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14. ABSTRACT
This TOP defines procedures for blast overpressure tests that must simultaneously address both the auditory and non-auditory hazards of a weapon or explosive during a single measurement opportunity.

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Blast Test Device (BTD) Blast Overpressure Transducer

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure 4-2-831 12 August 2008
DTIC AD No.

USE OF BLAST TEST DEVICE (BTD) DURING AUDITORY BLAST OVERPRESSURE MEASUREMENT

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1. SCOPE.

The objective of this Test Operations Procedure (TOP) is to define procedures for blast overpressure tests that must simultaneously address the auditory and non-auditory hazards of a weapon or explosive during a single measurement opportunity. Such testing requires pressure transducers to be positioned at the ear location for auditory evaluation and the chest position to evaluate non-auditory hazards to air filled organs. The Blast Test Device (BTD) is used to evaluate non-auditory hazards. Auditory measurements must conform to MIL-STD 1474D[1*]. Past experience has shown there is interference between the auditory and non-auditory signal transducers (see Figure 1).

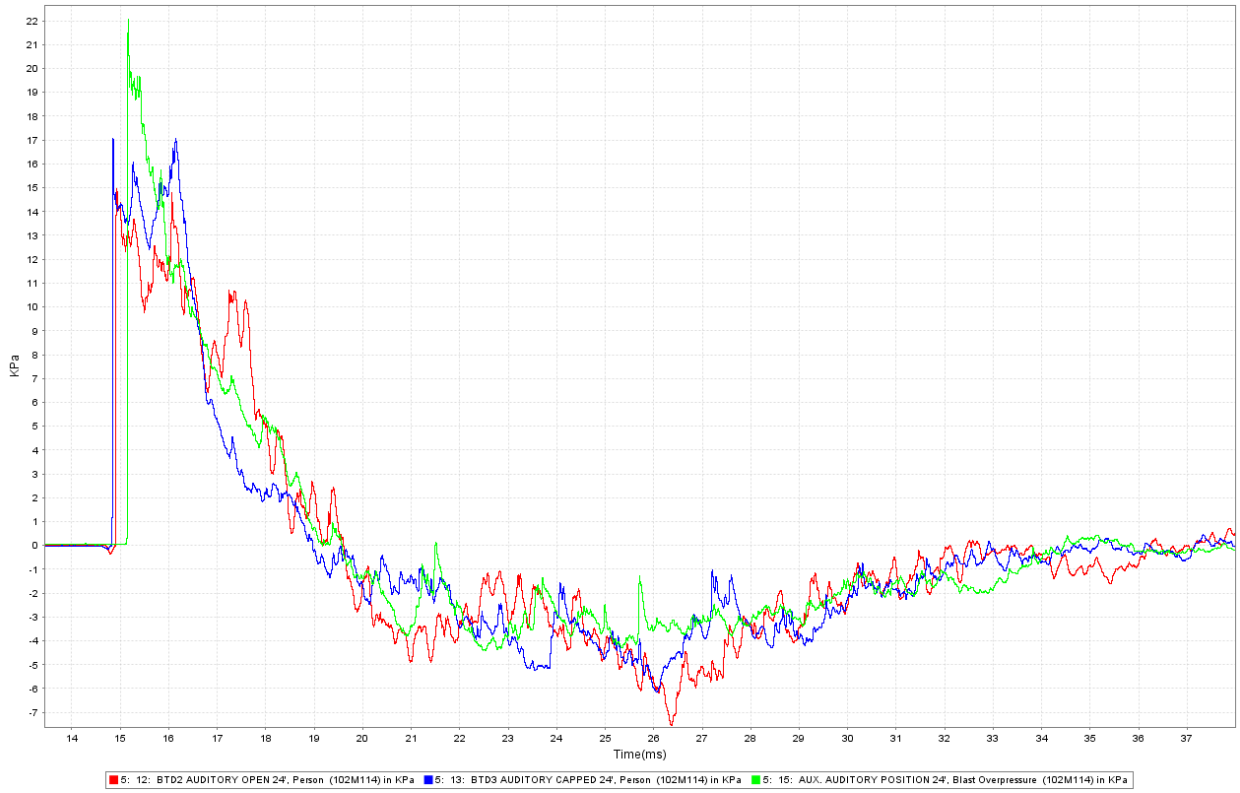


Figure 1. Auditory and Non-Auditory Signal Interference.

This measurement is from a 0.57 kilogram (kg) (1.25 pound (lb)) charge, with the BTD's located 7.3 meters (m) (24 feet (ft)) away. The theoretical value for a perfectly reflected surface burst is 19.8 kilopascal (kPa) at this 7.3 m (24 ft) location. The signal from bare auditory gage (shown in green) is slightly above this value. The signals from the two auditory gages located over the BTD's (shown in red and blue) are both below this value. Reflections from the BTD are present on those two signals (red & blue) at 0.6 milliseconds (ms) and 1.2 ms reflections. The highest reflection is equal to the initial peak value. The red curve (open BTD) shows continued oscillation. The green curve (bare auditory gage) has the most realistic shape.

* Superscript numbers correspond to those in Appendix B, References

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Firing Range	Selected to suit test requirements and to provide adequate protection for personnel and equipment; firing points must be sufficiently protected and remotely located to safely contain a premature ammunition detonation, ricochet, or a catastrophic weapon failure as well as contain discarding parts from projectiles.
Test Facility	Uniform grade free of all sound reflecting surfaces within 30 m (98 ft) of the test item and measuring equipment, if practical.

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty
Blast gauge	
Uncertainty	As required
Resonance frequency	Minimum 80 kHz, 100 kHz or larger desirable
Linearity	< 3% Full scale output (FSO)
Acceleration Sensitivity (axial)	Less than 1.5 $Pa/m/s^2$
Acceleration Sensitivity (transverse)	Less than 7 $Pa/m/s^2$
Overall System Linearity	≤ 3%
Electronic recording system	± 1%
Low Pass Filtering	
Auditory Transducers	40 kHz, 6-pole, Bessel
Non-Auditory Transducers	10 kHz, 6-pole, Bessel
Air pressure	±0.3%
Temperature	±0.7%
Wind speed and direction	± 0.3 m/s (± 0.1 ft/s) ± 1.6 °

The auditory and BTD pressure transducers can be either piezo-resistive or piezo-electric. The auditory sensors must have a 40 kilohertz (kHz) response (after filtering). The BTD pressure sensors must have a 10 kHz response after filtering. Rise times of 9μs and 35μs respectively are required.

3. REQUIRED TEST CONDITIONS.

3.1 Test Conditions.

Wind speeds shall not exceed 5 m/s (16.4 ft/s). Conditions may allow for higher wind speeds, provided that the steady state noise induced by the wind is 40 decibels (dB) below the maximum overpressure expected, and the increase in overpressure on the down wind side, caused by apparent shortening of the path length between the source and the sensor, is less than 2 dB.

The firing range selected should suit requirements to provide adequate protection for personnel and equipment; firing points must be sufficiently protected and remotely located to safely contain a premature ammunition detonation, a ricochet, or a catastrophic weapon failure as well as contain discarding parts from projectiles.

For free field testing, the test facility will be uniform grade free of all sound reflecting surfaces within 30m (100 ft) of the test item and measuring equipment, if practical.

Calibrate each gauge according to National Standards. Use of one of the verified laboratory calibration methods is required. Field testing of the entire acquisition system in front of a dynamic pressure by means of explosions (or equivalent) is desired.

Make sure transducers are isolated from ground, shock-mounted, flash/thermally protected, and operated within the specified temperature and pressure ranges. Place recording instrumentation far enough away from the detonation so as to be minimally affected by the blast. However make sure maximum cable length from the instrumentation point to most remote gauge does not exceed 150 m (500 ft). When long lines are required, line drivers are needed to reduce outside inference, to maintain required frequency response.

When taking measurements to compare data with national standards for human tolerance to muzzle blasts, other test requirements should not jeopardize these test results.

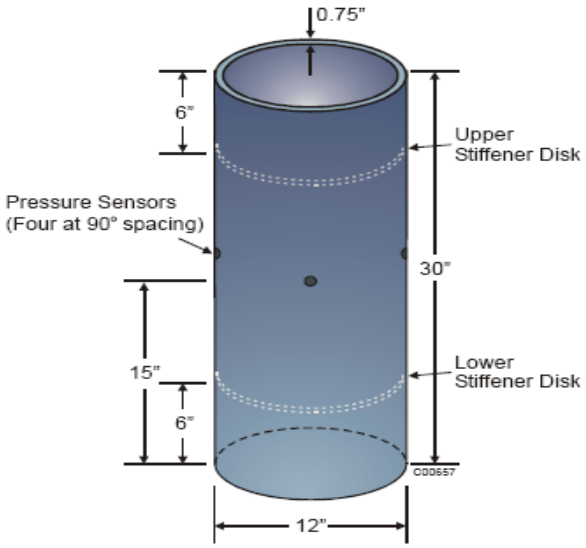
NOTE: Give careful attention to test setup and data analysis to ensure that results are representative of the blast wave, rather than displaying anomalies due to extraneous effects. The measurement situation will determine the type of transducer and mounting arrangement.

3.2 Blast Test Device.

The Blast Test Device (BTD) measures the external pressure loading on a human thorax due to blast overpressure. The BTD, shown in Figures 2 and 3, is an aluminum tube, with a 30.5 centimeter (cm) (12 inches (in)) outside diameter, a 6.4 to 19 millimeter (mm) (0.25 to 0.75 in) wall thickness, and are typically 61 to 76.2 cm (24 to 30 in) long. Two 6.5 to 19 cm (0.25 to 0.75 in) thick internal stiffener disks are fastened to the interior of the cylinder, one 15.2 cm (6 in) from the bottom and one 15.2 cm (6 in) from the top. Four piezo-electric or piezo-resistive transducers are mounted into the cylinder. Transducer mounts are designed to protect the transducers from mechanical shock and acceleration. The transducer faces should be flush with the surface. The pressure sensors are evenly spaced along the circumference at mid-height (38

cm (15 in) from the base) of the cylinder. To insulate the pressure sensor from flash temperatures of the blast, thermal protection is used. A 1 mm (0.04 in) thick layer of General Electric RTV type 106 silicone rubber coating on the diaphragm is an example of thermal protection for piezo-electric transducers.





Figures 2 and 3. Instrumented BTD.

The Blast Test Devices of various heights (15.2, 30.5, 61, 76.2 cm (6, 12, 24, and 30 in)) have been used in the past. Heights of 61 and 76.2 cm (24 and 30 in) are preferred. Some BTDs must be cut to accommodate certain weapon configurations. (See Figure 4)

The 76.2 cm (30 in) BTD is the original design and has been used successfully for research purposes. However the 76.2 cm (30in) BTD is not consistent with the torso of the 50th percentile male torso. The 61 cm (24 in) BTD is a more reasonable approximation of the crotch to shoulder dimensions of a 50th percentile male.

The 61 cm (24 in) BTD is approved for open air tests, but has not yet been evaluated for enclosed compartment, complex wave environments.

The 30.5 and 15.2 cm (12 and 6 in) BTDs are occasionally required for crouching, sitting, kneeling positions when using shoulder fired Anti-Tank Weapons or placement in certain combat vehicle seats.



Figure 4. Example of Blast Test Device Cut Down in Height to Accommodate a Specific Weapon Firing Configuration.

Typical Blast Over Pressure (BOP) testing is planned to model a 50th percentile male. The anatomical dimensions for a 50th percentile male, from DOD-HDCK-743A[2] are as follows:

Dimension	**Cm**	**Inches**
Height	175	69
Ear/Eye	163	64
Shoulder (Top of Torso)	144	57
Waist (Middle of Torso)	113	44.5
Crotch (Bottom of Torso)	84	33

Note that the distance from ear to shoulder is 19 cm (7.5 in). This spacing should be strived for between the auditory sensor and the top of the BTD. More importantly, note that the distance from shoulder to crotch (i.e. the torso height) is 61 cm (24 in). This fact explains why there are difficulties in fitting a 76.2 cm (30 in) BTD into a 61 cm (24 in) space.

Typical auditory and non-auditory (BTD) transducer locations are shown below.

61 cm (24 in) BTD, transducers centered at 30.5 cm (12 in), Lowered Slightly, and right hand edge trimmed to accommodate ± 20 deg. firing angle (in this case the BTD had to be cut to fit the weapon configuration)
Auditory PCB @ 160 cm (63 in)
Gun Tube centerline at 150 cm (59 in)
BTD Top @ 140 cm (55 in)
BTD Transducers @ 109 cm (43 in)
Bottom of BTD @ 79 cm (31 in)

3.3 Weapons and Threat Munitions.

The tests are to be conducted on an appropriate firing range. Unless otherwise stipulated, all weapons are positioned under realistic conditions comparable to those employed in combat or training missions. For weapons with various charges (e.g., separately loaded artillery ammunition), the charge that produces the highest peak pressure level will be measured in addition to those charges producing lower levels.

Support projectiles and warheads vertically, with the nose down and no less than 60 cm (24 in) from the ground, subject to test requirements. Support bare charges or mines at no less than 1.2 m (4 ft) above the ground on a suitable support.

Explosive charges are to be positioned at a height from the ground typical for their use. The method of support is to present a minimum of unwanted reflecting surfaces and to generate a minimum of fragments when the explosion occurs. For fragmentation munitions (for example, grenades) static measurement tests are recommended. Location of the explosive and mounting used must be specified. Avoid reflecting surfaces and structures (including personnel).

3.4 Transducer Locations.

When the location of the crew is known and stationary, auditory measurements are to be collected at the center location of the crew member's head, unless otherwise specified. The height of the auditory measurement points is to be set at 1.6 m (5.2 ft) above the ground for personnel in a standing position and 0.8 m (2.6 ft) above the seat for personnel in the seating position. When measurements are taken of personnel in a kneeling or prone position, the auditory measurements are to be taken at the normal position at the center location of the crew member's head.

4. TEST PROCEDURES.

General measurements are taken around the weapon in the firing position. The firing position shall be free of any extraneous structures. Impulse noise measurements for all weapons are to be recorded at the normal firing elevation. Handguns/shoulder weapons are preferably mounted to minimize reflecting surfaces, with the weapon being placed at the normal firing height, i.e. standing, kneeling, or prone position.

4.1 Handheld and Shoulder Weapons.

Mount hand held and shoulder weapons in a test firing fixture with their barrels or tubes 1.6 m (5.2 ft) above and parallel to the ground plane when practical. Remotely fire 3 rounds, allowing enough time between rounds for the noise pulses from the preceding round to decay to ambient before the next round is fired. In addition to the aforementioned single shot evaluation, when automatic weapons are tested, three separate 3-round bursts will be fired at the maximum cyclic rate of fire of the weapon.

4.2 Rifle with Grenade Launcher.

Mount the rifle in a test firing fixture with the rifle butt resting on the ground and the barrel elevated to its maximum safe position for launching grenades.
Launch at least 3 grenades.

4.3 Machine Guns (tripod mounted).

Mount the machine gun in a test firing fixture representative of its normal tripod mounting condition. Fire at least 3 separate rounds with enough time between rounds for the pulse envelope to decay to ambient before the next round is fired. In addition to the aforementioned single shot evaluation, when automatic weapons are tested, three separate 3-round bursts will be fired at the maximum cyclic rate of fire of the weapon.

4.4 Recoilless Rifles.

Mount the recoilless rifle in a firing fixture so that the tube is 1.6 m (5.2 ft) above and parallel to the ground plane, or in its tactical firing position. Fire at least 3 rounds.

4.5 Mortars.

Position the weapon for remote firing. Conduct tests with the weapon positioned at both the minimum and maximum safe tube elevations. Fire at least 3 rounds at each elevation.

4.6 Small Arms Mounted in Vehicles.

Mount the weapon in or on the vehicle as it would be under normal combat or training conditions. Position the vehicle to create the most severe noise conditions with respect to the crew members (e.g., gun firing directly over the hatch of a crew member) when firing the weapon. With the vehicle hatches closed, fire the weapon. Repeat firing with the hatches open. Repeat firing with the engine running at idle, and the vehicle hatches closed. Finally, repeat firing with the engine running at idle, and the vehicle hatches open. Follow ITOP 4-2-822[2] for interior vehicle measurements below 1 psi (171 dB / 7 kPa).

4.7 Towed Artillery.

Position the weapon on an appropriate range. The weapon will be tested at minimum quadrant elevation (QE), at medium QE, and at maximum QE within range safety limits of the weapon. In addition, the weapon will be tested at a minimum of two azimuth; center traverse and maximum left or right traverse. Fire at least 3 times for each elevation.

4.8 Self-propelled Artillery (open mount).

Position the vehicle on an appropriate range. The weapon will be tested at minimum QE, at medium QE, and at maximum QE within range safety limits of the weapon. Fire at least 3 times for each elevation.

4.9 Self-propelled Artillery (closed mount or turret).

Position the vehicle on an appropriate range. Elevate the gun muzzle to the position within the range safety limits that produces the highest noise level. Specify hatch conditions used during firing. Fire at least 3 rounds.

4.10 Air Defense Weapons.

Position the weapon on an appropriate firing range. Elevate the gun muzzle to the position within the range safety limits that produces the highest noise level. Fire at least 3 rounds.

4.11 Tank Main Gun.

Position the vehicle on an appropriate range. Elevate the gun muzzle to the position within the range safety limits that produces the highest noise level. Specify hatch conditions during firing. Fire at least 3 rounds.

5. DATA REQUIRED.

The following data are required:

a. Complete list of instrumentation used for the measurements, including name, type, serial number, and manufacturer, and state of calibration.

b. Complete identification of the weapon system.

c. Complete description of the operational conditions under which measurements were made, such as transducer locations and orientation, weapon height and elevation, muzzle velocity, hatch position, etc.

d. Date, time of day, and location of the test.

e. Physical description of the area, including the composition of the ground surface, the location of the reflecting surfaces, and a sketch of the weapon and transducer and microphone locations, as required.

f. Temperature, relative humidity, wind direction and velocity, and atmospheric pressure, as required. The recorded temperature and pressure may be used to compute peak pressure, duration and impulse data, scaled to standard temperature and pressure conditions, as required.

g. Type and lot number of projectiles, propellants, and/or explosives.

h. Mass of propellant charge and projectile.

i. Photographs and/or video of test setup as required.

j. Peak overpressure (Pa and/or dB) shall be reported for each round or event.

k. Pressure time histories and, if possible, typical spectra shall be given in the report.

l. All data obtained from the measurements, including all pressure time histories, shall be maintained in an accessible form.

6. PRESENTATION OF DATA.

Appendix A provides examples of summary reports that can be used to provide emerging results to test customers. Additional detailed requirements for presentation of test data should be coordinated with the IPT on a program by program basis and reflected in the test plan(s) as appropriate.

APPENDIX A. NOTIONAL EXAMPLE OF BLAST OVERPRESSURE TEST REPORT.

2.3 Blast Overpressure Report.

2.3.1 Objectives.

The objective of this testing is to determine the blast-overpressure and noise levels at various crew positions while firing the XXX weapon.

2.3.2 Criteria.

While firing the XXX weapon, the combination of blast overpressure and duration at the crew positions shall not exceed the impulse-noise limit, Category Z, as defined in MIL-STD-1474D (Test Agency devised, DTC approved).

2.3.3 Test Procedure.

a. A total of YY rounds were fired from the XXX weapon. The rounds were fired from X through XX July 2XXX at Aberdeen Proving Ground, Maryland. The rounds were temperature conditioned to –XX ^{o}F (-YY ^{o}C), and were fired from the XXX firing position. An IR detector was used to obtain the t-zero time for these test firings.

b. PCB and Endevco type pressure transducers were used to measure the blast overpressure levels. Measurements were taken at the gunner and assistant gunner positions. Blast Test Devices (BTDs) were used at the gunner and assistant gunner positions. Data from the PCB auditory transducers were sampled at a fixed sampling rate of two hundred thousand samples per second per channel and recorded digitally with a forty kilohertz low pass filter, while the Endevco transducers in the BTD (non-auditory locations) were sampled at a fixed sampling rate of two hundred thousand samples per second per channel and recorded digitally with a ten kilohertz low pass filter.

c. Measurements for the gunner's head and chest positions were derived after careful consideration of the physical features of the weapon and measurements for the fiftieth percentile soldier as presented in Department of Defense Handbook DOD-HDBK-743A.

d. The data were acquired using the Ballistic Test Site (BTSX) data acquisition system. The system provides for signal conditioning (analog amplification and filtering) of various transducers and digital conversion and storage of the data. Personnel of the Ballistics Instrumentation Division, Survivability/Lethality Directorate performed the data acquisition.

2.3.4 Test Results.

a. Ambient atmospheric pressure and temperature data values were averaged over the firing times on each of the firing days. The data presented in this report have not been corrected to standard atmospheric conditions because of the close proximity of the firing site to sea level.

b. The peak side-on blast overpressure Ps, the A and B duration times, the allowable number of rounds per day, NB, and the impulse were recorded for each test round fired. The peak pressure levels were taken in kilopascals (kPa) and converted to decibels (dB) using the formula: dB = 153.98 + 20 log (kPa). The mean and worst case condition for each group of rounds fired was also calculated. The round by round blast overpressure data is available from the Analytical Team upon request.

2.3.5 Technical Assessment.

a. The allowable number of rounds per day that can be fired with single hearing protection, in accordance with MIL-STD-1474D, was less than five rounds per day

b. The non-auditory blast overpressure data obtained at the chest positions for the gunner and assistant gunner from this test will be forwarded to the Center for Health Promotion and Preventative Medicine (CHPPM) for further auditory and non-auditory data.

Summary Table of Blast Test Device (BTD) and **Auditory Data (Shown in Bold)**.

Date Fired: X July 2XXX Round Type: Model XYZ Firing Position: XXXX Cond. Temp.: -XX°F (-YY°C)											
		Location									
Channel Number	Crew Position	Radial from center of weapon, degrees	Distance from front of weapon, cm	Distance from center axis of weapon, cm	Height relative to weapon, cm	Peak Pressure, kPa		B Duration Time, ms		[b]ANOR/day	
						Mean	[a]Worst Case	Mean	[a]Worst Case	Mean	[a]Worst Case
1	Gunner (Chest)	N/A	72	20.3	-6.6	13	15	15	14	57	24
2	Gunner (Right)	N/A	72	20.3	-6.6	15	18	15	15	32	12
3	Gunner (Back)	N/A	72	20.3	-6.6	36	50	11	10	1	0
4	Gunner (Left)	N/A	72	20.3	-6.6	21	31	13	11	13	2
5	**Gunner (Head)**	**N/A**	**58.4**	**16.7**	**6.6**	**24**	**23**	**45**	**76**	**1[d]**	**0[d]**
6	**Asst Gunner (Head)**	**N/A**	**50**	**42.1**	**2.3**	**20**	**21**	**18**	**17**	**6**	**5**
7	Asst Gunner (Chest)	N/A	46.6	58.4	-17.1	21	25	12	12	9	4
8	Asst Gunner (Right)	N/A	46.6	58.4	-17.1	14	15	15	15	37	26
9	Asst Gunner (Back)	N/A	46.6	58.4	-17.1	20	24	14	12	9	4
10	Asst Gunner (Left)	N/A	46.6	58.4	-17.1	38	42	11	10	0	0

Summary Table Notes:

[a] Worst case value is $P^{3.0103} * t$.

[b] ANOR/day is NB, the allowable number of rounds per day with single hearing protection.

[c] Exceeds one thousand rounds per day.

[d] Data exceeds the Z-curve. Prior approval by the Surgeon General's Office is required.

[e] Height above ground.

[f] Distance from center of weapon along the radial.

APPENDIX B. REFERENCES:

1. US MIL-STD-1474D, Department of Defense Design Criteria Standard, Noise Limits, 12 February 1997

2. FR/GE/US International Test Operations Procedure (ITOP) 4-2-822, Electronic Measurement of Airblast Overpressure, 25 September, 2000.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: US Army Aberdeen Test Center (TEDT-AT-SLT), 400 Colleran Road, Aberdeen Proving Ground, MD 21005-5059. Additional copies are can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.