setback and Spin for Artillery, Mortar, Recoilless Rifle and Tank Ammunition*, Materiel Testing Directorate, Aberdeen Proving Ground, MD, Final Report APG-MT-4503 (1974).

TABLE II. CHARACTERISTICS OF SELECTED ARMY AMMUNITION*

Projectile	Size (diam)	Projectile weight		Maximum muzzle velocity		Propellant weight		Maximum kinetic energy at muzzle	
		(lb)	(kg)	(ft/s)	(m/s)	(lb)	(kg)	(ft-lb × 10 ⁶)	(J × 10 ⁶)
XM720	60 mm	3.9	1.8	778	237	0.08	0.036	0.036	0.049
M374A2	81 mm	9.1	4.1	877	267	0.23	0.104	0.108	0.147
M329A1	4.2 in.	22.2	10.1	1035	315	0.58	0.262	0.370	0.50
M48	75 mm	14.7	6.7	1250	381	0.91	0.4122	0.357	0.485
M1	105 mm	33.0	14.9	2170	661	4.4	1.993	2.42	3.28
XM549	155 mm	96.0	43.5	2710	826	25.25	11.438	11.	14.9
M106	8 in.	200.0	90.6	2200	671	34.5	15.629	15.	20.4
M437	175 mm	147.4	66.9	3000	915	57.7	25.912	20.	27.2

*Abstracted from L. Heppner, *Setback and Spin for Artillery, Mortar, Recoilless Rifle and Tank Ammunition*, Materiel Testing Directorate, Aberdeen Proving Ground MT-4503 (1974).

It is conceivable that rocket fuzes, particularly those meant for anti-tank service, could be tested in the FESB. The use of rockets in the FESB was not investigated in the course of this study.

An adaptable cannon mount should be provided in the FESB to accommodate the many models of differently sized cannon. Such mounts are used at other firing ranges. A sleigh, which is a trough with adapter rings, is used to clamp the gun tube in the mount. Figure 3 shows one sleigh developed at Rock Island Arsenal. It is placed in a standard gun carriage and holds 75-mm to 8-in. (203-mm) cannon. Personnel at Rock Island Arsenal suggest that the XM153 carriage (see fig. 4), normally used with the 8-in. howitzer, be used in the universal mount. The upper part can be removed from the wheels. Personnel at Aberdeen Proving Ground have suggested using the M158 carriage normally used with the 155-mm howitzer. Figure 5 shows a 152-mm gun mounted in a sleigh and placed in the M158 carriage. This assembly is mounted on the pedestal used in the 175-mm self-propelled howitzer and is placed on a massive steel plate. Although weighing 63,000 kg, this system can be moved readily with a crane.

A certain amount of recoil as well as structural ringing and whip of the gun tube can be expected before a shell leaves the muzzle of a weapon. Not much is known about the degree to which these events take place, about their effect on fuzes mounted in the shell, nor about the difference in such phenomena when the cannon is mounted on a standard carriage and when it is placed in a universal mount. The effects are believed to be small. The controlled conditions of the cannon mounted in the FESB would greatly facilitate a study of these phenomena.

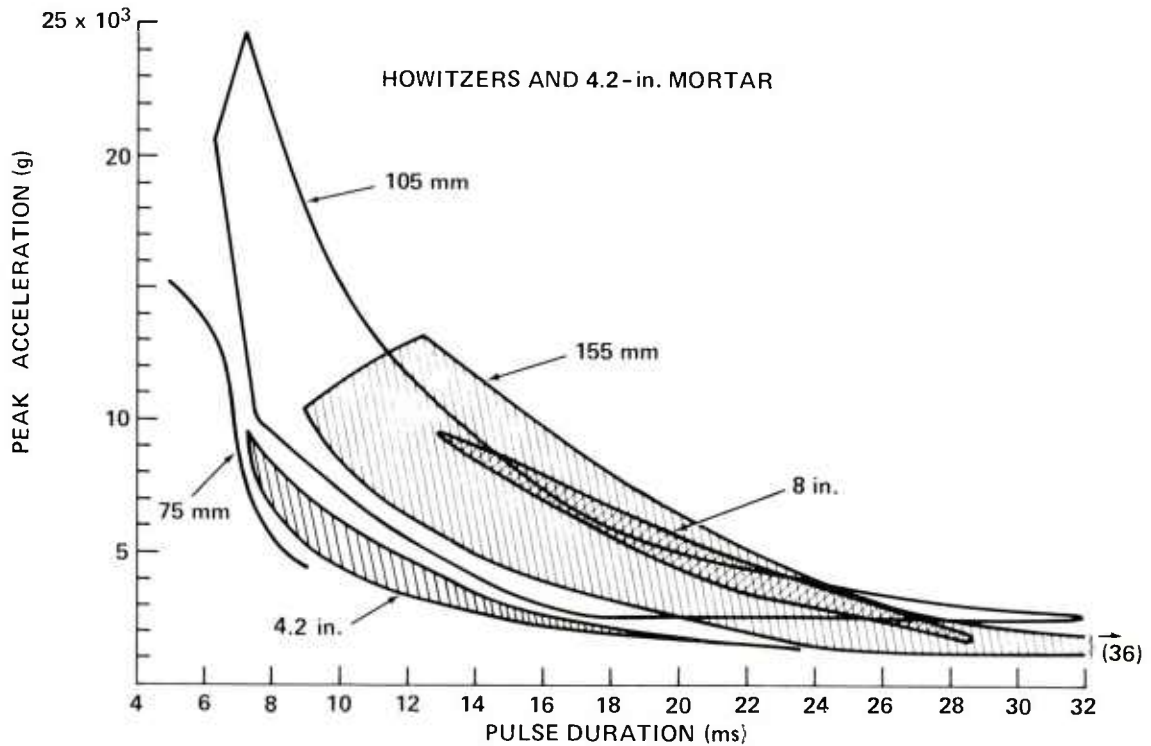
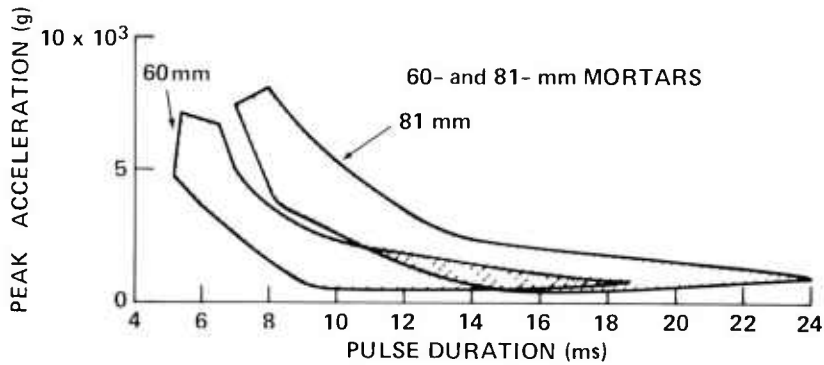


Figure 1. Amplitude and duration of mortar and howitzer firing pulses.

The design of standard gun mounts is such that the weapon's recoil is absorbed by its recoil mechanism and ultimately by the earth, since the weapon's spades are usually buried. The neighbors of the FESB and any delicate equipment in the vicinity must be protected from vibration caused by firing. Specialists in shock and vibration attenuation indicate that this is well within the state of the art. Reductions of vibration amplitude to 0.000254 cm at the boundary of the building are possible if the rigidly mounted weapon is seismically mounted. Another method, used by NSWC at White Oak (see app C), is to allow the gun carriage to recoil on rails, so that friction damps its motion. The Research Laboratories of the Corps of Engineers have volunteered to study any proposed vibration-attenuation designs.

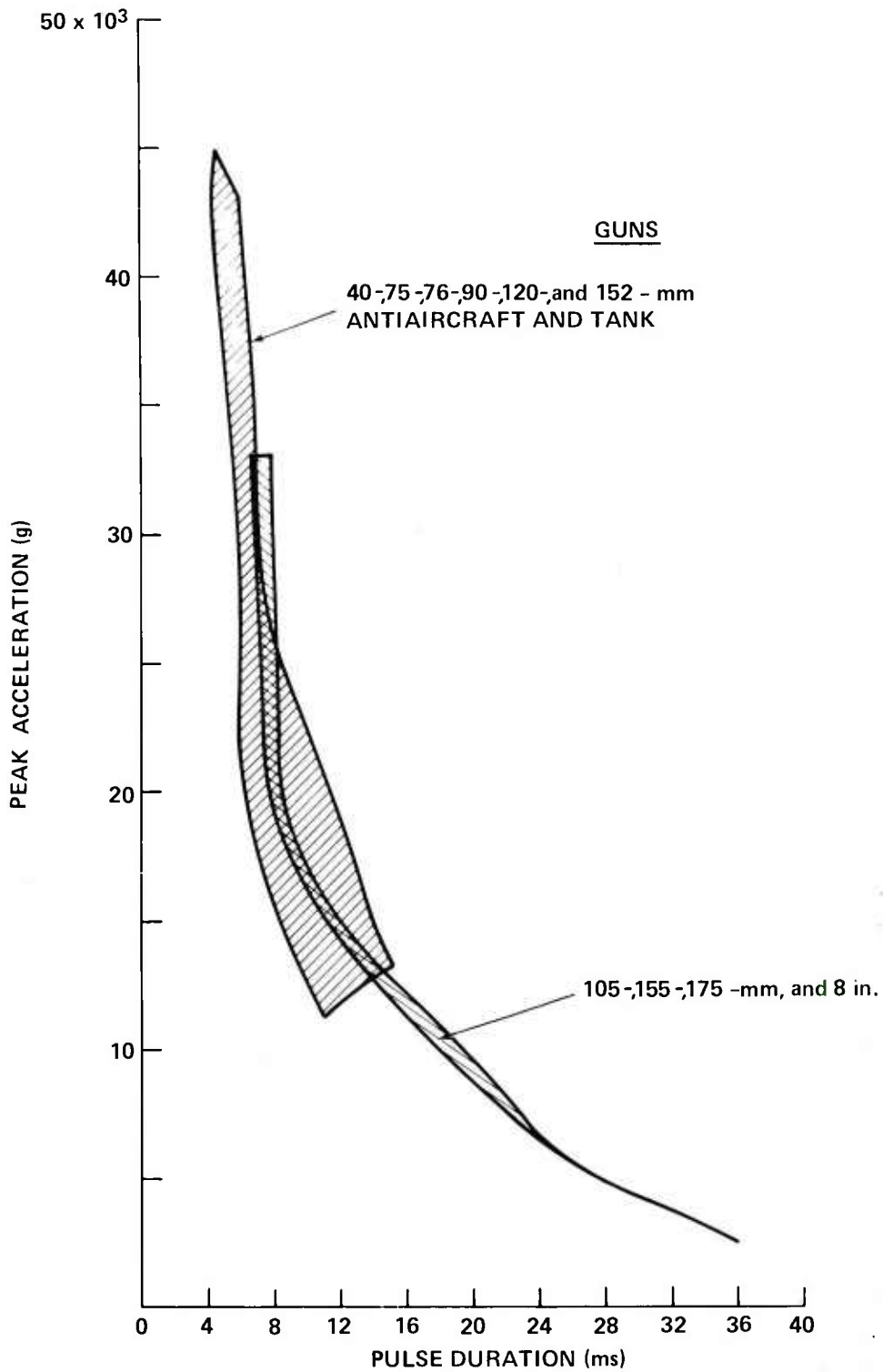


Figure 2. Amplitude and duration of gun firing pulses.

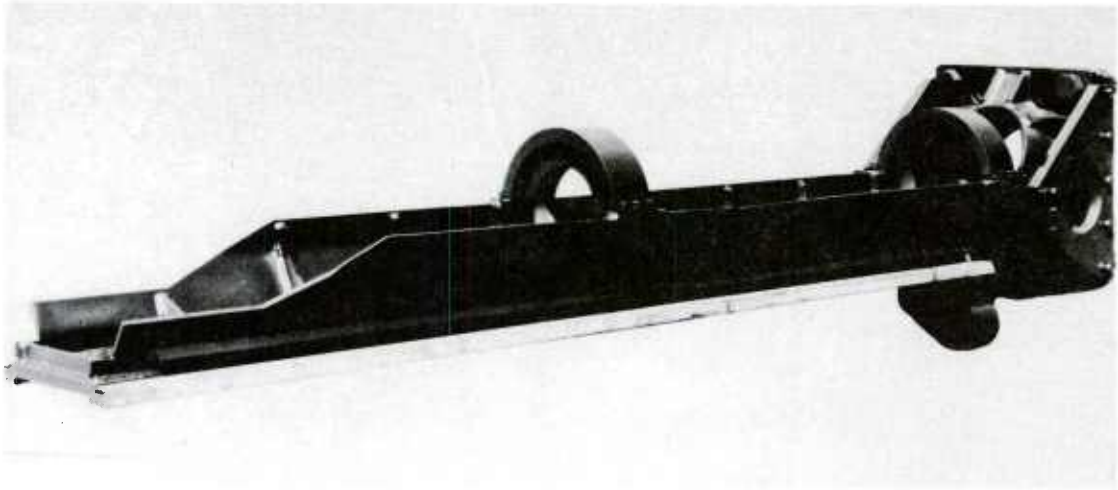


Figure 3. Artillery sleigh developed at Rock Island Arsenal.

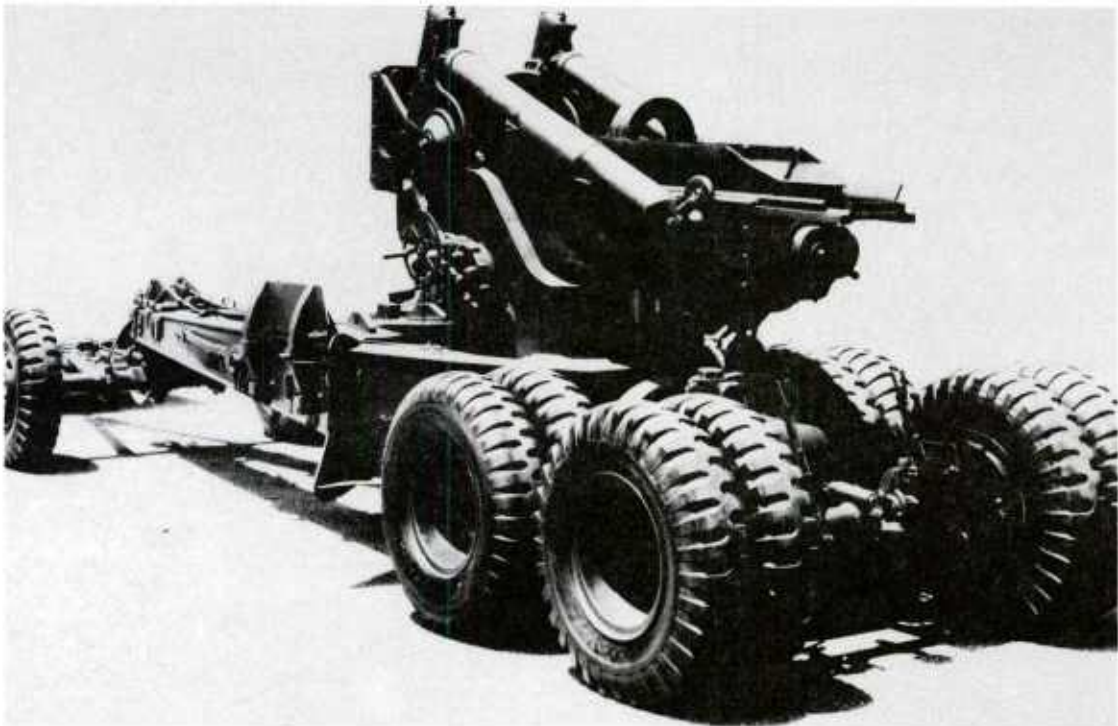


Figure 4. XM153 artillery carriage.

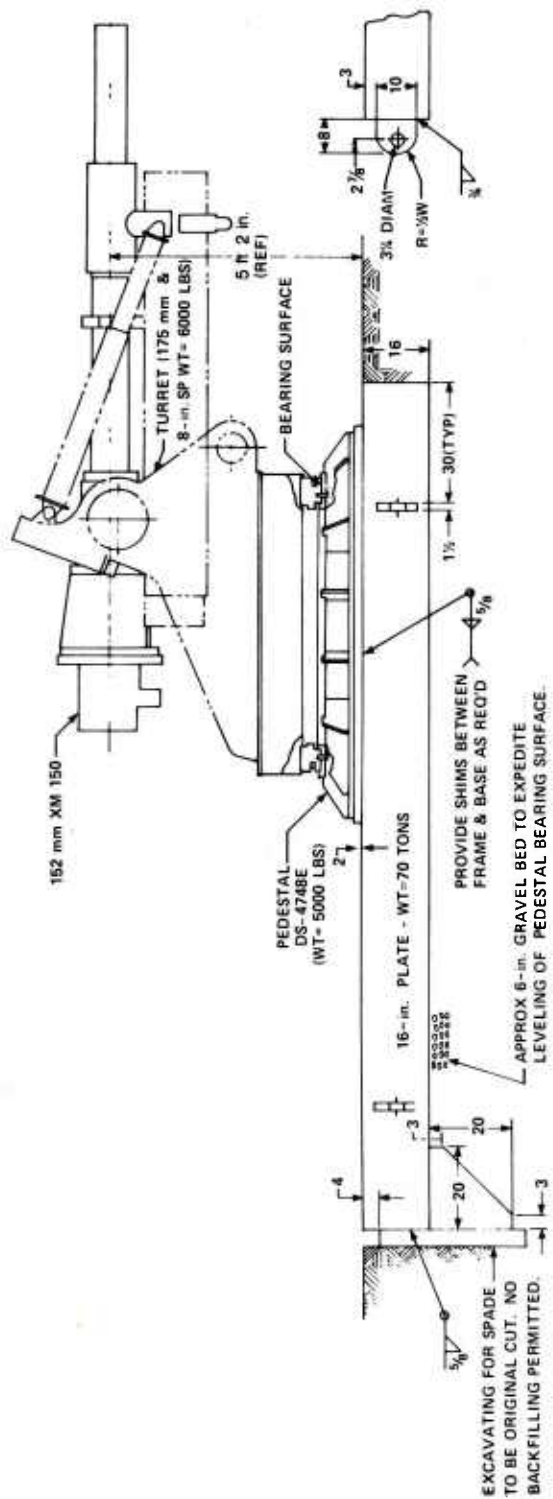


Figure 5. XM158 artillery carriage used as universal test mount.

4.4 Control of Blast, Noise, and Propellant Gas

High pressures and noise levels are generated when an artillery weapon fires.⁹ Although extensive work on artillery silencers has been described,^{10,11} the reported success of the blast-tank technique used in the NSWC hypervelocity facility (app C) makes this an obvious choice for the FESB. The vacuum in the tank ensures that the blast wave is weakened. The tank contains both the blast wave and the propellant gas. Propellant gas can safely be eliminated either by diluting it with an inert gas such as nitrogen or by passing it through a scrubber as it is expelled to the atmosphere.

To avoid any possible buildup of toxic material in the residue generated by firing peculiar types of propellant, examinations of the residue in the blast tank would be examined by personnel from the Army's Environmental Health Group.

4.5 Control of Projectile Motion

The stability of a shell in flight is a matter of obvious concern. Requirements governing the development of standard Army shell prescribe that shell fired from well-mounted, well-aimed weapons should not deviate from the established trajectory by more than two milliradians. Thus, there is virtually no chance that standard Army shell which have gone through the development cycle will become unstable and move off trajectory, particularly over the short range involved in the FESB. Placing the flight range underground, with reinforced walls, will assure shell containment.

If the soft- or moderate-recovery device fails, building construction features will assure that shell are contained. The Waterways Experimental Station (WES), Vicksburg, MS, uses the data of an Army Manual¹² to get estimates of the thicknesses of earth-like materials needed to stop shell. Figure 6 is a nomograph which provides the required data. It can be seen that 4.3 m of sand or 8.5 m of clay will stop a 43-kg, 155-mm shell travelling at 8500 m/s. Note that the trajectory of a shell in earth-like material is not a straight line. This can be further seen from the experimental data of Lascher et al¹³ which shows the trajectory variations that can occur when 20- and 155-mm shell are fired into sand. The width of the shell catchbox should be large enough for the shell to turn without hitting the walls of the box. Personnel at WES can design composite walls to stop shell, the outer layers of such walls being filled with sand or other material that is readily replaceable. Figure 6 shows that a wall of concrete 1.8 m thick will stop the largest shell likely to be tested in the facility.

Projectiles fired from actual weapons can be soft caught if the projectile is guided from the launcher to the catch mechanism. Such guidance precludes testing in the external ballistic regime but provides a means of studying fuze phenomena that take place in the internal ballistic regime. As pointed out in appendix B, two such soft-catch techniques have been developed. Firing a shell into a water

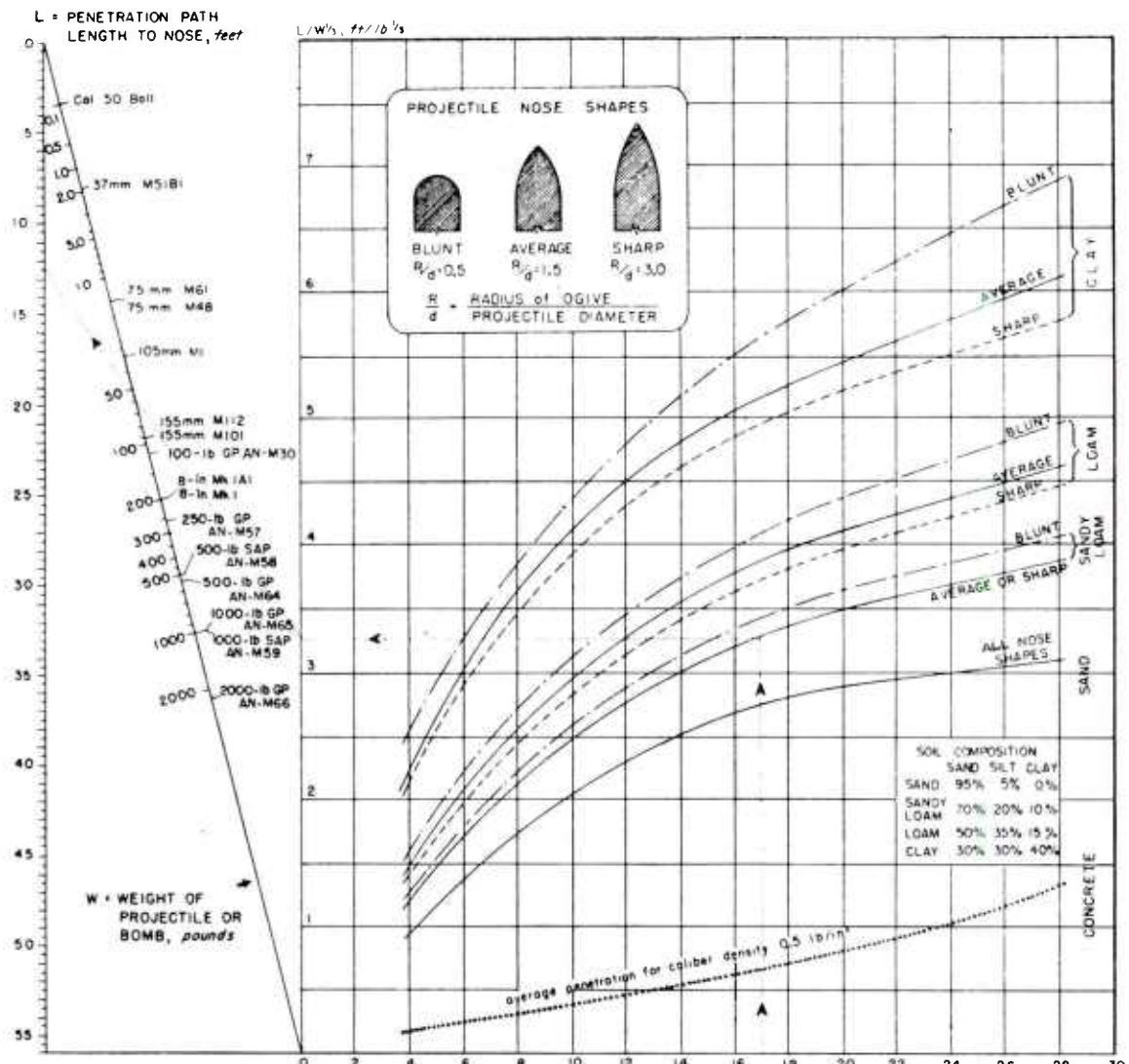
⁹M. J. Salsbury, *Blast Field Study for Proposed RIA Firing Tunnel*, Rodman Laboratories, Rock Island Arsenal, Summary Report R-TR-74-007 (1974).

¹⁰O. C. Bixler et al, *Analytical and Experimental Studies of Weapon Muffling*, LTV Research Center Report on U.S. Army Rock Island Arsenal Contract DAAG05-67C-0048 (1967).

¹¹H. J. Sneck, *Cannon Muzzle Blast Noise Suppression Facility*, Watervliet Arsenal Technical Report 75043 (1975).

¹²Anon., *Fundamentals of Protective Design (Non-Nuclear)*, Headquarters, Department of the Army, Technical Manual 5-855-1 (July 1965).

¹³F. Lascher et al, *Projectile Impact and Penetration Forcing Functions Engineering Study, Phase II*, AVCO Government Products Group Final Report on Contract DAAA21-71-C-0517 (1972).



The graph and nomogram give the relation between striking velocity and penetration path length, measured to the nose, for projectiles or bombs of various weights penetrating into several soils. Curves marked *blunt*, *average*, and *sharp* are for projectiles of different nose shapes as sketched. Where no appreciable effect of nose shape on penetration has been observed only a single curve is drawn. The dependence of penetration path length on projectile weight, as given by the nomogram, agrees with observations for projectiles or bombs having caliber densities from 0.15 to 0.65 lb/in³. Most bombs and artillery projectiles have caliber density values (weight of projectile in pounds divided by the cube of the diameter in inches) within the above range.

Trajectories in soils are usually straight for two-thirds or more of the path length, but curve near the end of the path (see sketch). For this reason final distance from the surface is usually 10% to 30% less than the penetration path given here.

Curves given are for average soil types. Penetrations into rich plastic clay are approximately 30% greater than those observed in clay. The dotted curve at the bottom of the graph gives average penetration into good quality reinforced concrete, and is added here for rough comparison.

EXAMPLE: The dotted line shows that a projectile of average nose shape and weight of 60 lb striking sandy loam soil with a velocity of 1700 ft/sec will have a path length of approximately 12.5 ft, measured to the nose. Because of the curvature of the underground trajectory, the actual penetration from the surface will be somewhat less.

SOURCE: British and American tests with bombs and large caliber projectiles at velocities below 1100 ft/sec. Small caliber tests for the Corps of Engineers, U.S.A. extending over entire velocity range. The curves agree with measurements to ±20%. NDRC Weapon Data.

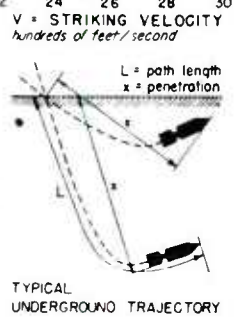


Figure 6. Penetration of bombs and projectiles into soil (excerpted from *Fundamentals of Protective Design (Non-Nuclear)*, Department of the Army Technical Manual 5-855-1, July, 1965).

trough requires mounting the fuze on an internal bulkhead and modifying the nose of the shell to control its resistance as it moves through water. In addition to abnormalities generated by this arrangement, there is danger of water entering the fuze casing.

A second guided soft-catch technique (wherein the shell is fired into a closed-end tube and brought to rest by the compression of the air trapped in the tube) is used at NSWC at Dahlgren to catch Naval 5-in. projectiles. Numerous analyses of this technique have been performed.¹⁴ *

Currently, free-flying flat-nosed projectiles weighing less than 1.81 kg with velocity less than 420 m/s can be moderately caught using aluminum honeycomb.¹ Preliminary experiments indicate that honeycomb can be used to catch projectiles with characteristics larger than those mentioned above, but further work is needed to define the properties of the honeycomb under these new conditions. Yet another target material that could be used to stop free-flying projectiles might be a mixture of sand and plastic pellets, the sand to act as a means of taking momentum from the projectile, the plastic pellets to act as a means of absorbing energy and to insure that only a limited amount of sand is accelerated by the projectile at a single instant of time.

4.6 Measurement and Control

Instruments in the FESB should be used to maintain safety, to control operations, and to measure phenomena occurring during testing. Data transmission and analysis capabilities must also be provided.

Safety and control instrumentation would include (1) interlocks to prevent admittance to hazardous areas during a firing and preclude firing until all firing procedures have been carried out, (2) sensors inside the building to detect gases generated during a firing, (3) detectors to determine the presence of fire, and (4) sensors outside the building to verify that acoustic or seismic waves do not affect the neighborhood.

Not only would high- and regular-speed cameras be used to make measurements during a test, but also photodetectors would be used to determine the time and place of a pyrotechnic functioning. Transducers would be used in the shell to measure component motion, projectile acceleration, and the functioning of various fuze subsystems. This information would be telemetered and picked up by ground receivers. Development of such instrumentation systems is continuing at a number of locations.¹⁵⁻¹⁹ Transducers would be placed in the target to determine time and place of impact. Flash x rays would be used to determine the projectile's motion through the propellant gas and blast wave and, if proven useful, would be used to determine the state of fuze components at various points in the shell's flight.

¹H. Curchack, *Artillery Simulator for Fuze Evaluation*, Harry Diamond Laboratories TR-1330 (1966). See also Shock and Vibration Bulletin 41, Part 3 (1970), 155.

¹⁴P. G. Baer, *A Digital Computer Analysis of a 155mm Soft Recovery System*, Ballistics Research Laboratories R1634 (1973).

¹⁵E. A. Gurtler and J. B. Gibbons, *High G Telemetry Status and Capabilities*, Picatinny Arsenal Technical Report 4784 (1975).

¹⁶M. R. Condit, *Application of an L Band FM-FM Telemetry System for Use with the 5" Air Gun*, Picatinny Arsenal TR 10-74-1 (1974).

¹⁷W. Evans, *In-Bore Measurement of Projectile Acceleration and Base Pressure Using an S Band Telemetry System*, Proceedings of the Second Fuze/Munitions Environment Characterization Symposium (1975).

¹⁸V. W. Richard, *Development of a UHF Telemetry System for Projectiles*, Ballistics Research Laboratories R1486 (1970).

¹⁹V. Oskay and W. Mermagen, *Transonic Flight Dynamics of Long Shell*, Ballistics Research Laboratories MR 2545 (1975).

*L. Anderson, *Ballistic Recovery Tube Facility*, Naval Surface Weapons Center unpublished report (1975).

Transmission lines would be installed along the length of the FESB to transmit information from sensors, control signals, and voice communications. Measurement information would be handled and stored by minicomputers in the FESB with provision for data transmission to the HDL computer.

4.7 Storage and Operating Procedures

Arrangements have been made with NSWC at White Oak to store some propellant in the bunkers there. Arrangements can be made with nearby military facilities to store larger amounts if needed by (for example) a designer who wishes a large supply from a single lot.

Only enough rounds for immediate operation would be stored in the FESB at any time. Thus, a limited number of rounds would be undergoing temperature conditioning at any one time. These rounds would be stored in the equivalent of the suppressive shielding structure developed by Edgewood Arsenal.

Table III lists Standard Operating Procedures (SOP's) developed by the Materiel Testing Directorate, Aberdeen Proving Ground. These SOP's would provide the basis for operations in the FESB.

TABLE III. ABERDEEN PROVING GROUND STANDARD OPERATING PROCEDURES (SOP's)

No.	Title	Date
385-2	Range Control Regulations	3 June 1971
385-5	Propellant Weighing Operations	8 October 1970
385-6	Crimping and Chamber Gaging Complete Rounds	6 November 1970
385-9	Inspection of Ammunition Packing Materials	17 February 1965
385-23	Field Observation and Recovery of Ammunition Items	4 December 1972
385-26	Maintenance and Clearing Operations Within the Range Areas	14 January 1975
385-37	Unpacking Explosives, Ammunition and Ammunition Components	30 October 1970
385-49	Assembly, Disassembly and Drilling of Ammunition and Ammunition Components	1 December 1971
385-60	Controlled Temperature/Climatic Chamber Test Operations	6 November 1970
385-67	Firing of Weapons Ground-to-Ground and Ground-to-Air	10 September 1968
385-82	Stratosphere and Blast Chamber Operations	15 May 1970
385-112	Handling of Ammunition During Firing of Small Arms and Automatic Weapons	23 September 1966
385-120	Intra-Plant Transportation of Explosives and Ammunition	15 August 1972
385-129	Disassembly of Projectiles from Cartridge Cases	4 December 1970
385-130	Delivery of Ammunition Items to MTD Shops	7 January 1966
385-135	Machining of Ammunition Items or Components	14 September 1973
385-150	Assembly and Disassembly of Ammunition for Mortars	5 June 1967
385-153	Measurement of Ammunition	16 June 1971
385-196	Black Powder Loading Operations	21 September 1972
385-206	Pressing Projectiles into Cartridge Case (Fixed Ammunition)	8 October 1970
385-264	Handling and Processing Fuzes w/wo Boosters	8 November 1967

5. SUMMARY AND CONCLUSIONS

Development testing of many specialized items such as gun tubes, gun carriages, and ammunition propellants is carried out at various sites dedicated to the testing of these specific items. General or large-scale electronic fuze testing is carried out at the various proving grounds, with some development testing done at Blossom Point, MD. Fuze testing is inhibited by the limitations of existing test techniques and procedures and by the size of the Blossom Point test site. HDL should have an improved facility dedicated to electronic fuze testing.

Electronic instrumentation, together with modern analysis techniques, holds the promise of revolutionizing fuze design by defining the effect of ballistic environments upon fuze behavior. These instruments can be used, the ballistic environment can be controlled, and dynamic data can be gathered repeatably if the weapon, flight range, and projectile-catch mechanism are enclosed in a building.

The integration of a test range into the fuze development cycle can be accomplished more readily if the development and testing activities are carried out at the same place. Accordingly, the artillery weapons should be in the FESB at HDL, Adelphi, MD. Second- and third-priority locations are NWSC at White Oak, MD, and the HDL test site at Blossom Point, MD.

The FESB should include (1) a guided-flight soft-catch mechanism which stops the shell in a closed-end tube and (2) a free-flight range about 120 m long with moderate-catch capability. The guided-flight mechanism would be used to determine the effects on fuzes of internal ballistic phenomena. It should be built to catch 105-mm shell. General ballistic fuze tests would be carried out on the free-flight range. A universal mount that can hold 75- to 155-mm cannon should be used on this range. Provision for firing smaller caliber weapons and mortars should be made.

All known problems that would affect the test facility or the surrounding residential neighborhood can be solved using existing techniques. Thus, the recommendations of specialists in vibration attenuation should be followed with respect to the cannon mount. A blast tank should be used to control blast, noise, and propellant gas in the FESB. The walls of the FESB should be designed in accordance with accepted ordnance protective practices to stop shell. Free-flying shell can be recovered from earth in the FESB to the same degree as is currently done in the field. Efforts to develop techniques to soft-catch heavy, high-velocity shell should continue.



Acknowledgement

Conversations with personnel of the HDL Relocation and Planning Office and with R. R. Palmisano of HDL are gratefully acknowledged. In addition, considerable information was obtained from personnel at the Ballistics Research Laboratories and the Materiel Testing Directorate, Aberdeen Proving Ground; the Rodman Laboratories, Rock Island; the Research and Engineering Directorate, Watervliet Arsenal; the Waterways Experimental Station, Vicksburg, MS; and the Naval Surface Weapons Center, White Oak, MD.

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14. P. G. Baer, *A Digital Computer Analysis of a 155mm Soft Recovery System*, Ballistics Research Laboratories R1634 (1973).
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18. V. W. Richard, *Development of a UHF Telemetry System for Projectiles*, Ballistics Research Laboratories R1486 (1970).
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APPENDIX A. — ELECTRONIC FUZE TESTS PERFORMED IN THE FIELD

The following list shows fuze tests performed on firing ranges. The fuzes tested in these ways are electronic and are mostly proximity or electronic time fuzes. Other fuzes with electronic capability, such as used in antitank weapons or to deliver battlefield sensors, undergo some of these tests and others peculiar to their own characteristics. The list is therefore not exhaustive; it is intended to provide a conceptual outline.

1. Study initiation and operation of power supplies.
2. Study functioning and performance of safety and arming mechanisms.
3. Study performance of mechanical impact elements.
4. Determine electronic proximity or time fuze turn on, operation, and functioning.
5. Determine reliability of entire fuze under varying conditions.
6. Measure dynamic behavior of mechanical fuze components in and near gun.

The thermal and liquid reserve batteries used as power supplies in electronic fuzes are usually tested functionally in the field; the round is fired and the battery either works or it doesn't. Performance is determined by whether the fuze operates as measured by a ground receiver, or by whether the fuze causes an explosion at the appropriate time. If the battery does not function, various modifications may be made in the battery design and the test is rerun. The cause of the problem is then deduced from the design change that solved it. Telemetry systems are sometimes used to obtain battery information. In a similar fashion, the safety and arming (S&A) mechanism is usually field tested by detonating the fuze's booster when the explosive train comes into line. The resulting flash of light is a positive indication not only of the functioning of the S&A but also of the distance from the launch point that this functioning took place.

Electronic fuzes that have backup mechanical-impact elements are field tested not only for proper functioning at the target but also for improper in-flight functioning caused by projectile vibration, or by impact with raindrops, tree branches, etc. In functional testing in the field, the functioning of the impact element sets off a pyrotechnic booster. Telemeters can be substituted for these boosters. The circuitry of the electronic sensor of a proximity fuze may also be functionally tested. Ground receivers can be used to detect the turn-on and performance of this fuze subsystem, as can the timers of electronic time fuzes.

Ground receivers and special telemeters are sometimes used in field tests of the complete fuze, particularly in the early stages of the development program. Functional testing as described above is the usual technique used at this stage. Functional testing is resorted to in the reliability testing of hundreds of fuzes in the latter part of a development program. Dynamic measurements of the behavior of fuze components in and near guns are seldom, if ever, carried out during a fuze development program. Measurement techniques, while available in principle, have not been developed to the point where they are used routinely. Therefore, using existing test techniques, considerable deductive reasoning is necessary to determine the cause of a specific failure.

APPENDIX B. — CHARACTERISTICS OF ARTILLERY FIRING RANGES

B-1. INTRODUCTION

An understanding of the state of electronic-fuze field testing was obtained by surveying certain test ranges and facilities. The facilities listed in table B-1 were considered for their fuze testing characteristics. The Army Test and Evaluation Command (TECOM) register of test facilities, when it appears, will give complete information on these and other military ranges. Army Training and Doctrine Command (TRADOC) ranges are not treated here since they appear to be oriented toward operational studies rather than hardware development. Those nonmilitary ranges that were identified are also listed. Ranges using air-driven guns rather than propellant-driven guns, such as the one listed at the Naval Surface Weapons Center at White Oak — NSWC (WO) — and special purpose ranges (such as the

TABLE B-1. RESEARCH AND DEVELOPMENT FACILITIES USING ARTILLERY WEAPONS

Facility name and location	Use of facility	Weapon(s)	Type of facility*	Remarks
TECOM RANGES				
Material Testing Directorate Aberdeen Proving Ground (APG) Aberdeen, MD	Acceptance testing of Army Weapons	All	APG's ranges	Jefferson, Dugway, and Yuma Proving Ground ranges assumed similar, a 30-m Celotex trough has been used with 155's, vertical recovery facilities available
White Sands Missile Range White Sands, NM	Atmospheric science laboratory testing	5 in./34	—	Smooth-bore gun, lead block stop
ARMCOM RANGES				
Picatinny Arsenal Dover, NJ	General round testing	All 155 mm	Open range Outdoor range	— Water trough stop
Rock Island Arsenal Rock Island, IL	Test carriage and recoil mechanisms	105, 155 mm	Open range	Indoor flight range proposed
Watervliet Arsenal Malta, NY	Test gun tubes	All	Open range	—
LABORATORY RANGES				
Internal Ballistics Lab Ballistics Research Labs APG, MD	Study internal ballistics	< 37 mm 155 mm	Four indoor ranges Outdoor range	Armor plate stop Water trough stop planned
External Ballistics Lab Ballistics Research Labs APG, MD	Study external ballistics	< 37 mm 155 mm, all	Indoor range Outdoor range	Armor plate stop Lead blocks, gun fired through 305-m enclosed flight range, sand pit stop, fire-fighting foam used to recover projectile on other range
Harry Diamond Laboratories Blossom Point, MD	Test fuzes	< 81 mm	Open range	Sand trough stop

* Open range — a range where shell are fired into the earth or water

Outdoor range — a range where shell are stopped by specified means (see Remarks)

Indoor range — self explanatory

APPENDIX B

TABLE B-1. RESEARCH AND DEVELOPMENT FACILITIES USING ARTILLERY WEAPONS (Cont'd)

Facility name and location	Use of facility	Weapon(s)	Type of facility*	Remarks
OTHER MILITARY SERVICES				
Environmental Group Naval Surface Weapons Center (NSWC) White Oak, MD	General testing	—	Indoor range	Gas gun made of 5-in. Naval cannon, air tube stop
Ballistics Group NSWC White Oak, MD	Hypervelocity projectile and impact studies	8-in. Naval gun (modified)	Indoor range	Steel plate stop, breech of gun only, fires small (~0.5 kg) projectiles at high velocity (> 1525 m/s), one of four similar indoor ranges
NSWC Dahlgren, VA	General testing	All	Outdoor range	Parachute recovery technique available, rifled air tube or waste-filled boxcar stop
Naval Weapons Center China Lake, CA	Test fuzes for Picatinny Arsenal	155 mm	—	Rocket sled catches moving shell
NONMILITARY RANGES				
Lawrence Livermore Labs Livermore, CA	Penetration studies	155 mm	Open range	—
Sandia Albuquerque, NM	Study internal ballistics	All	Open range	Horizontal parachute recovery available
Honeywell Minneapolis, MN	General shell/fuze studies	All	Open range	—
		155 mm	Outdoor range	Water trough stop
		40 mm grenade	Indoor range	Plastic pellet trough
Sanders Associates Nashua, NH	Contract testing	20 mm, 90 mm	Outdoor range	Air tube stop
J. P. White Bel Air, MD	HDL fuze study	20 mm	Outdoor range	Air tube stop
AVCO Wilmington, MA	Target penetration studies	155 mm, 20 mm	Outdoor range	Various earth, sand targets
Battelle Institute Columbus, OH	Penetration studies	< 5/8 in. smooth bore	Outdoor range, fires through pipe	Enclosed butt, various stopping materials
Calspan Buffalo, NY	General ordnance studies	All	Outdoor range	Fire into bay
		20, 25, 27 mm, 81 mm (low zone)	Indoor range	Four 305-m indoor ranges, sand butt stop
Southwest Research Institute San Antonio, TX	Blast studies	105 mm	Outdoor range	Silicon foam used in arena tests
Pacific Car and Foundry Renton, WA	Inactive	—	Indoor range	

* Open range — a range where shell are fired into the earth or water
 Outdoor range — a range where shell are stopped by specified means (see Remarks)
 Indoor range — self explanatory

hypervelocity ranges at NSWC (WO)) are listed when they contribute to this study. Though grossly oversimplified, table B-1 gives the main apparent use of the range, the size of the weapons used (small arms to 20.32 cm — 8 in.) and the general type of range. The *remarks* column presents general comments and information about facilities significant to this study.

B-2. GENERAL DESCRIPTION

The Proving Grounds — Aberdeen (APG), Dugway (DPG), Jefferson (JPG), and Yuma (YPG) — provide the resources for general-purpose artillery testing. These resources include open ranges and large areas of open ground, large stocks of guns and ammunition on hand, and a generally high level of competence of the range staff. Fuze testing is only part of the operations of these ranges. All ranges perform artillery tests but JPG appears to be especially prepared for ammunition production testing, YPG for aircraft testing, DPG for chemical testing, and APG for general testing of most items of ordnance issue except aircraft.

Picatinny, Rock Island, and Watervliet Arsenals have ranges geared to the performance of their missions and, in particular, to specific hardware-development projects going on at those installations. The gun at Frankford Arsenal, although it is made from a 155-mm howitzer, is an air-driven device. The complete sphere of DARCOM range operations is beyond the scope of this report.

The Internal Ballistics Laboratory (IBL) and External Ballistics Laboratory (EBL) of the Ballistics Research Laboratories, APG, maintain ranges dedicated to their specific missions. Artillery work at IBL has included studies of the effects of internal ballistics on the dispersion of projectiles and of the burning properties of various propellants. Personnel at IBL have recently initiated work on instrumentation to study shell phenomena during the internal ballistic phase of a shell's flight. On the other hand, EBL is concerned with the characteristics of shell in free flight. Terminal ballistic studies are carried out on the EBL range. The Harry Diamond Laboratories (HDL) range at Blossom Point, MD, is comparatively small (< 81-mm cannon), and is geared to fuze development projects.

The Naval Surface Weapons Center has propellant-driven guns at Dahlgren, VA, and White Oak, MD. The Dahlgren range is an artillery proving ground, White Oak's ballistic ranges being devoted to hypervelocity (of the order of 3000 m/s — 10,000 ft/s) impact and flight studies. Because of their significance for this study, the White Oak ranges are described in more detail in appendix C. The Environmental Group at NSWC (WO) has a series of air guns made from Naval weapons. The Naval Weapons Center at China Lake, CA, is geared to missile testing. It has a rocket-sled facility which has been used for fuze testing.

Various studies in connection with atomic weapons are carried out at the Lawrence Livermore Laboratories (LLL) and Sandia ranges. LLL's range is a relatively simple one, whereas extensive, highly instrumented studies of artillery projectile behavior have been carried out at Sandia.

Commercial firms operate their ranges primarily under Government contract. They have carried out field tests in connection with development projects for the military services. Honeywell has developed testing techniques and instrumentation. AVCO's range has been extensively used to study terminal ballistic phenomena. The other ranges listed have been used for various studies, usually in connection with hardware-development projects.

APPENDIX B

B-3. INDOOR RANGES

A number of ranges are indoors. Except as noted below, the weapons used in these ranges are small (< 40 mm). The projectiles involved are relatively light and small amounts of propellant are used.

As outlined in appendix C, NSWC (WO) has a number of indoor hypervelocity ranges. These ranges use relatively large caliber launchers, one of them being the breech and recoil mechanism of an 8-in. Naval rifle. Large amounts of propellant (up to 23 kg) are used. These ranges have been operated routinely for a number of years.

The External Ballistics Laboratory, BRL, APG, fires artillery weapons through a 305-m long open shed. This shed is optically instrumented to measure projectile free-flight characteristics. The shell impact a large mound of sand at the end of the shed. The Rodman Laboratories, Rock Island Arsenal, IL, proposed what appears to be a similar arrangement to study gun-firing effects and shell behavior at their range which is on an island in the Mississippi river between two cities. The weapon would be fired into a man-made tunnel.

B-4. BLAST AND NOISE CONTROL

The size and remote location of artillery test ranges has, in the past, made control of blast and noise a matter of little importance. The shrinking of the amount of available usable land and the emphasis upon environmental protection have created the need for more controls. Attempts to develop artillery silencers similar to those used on small arms have been undertaken by Watervliet and Rock Island Arsenals and by Physics International (PI). PI claims to have reduced the sound level generated by a 90-mm cannon firing 4.53 kg of propellant from a level of 145 dB to a level of 138 dB at the source using a silencer with water vapor as an energy absorber.

Rock Island Arsenal proposed to reduce the sound level on their test range by firing into a man-made tunnel. To support this effort, Salsbury¹ gathered experimental data on the blast generated by the M103 105-mm howitzer. Salsbury also presents techniques of scaling these data to weapons of other sizes and an empirical method of accounting for the blast effect of muzzle brakes. At the time of this writing, the status of Rock Island's proposed tunnel was uncertain.

The blast tanks used with hypervelocity guns (see app C) reportedly control blast and noise. Twenty-three kg of propellant fired in the NSWC (WO) 4-in. (10.16 cm) launcher, used in their 305-m range does not disturb the environs and is reported to have caused the workers in the immediate vicinity no trouble.

B-5. PROJECTILE STOPPING TECHNIQUES

Shell on ranges are usually fired into the earth or into water. Impact tests, of course, may dictate other targets but free-flying projectiles are normally fired so as to impact soil, sand, or water. The fuze or other contents are usually destroyed, either by the detonation, if the shell is loaded with explosives, or by impact forces. In those cases when the ordnance designer wishes to recover the shell,

¹M. J. Salsbury, *Blast Field Study for Proposed RIA Firing Tunnel*, Rodman Laboratories, Rock Island Arsenal, Summary Report R-TR-74-007 (1974).

special arrangements must be made with the test facility. A technique often resorted to is to fire an artillery piece at a quadrant elevation of about 89 deg. After its flight, the spin-stabilized shell hits the earth base downward. The point of impact is observed and the shell dug up with mechanical excavators. This test is often not valid because the impact force affects the shell and its contents more than the forces encountered during the actual firing. The use of snow and of lava ash as shell-stopping materials has been reported but no detailed information is available.

Various methods have been tried to recover free-flying shell without damage (listed in table B-II). Considerable effort has been expended in developing special target materials. Sawdust, Celotex, and cotton waste have been used with varying results, damage to the shell and fires in the material having been reported. Light projectiles moving at relatively slow velocities (less than 100 m/s) have reportedly been caught successfully in targets made from foam normally generated to fight fire, in troughs filled with styrofoam-like plastic pellets, and in nylon blankets spread between poles. The length of foam or pellets needed to stop large-caliber, high-velocity projectiles is not known.

Fuzes can sometimes be recovered if they are ejected from the shell with an attached parachute. The ejection forces are generally soft to moderate and the impact forces are small. Shell modified to carry parachutes are expensive and it is often difficult to track the descending parachutes. Rocket sleds whose motion is synchronized with gun firings have been used to catch entire projectiles. The sled is decelerated and the rounds are recovered. This system has been used successfully but is quite expensive.

Aluminum honeycomb is successfully used with the HDL air and vacuum guns to stop flat-nosed projectiles moving at velocities up to 425 m/s. A great deal is known about this technique. Preliminary experiments indicate, however, that pointed projectiles cause the honeycomb to fail in a different manner from the way flat-nosed projectiles do. More work needs to be done to gather data on this technique.

In addition to the work done to capture free-flying projectiles, soft-catch methods have been developed that depend upon guiding the projectile from the weapon to the catcher. Honeywell, Picatinny Arsenal, Martin Marietta Corporation, and IBL are using or are planning to use a water trough in which the shell, after being fired from the gun, is guided by rails into a trough of water. The shell is modified so as to have a cupped nose (which slows its motion through the water) and to contain the fuze internally.

TABLE B-II. FREE-FLIGHT SHELL-RECOVERY TECHNIQUES

Target impacts		Mechanical means
Standard	Special	
Earth Water	Sawdust, Celotex, cotton waste Fire-fighting foam Plastic pellets Aerated water Aluminum honeycomb Plywood	Parachute Rocket sled Nylon net

APPENDIX B

A second guided technique depends upon the compression of air in front of a shell travelling into a closed-end tube. The gun and compression tube are coupled by a slotted tube, the slots permitting the driving gas to escape. A close fit between the shell and the walls of the compression tube traps and compresses air in the tube. The technique is in use with air-driven guns at Frankford Arsenal and NSWC (WO) and with propellant-driven guns at NSWC (Dahlgren), H.P. White, and Sanders Associates.

Considerable effort has been expended in developing techniques to catch small-arms projectiles for criminal ballistics studies. The FBI and the police departments of Montgomery County, MD, and the District of Columbia were consulted on the techniques they use to retrieve bullets during ballistic tests. Their main interest is in preserving the land and groove pattern engraved on the surface of the bullet, deformation of the nose being of secondary importance. Because of this, they fire into cotton waste or, to facilitate the testing process, water.

B-6. RANGE INSTRUMENTATION

Parameters measured during a field test depend upon the technical requirements and funding limitations of the project involved. Visual and photographic techniques are widely used to determine fuze functioning. Telemetry measurements of the radiation from an electronic fuze are often called for. Muzzle velocities are usually measured, whereas chamber pressures may be measured if required. There has been a low-level but steady effort to improve data-transmission techniques suitable for use in artillery shell. The results have been acceptable but more work is needed to make accurate and reliable measurements. Further information on ballistic instrumentation, particularly that used to make in-bore measurements, is given in appendix D.

APPENDIX C. — NAVAL SURFACE WEAPONS CENTER (WHITE OAK) HYPERVELOCITY FACILITIES

The Naval Surface Weapons Center at White Oak — NSWC (WO) — has five ranges in various stages of operation that are used to study the aerodynamics and impact characteristics of projectiles flying at hypervelocities. Projectiles weighing 1.8 kg have been fired at 3048 m/s in these ranges.

Two of the ranges at NSWC (WO) are shown in figures C-1 and C-2. Figure C-1 is a schematic drawing and photograph of Impact Range Number 2. Up to 13.59 kg of solid propellant are used with the recoil mechanism, breech, and a portion of the compression chamber of a Naval 8-in. rifle to

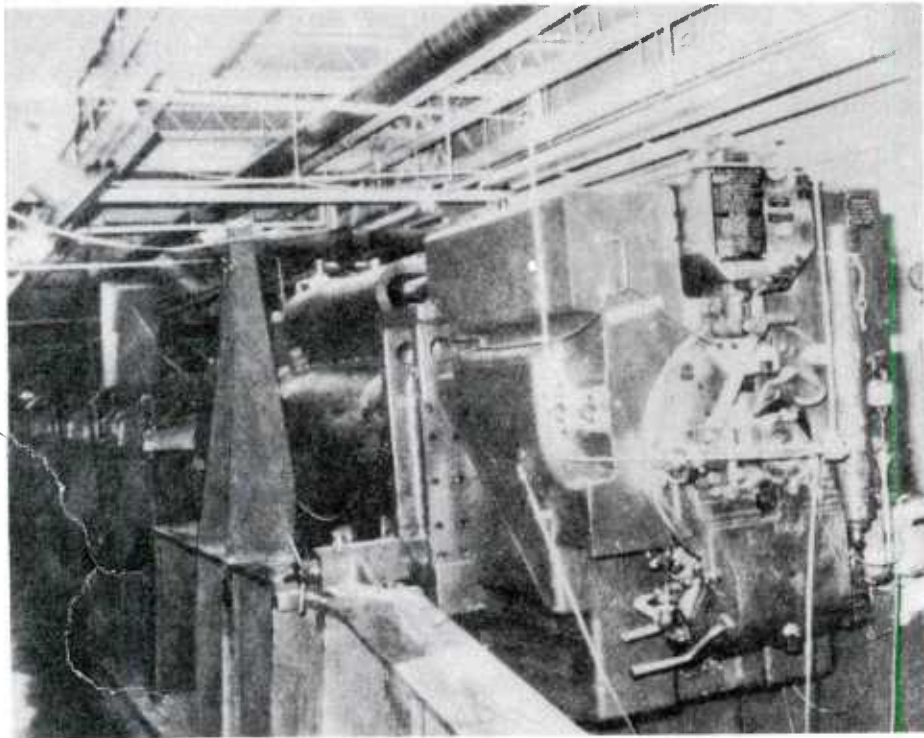
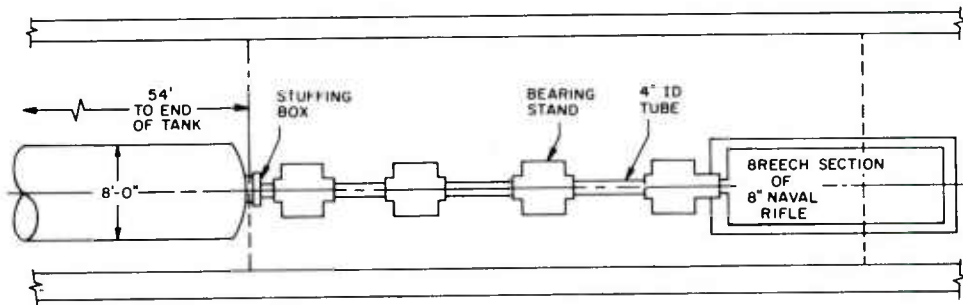


Figure C-1. Naval Surface Weapons Center at White Oak — hypervelocity impact range using 8-in. Naval rifle.

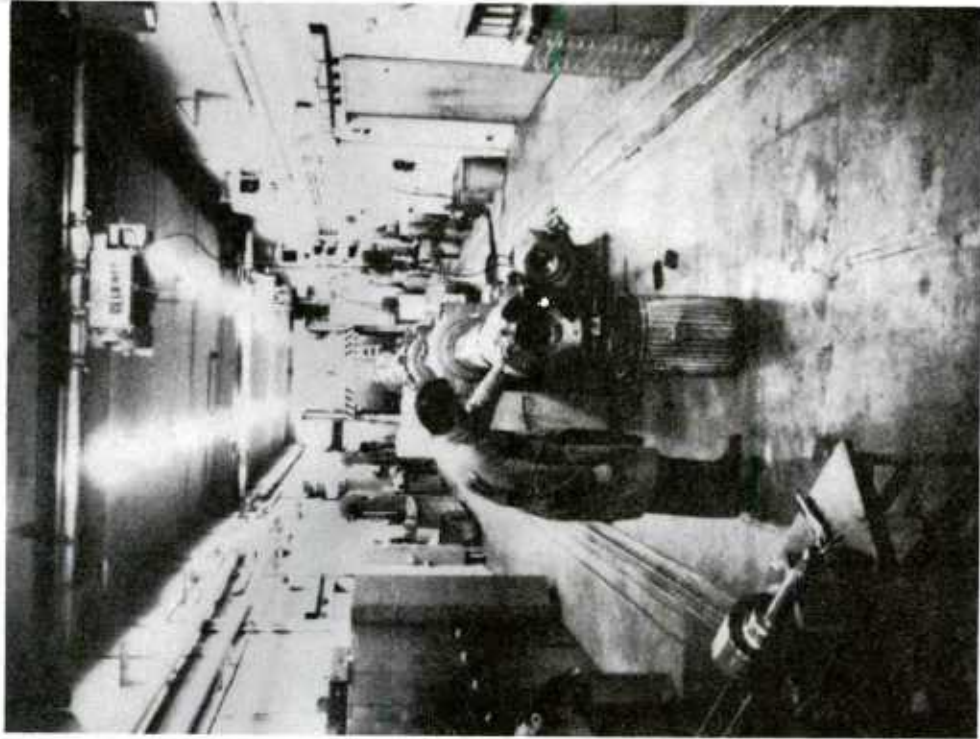
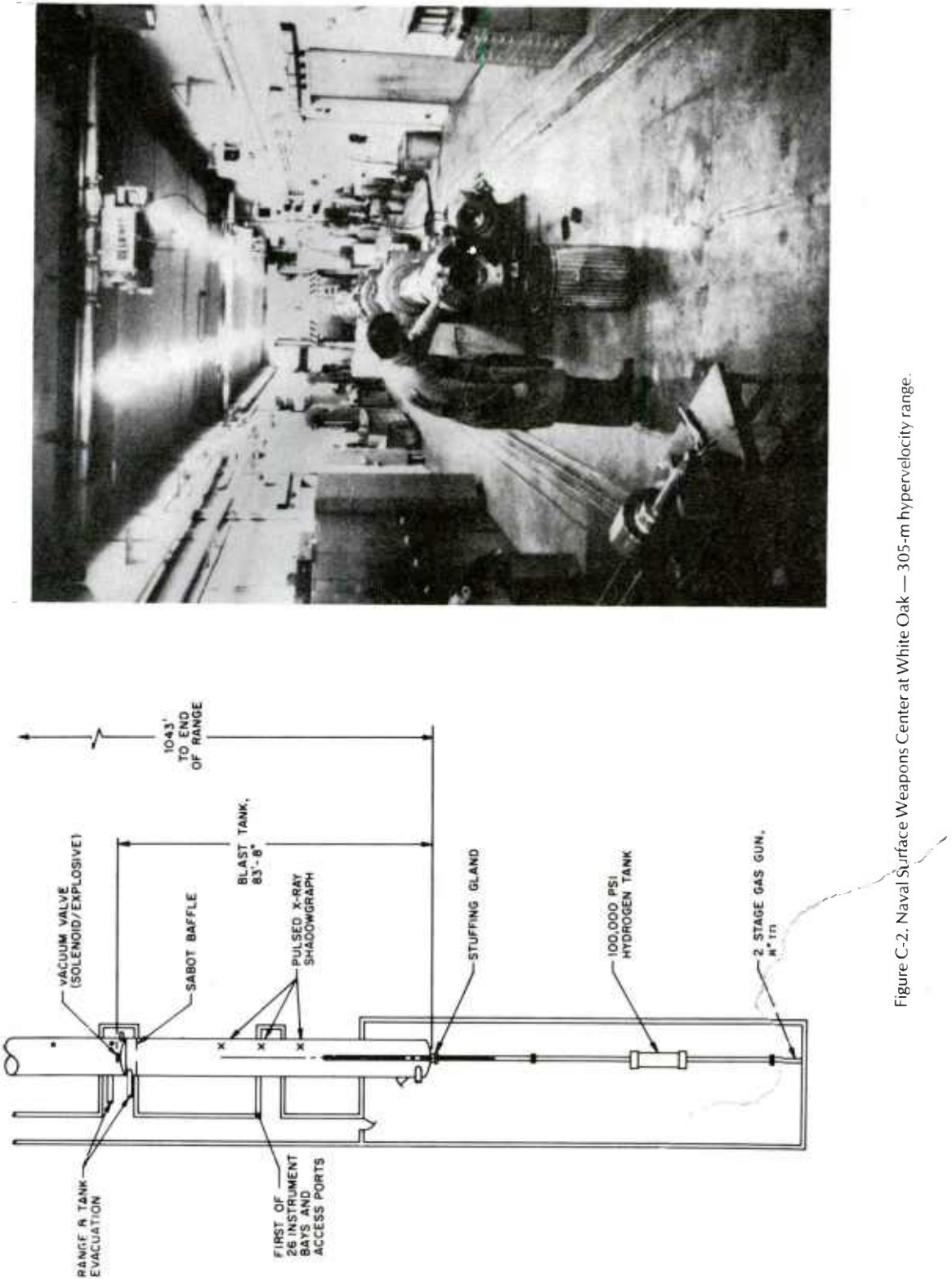


Figure C-2. Naval Surface Weapons Center at White Oak — 305-m hypervelocity range.

compress hydrogen gas. This gas, in turn, is used to shoot a projectile through the range. The rifle and the 10.16-cm barrel attached to it are free to translate under recoil forces; a 5.08-cm layer of cork under the entire system is used to damp out vibration. A 2.44-m o.d. by 16.46-m long steel tank is used to retain the blast, noise, and gas. The tank is evacuated before firing (to about 10-mm Hg). Projectiles are stopped by a massive steel plate at the end of the tank. There are numerous doors, windows, and instrument-access ports in the tank. One of these is a rectangular entry way (approximately 1.83 by 2.13 m) to the tank at its target end.

A schematic drawing and photograph of the breech end of the NSWC (WO) 305-m long hypervelocity range is shown in figure C-2. Up to 23 kg of solid propellant have been used to compress hydrogen gas which serves as a driver for the test projectile which may be equipped with a sabot. Because the gun is not fixed to the floor, recoil causes it to move on tracks, the muzzle sliding through a stuffing gland. A solenoid valve at the end of the 3.05 m o.d. by 2550 m long blast tank is opened immediately before the shot, and the gun fires when the valve is fully opened. A manually operated explosive driver is used to close the valve after the gun is fired. The walls of the 305-m tunnel are 2.54-cm thick steel and are 1.52 to 3.05 m underground. No complaints about blast, noise, or the propellant gas were reported by NSWC (WO) personnel.

The range, including the blast tank, is 317.9 m long by 3.05 m o.d. It can be evacuated to pressures below atmospheric. It has been instrumented with optical shadowgraphs and Schlieren systems, luminosity monitors, radars, microwave interferometers, and pulsed x-ray shadowgraphs.

APPENDIX D. — BIBLIOGRAPHY OF MEASUREMENT INSTRUMENTS AND TECHNIQUES USED IN INTERIOR BALLISTICS

A survey was made of the literature describing measurement instruments and techniques used in the course of interior ballistics studies. The references uncovered are presented in this appendix. The bibliography is not complete, particularly in certain aspects, nor are the references given devoted exclusively to interior ballistics, since references to closely related topics are included.

An outline of the topics treated in the references is presented below. Some conclusions on the state of the art of these measurements can be drawn on the basis of this table and from a reading of the references. Thus, considerable effort has been expended on muzzle velocity, propellant gas pressure, and projectile in-bore displacement and velocity measurements. Less effort has been expended on measuring other quantities.

Strain gages, whether placed on the gun tube, in pressure and acceleration transducers, or on the projectile itself, have yielded the largest quantity of usable, reported data. Mechanical crusher gages have been widely studied and used but few quantified data have been reported. In the same fashion, data obtained from acceleration transducers (primarily piezoelectric) appear to be widely used as guides in forming engineering judgements.

Cables and wires connected directly to an instrument in the moving projectile (*hardwire*) have yielded the largest quantity of usable data taken in the internal ballistic regime. A large effort, of recent origin, has been made to develop suitable in-bore microwave telemetry systems. An on-board recoverable recorder that works in the moving projectile has been developed and various attempts have been made to develop optical telemetry systems.

Data on the behavior of the projectile's structure and its explosive load have been obtained. Few data have been published on fuze behavior. Some numerical techniques have been applied to the processing of the data but the main effort is still analog. Military sources have worked extensively on the calibration of copper crusher gages, industrial and nonmilitary governmental researchers having done extensive work on the calibration of other forms of accelerometer and pressure transducers.

Outline of Topics Covered in Bibliography (Numbers refer to references in bibliography)

I. Interior ballistic quantities measured

A. Propellant gas pressure	3, 20, 21, 27, 38, 50
B. Barrel temperature	40
C. Projectile displacement, velocity	28, 35, 47, 48, 51, 60, 80, 82, 83, 85
D. Muzzle velocity	6, 16, 28, 34, 36, 76, 84, 88
E. Projectile acceleration	19, 22, 54, 82
F. Projectile strains	39, 72
G. Projectile rotation	60

APPENDIX D

Outline (Cont'd)

II. Instruments and techniques

A. Transducers and sensors

- | | | |
|------------------------|------------|--|
| 1. Strain gages | | 4, 10, 20, 21, 27, 32, 33, 34,
39, 44, 51, 52, 53, 58, 69, 72, 76 |
| 2. Accelerometers: | Electrical | 1, 12, 19, 22, 24, 26, 30, 31,
41, 42, 54, 77, 79, 82, 90 |
| | Mechanical | 13, 19, 23, 25, 58, 63, 71, 87 |
| 3. Pressure gages | | 3, 9, 20, 21, 27, 30, 38,
59, 69, 83, 91 |
| 4. Electrical contacts | | 68, 80, 88 |
| 5. Flash x rays | | 36 |

B. Information transmission

- | | | |
|-------------------------|----------|---|
| 1. Hardwire | | 10, 15, 22, 26, 31, 39, 41
42, 54, 65, 73, 75, 79, 82 |
| 2. Microwave telemetry: | On-board | 5, 14, 17, 18, 28, 30, 35, 43, 48, 49
54, 56, 57, 64, 74, 80, 81, 82, 86 |
| | Exterior | 6, 7, 47, 48, 55, 80, 85 |
| 3. Optical telemetry | | 46, 67 |
| 4. On-board recorders | | 8 |

C. Miscellaneous

- | | | |
|----------------------|--|--|
| 1. Component studies | | 11, 22, 24, 26, 29, 45
57, 58, 61, 68, 70, 72 |
| 2. Signal processing | | 2, 12, 24, 59 |
| 3. Calibration | | 13, 62, 63, 71, 78, 87 |

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APPENDIX E. — U.S. ARMY ARTILLERY WEAPON, PROJECTILE, AND CHARGE CHARACTERISTICS

E-1. INTRODUCTION

The evolutionary development of U.S. ordnance has led to the existence of many different sizes and models of artillery weapons. The difficulty of deciding which of these weapons should be selected for use in a fuze test range is compounded by the many different projectiles fired from these weapons and by the many different conditions under which firings are made.

E-2. U.S. ARMY ARTILLERY WEAPONS

Table E-1 presents a list of artillery weapons developed by the U.S. Army. Cannon (gun tube plus breech) and weapon system are given in the table. Obsolete, contingency, and limited procurement weapons are listed in the table since they may appear in special tests or applications, or can be used by an ally of the U.S. It can be seen that there are a large number of models of 105- and 155-mm howitzers and that 105- and 155-mm and 8-in. howitzers are scheduled to be the standard howitzers of the future.

TABLE E-1. U.S. ARMY CANNON AND THEIR USES

Note: Cannon grouped as in source 2 (see end of table). For abbreviations, also see end of table.

Cannon Nomenclature	Use
40-mm Gun, M1	M1/A1 T AA Gun Mount
40-mm Gun, M2A1*	M42, A1, M19A1 SP AA Twin Gun
57-mm RR, M18/A1	M18/A1 RR
60-mm MTR, T18E6	INF MTR
60-mm MTR, M2	INF MTR
60-mm MTR, M19	INF MTR
60-mm MTR, XM224*	INF MTR
75-mm HOW, M1A1	M116 Pack HOW
75-mm HOW, M1A1C	M120 Saluting HOW
75-mm Gun, M6	M24 Tank
75-mm RR, M20	M20 RR
75-mm AA, M35	M51 Weapons system
76-mm Gun, M1	M483 Tank
76-mm Gun, M1A1	—
76-mm Gun, M32	M41 Series Tanks
81-mm MTR, M1	INF MTR
81-mm MTR, M29*/E1	INF MTR
	M125 SP FT MTR

**Cannon drawings available from Harry Diamond Laboratories. All drawings available from Watervliet Arsenal.*

APPENDIX E

TABLE E-1. U.S. ARMY CANNON AND THEIR USES (Cont'd)

Note: Cannon grouped as in source 2 (see end of table). For abbreviations, also see end of table.

Cannon Nomenclature	Use
90-mm AA, M1/A2 or A3	M117 T AA Gun
90-mm AA, M2/A1 or A2	M118 T AA Gun
90-mm Gun, M1, M1A1, M2, M3	M3A2=M46A1 Tank
90-mm Gun, M36	M47 Tank
90-mm Gun, M41	M48 A1, A2, or C Tank
90-mm Gun, M54	M56 AT SP Gun
90-mm RR, M67	M67 RR
105-mm HOW, M2A1, M4	M2A1=M101 L T HOW M4=M52/A1 L SP HOW
105-mm HOW, M2A2, M4A1, M49	M2A2=M101A1 L T HOW M4A1=M37 L T SP FT HOW M49=M52/A1 L SP FT HOW
105-mm HOW, M3*	—
105-mm HOW, M103, M137, M165	M103=M108 L SP FT HOW M137=M102 L T HOW
105-mm HOW, M165E1	M164 L T HOW
105-mm HOW, XM205*	XM204 L T HOW†
105-mm Gun, M68*	M60A, M60A1 Tank
105-mm RR, M27	—
106-mm RR, M40/A1 or A3	M40A1C=M50 SP FT RR
106-mm RR, M206*/A1	M40A2/A4 RR, M40A3/A5 RR
4.2-in. MTR, M30*	—
120-mm Gun, M58	M102, M103A1 Tank
120-mm AA, M1	—
120-mm RR, M63	M28 Battle Group Atomic Weapon
152-mm Gun/Launcher, M81 E1*	M551 ARAAV FT Tank
152-mm Gun/Launcher, XM150ES	—
152-mm Gun/Launcher, XM150	MBT-70/XM803 FT Tank
152-mm Gun/Launcher, XM162E1	M60A1/E2 FT Tank
155-mm HOW, M1*/A1, M45	M1/A1=M114/A1 M T HOW M1/A1=M123 A1 Auxil. Propel. M T HOW M45=M44A1 M SP FT HOW
155-mm HOW, M126*/E1	M109 M SP HOW

*Cannon drawings available from Harry Diamond Laboratories. All drawings available from Watervliet Arsenal.

† Active artillery cannon of the near future.

TABLE E-I. U.S. ARMY CANNON AND THEIR USES (Cont'd)

Note: Cannon grouped as in source 2 (see end of table). For abbreviations, also see end of table.

Cannon Nomenclature	Use
155-mm HOW, M185*, XM181, XM199*	M185=M109A1 M SP HOW† XM199=XM198 M T HOW†
155-mm HOW, EXP. XM	XM M SP HOW
155-mm Gun, M2*/A1	M59 T Gun
155-mm Gun, M46	M53 FA SP Gun
155-mm RR, M64	M29 Battle Group Atomic Weapon
165-mm Gun, M135	M728 Combat Engr. Vehicle
175-mm Gun, M113A1	M107 FA SP Gun
8-in. Gun, M1	M1/T2 Gun
8-in. HOW, M2/A1, A2, M47	M2A1=M115 H T HOW M2A2=M110 H SP HOW M47=M55 H SP HOW
8-in. HOW, XM201	M110E2 H SP HOW†
240-mm HOW, M1	—
280-mm Gun, M66	M65 H Motorized Gun

* Cannon drawings available from Harry Diamond Laboratories. All drawings available from Watervliet Arsenal.

† Active artillery cannon of the near future.

Abbreviations

AA	anti-aircraft	INF	infantry
ARAAV	Armored Reconnaissance Airborne Assault Vehicle	L	light
AT	antitank	M	medium
FA	field artillery	MTR	mortar
FT	full track	SP	self propelled
H	heavy	RR	recoilless rifle
HOW	howitzer	T	towed

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APPENDIX E

E-3. U.S. ARMY ARTILLERY PROJECTILES AND CHARGES

Table E-II presents a compilation of the data given by Heppner.¹ The weight, range of muzzle velocities, and maximum kinetic energy of U.S. Army projectiles are given, as well as the range of propellant weights and chamber pressures resulting from the use of these propellant charges. It can be seen that the highest zones of firing of many of the weapons entail disproportionately large quantities of propellant. These zones are listed separately. For completeness, data are included on the Navy's 5-in. gun and the Improved Light Assault Weapon antitank rocket.

TABLE E-II. SUMMARY OF U.S. ARMY PROJECTILE AND CHARGE CHARACTERISTICS

Weapon*		Charge		Projectile				
Size (mm)	Type	Cannon nomenclature	Zones	Weight (lb)†	Chamber pressure (lb/in. ² × 10 ³)	Weight (lb)	Muzzle velocity (ft/s)	Maximum energy (ft-lb)
40	Gun	M1	—	0.65,0.71	40.5,45.2	1.96	2870	2.51 × 10 ⁵
57	RR	M18	—	0.88	6.2	2.75	1200	6.15 × 10 ⁴
60	MTR	M2	0-4	0.006-0.03	0.5-4.5	2.9-4.8	138-518	2.0 × 10 ⁴
		XM224	0-4	0.007-0.08	0.8-6.6	3.9	210-778	3.67 × 10 ⁴
75	HOW	M1A1	1-4	0.4-0.9	9.2-34.7	14.7	700-1250	3.57 × 10 ⁵
	Gun	M6	—	2.4	2.0	13.16	2340	1.12 × 10 ⁶
	RR	M20	—	3.2-3.4	7.6-9.8	8.6-14.4	990-1400	4.38 × 10 ⁵
	AA	M35	—	3.4	44.3	12.2	2800	1.48 × 10 ⁶
76	Gun	M32	—	3.5-5.7	33.4-53.1	8.2-15.7	2400-4125	4.14 × 10 ⁶
	Gun	M1, M1A2	—	1.1-3.8	22.3-50.0	9.3-15.4	1550-3400	2.76 × 10 ⁶
81	MTR	M1, M29	0-8	0.02,0.23	0.8-8.5	7.0-11.4	165-821	1.19 × 10 ⁵
	MTR	M29	9	0.23,0.26	8.4,9.0	9.1,10.2	819,877	1.22 × 10 ⁵
90	Gun	M1	—	5-8.3	27.4-43.6	12.4-24.1	2700-3825	5.47 × 10 ⁶
	Gun	M41	—	4.5-9.4	28.5-56.3	12.6-24.1	2400-3950	5.83 × 10 ⁶
	RR	M67	—	1.2-1.5	6.3-7.3	4.4-11.0	470-1100	2.07 × 10 ⁵
	AA	M1	—	7.2	42.5	23.4	2700	2.65 × 10 ⁶
105	HOW	M103	1-7	0.2-3.2	5.3-36.5	28.5-33.0	420-1800	1.66 × 10 ⁶
		M103	8	4.4,3.6	42.6,40.5	28.5	2200,2330	2.40 × 10 ⁶
	HOW	M2A1, M2A2	1-7	0.5-3.6	8.0-37.8	23.5,33.0	394-1880	1.81 × 10 ⁶
		M2A2	8	4.1	35.6	23.5	2060	1.55 × 10 ⁶
	HOW	M3	1-5	0.6-1.2	9.5-19.9	28.8,33.0	650-1020	5.33 × 10 ⁵
	HOW	XM204	1-7	0.5-2.8	6.48-37.8	33.0	648-1661	1.41 × 10 ⁶
		XM204	8	4.4	44.7	33.0	2170	2.41 × 10 ⁶
	Gun	M68	—	6.0-12.2	24.-59.3	13.0-30.8	2400-4850	1.12 × 10 ⁷
106	RR	M40	—	7.6-8.0	10.2-11.8	17.5	1635,1650	7.4 × 10 ⁵
	RR	M206	—	7.7-9.1	9.3-9.9	17.5,21.8	1440-1650	9.2 × 10 ⁵
107	MTR	M30	5-34	0.08-0.57	3.9-15.0	22.5-26.2	315-1035	4.35 × 10 ⁵
120	Gun	M58	—	12.4-29.4	41.4-54.0	31.1-50.8	2500-3750	1.11 × 10 ⁷
	AA	M1	—	23.4	43.5	50.0	3100	7.46 × 10 ⁶
152	Gun	M81	—	5.7-6.1	32.6-37.3	41.8-42.2	2240	3.26 × 10 ⁶
	Gun	XM150	—	5.8;18.1	37.3,59.0	19.7,42.8	2440,4950	1.62 × 10 ⁷
	Gun	XM162	—	5.8	37.3	42.85	2260	3.4 × 10 ⁶

*†See notes at end of table.

¹L. Heppner, *Setback and Spin for Artillery, Mortar, Recoilless Rifle and Tank Ammunition*, Materiel Testing Directorate, Aberdeen Proving Ground, MD, Final Report APG-MY-4503 (1974).

TABLE E-II. SUMMARY OF U.S. ARMY PROJECTILE AND CHARGE CHARACTERISTICS (Cont'd)

Weapon*				Charge		Projectile		
Size (mm)	Type	Cannon nomenclature	Zones	Weight (lb)†	Chamber pressure (lb/in. ² × 10 ³)	Weight (lb)	Muzzle velocity (ft/s)	Maximum energy (ft-lb)
155	HOW	M1	1-6	1.8-9.7	5.4-21.7	95.0	680-1520	3.41 × 10 ⁶
	HOW	M1	7	13.1	34.7-38.4	95.0	1850	5.05 × 10 ⁶
	HOW	M1	1-3	5.1-17.3	17.0-32.7	120.	1020-1820	6.17 × 10 ⁶
	HOW	M126	1-6	1.8-9.7	6.4-22.4	95.,96.	680-1510	3.36 × 10 ⁶
	HOW	M126	7	13.2	36.2-39.0	96.0	1840-1849	5.1 × 10 ⁶
	HOW	M185	1-6	1.9-9.8	4.9-15.5	95.0	700-1980	5.78 × 10 ⁶
	HOW	M185	7,8	13.1-20.3	25.1-29.9	95.,96.	1852-2710	1.08 × 10 ⁷
	Gun	M2	—	20.6,30.9	2100,2800	95.0	2100,2800	1.16 × 10 ⁷
70	AT rocket	ILAW	—			~ 2.5	~ 900.	3.1 × 10 ⁶
127	Gun	Navy -38	—	~ 17.	18.	55.18 ± 2	2600	6.00 × 10 ⁶
	Gun	Navy -54	—	~ 20.5	20.5	70 ± 2.	2650	7.85 × 10 ⁶

* Abbreviations

AA	anti-aircraft
AT	antitank
HOW	howitzer
ILAW	Improved Light Assault Weapon
MTR	mortar
RR	recoilless rifle

† Metric Conversion Factors

(lb) × 0.453 = (kg)
(lb/in. ² × 10 ³) (6.895 × 10 ⁶) = (kPa)
(ft/s) × 0.305 = (m/s)
(ft-lb) × 1.35 = (J)

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