Department of Defense
MANUAL

NUMBER 6055.09-M, Volume 5
February 29, 2008
Administratively Reissued August 4, 2010
Incorporating Change 1, September 2, 2011

USD(AT&L)

SUBJECT: DoD Ammunition and Explosives Safety Standards: Quantity-Distance Criteria for Intentional Burns or Detonations, Energetic Liquids, and Underground Storage

References: See Enclosure 1

V5.1. PURPOSE

V5.1.1. Manual. This Manual is composed of several volumes, each containing its own purpose, and administratively reissues DoD 6055.09-STD (Reference (a)). The purpose of the overall Manual, in accordance with the authority in DoD Directives 5134.01 and 6055.9E (References (b) and (c)), is to establish explosives safety standards (hereafter referred to as "standards") for the Department of Defense.

V5.1.1.1. These standards are designed to manage risks associated with DoD-titled ammunition and explosives (AE) by providing protection criteria to minimize serious injury, loss of life, and damage to property.

V5.1.1.2. Due to the size and complexity of this Manual, alternate paragraph numbering has been approved for use throughout. The initial numeric set (V#) refers to the volume number within the Manual; the second set (E#) refers to the enclosure number; and subsequent numbers refer to the section, paragraph, and subparagraph numbers. If there is no E#, the reference is to a section above the signature of the volume.

V5.1.2. Volume. This Volume provides quantity-distance (QD) criteria for intentional burning or detonation of AE, storage and operations involving energetic liquids, and underground storage of AE.

V5.2. APPLICABILITY. This Volume:

V5.2.1. Applies to:

V5.2.1.1 OSD, the Military Departments, the Office of the Chairman of the Joint Chiefs of Staff and the Joint Staff, the Combatant Commands, the Office of the Inspector General of the Department of Defense, the Defense Agencies, the DoD Field Activities, and all other organizational entities within the Department of Defense (hereafter referred to collectively as the "DoD Components").

V5.2.1.2. DoD-titled AE wherever it is located.

V5.2.1.3. DoD personnel and property when potentially endangered by known host-nation or off-installation AE hazards.

V5.2.1.4. DoD facilities siting and construction, except as indicated in paragraph V5.2.2.

V5.2.1.5. The evaluation of non-DoD explosives siting submissions on DoD installations (see section V4.E5.21.).

V5.2.2. Provided the documentation requirements of paragraph V5.E2.3.5. are met, does not apply to:

V5.2.2.1. Existing facilities, or those approved for construction under then-current editions of these standards. This exception applies for the balance of the useful lives of such facilities provided:

V5.2.2.1.1. The facility continues to be used for its intended purpose.

V5.2.2.1.2. The explosives safety hazards are not increased.

V5.2.2.1.3. Redesign or modification is not practicable.

V5.2.2.1.4. The quantity of AE cannot be reduced for reasons of operational necessity.

V5.2.2.2. Those planned facilities that do not meet these standards, but have been certified by the Heads of the DoD Components (see section V1.E3.4.) as essential for operational or other compelling reasons.

V5.2.2.3. Other situations that, upon analysis by the Heads of the DoD Components and the Department of Defense Explosives Safety Board (DDESB), are determined to provide the required degree of safety through use of protective construction or other specialized safety features.

V5.3. <u>DEFINITIONS</u>

V5.3.1. <u>Abbreviations and Acronyms</u>. See Glossary.

V5.3.2. Terms. See Volume 8 of this Manual.

V5.4. POLICY. As established in Reference (c) and consistent with peacetime, contingency, or wartime operational requirements and corresponding DoD military munitions requirements from the broadest and most fundamental explosives safety management perspective, it is DoD policy to:

V5.4.1. Provide the maximum possible protection to people and property from the potential damaging effects of DoD military munitions (explosive and chemical). Applying the standards herein provides only the minimum protection criteria for personnel and property, and greater protection should always be provided when practicable.

V5.4.2. Minimize exposures consistent with safe and efficient operations (i.e., expose the minimum number of people for the minimum time to the minimum amount of explosives or chemical agents).

V5.5. RESPONSIBILITIES. See Enclosure 2.

V5.6. PROCEDURES. See Enclosures 3 through 5. Criteria provided in this Manual are given in English units (e.g., foot or feet (ft), pounds (lbs), pounds per square inch (psi)), with metric equivalents shown in brackets (e.g., meters (m), kilograms (kg), kilopascals (kPa)).

V5.7. RELEASABILITY. UNLIMITED. This Volume is approved for public release and is available on the Internet from the DoD Issuances Website at http://www.dtic.mil/whs/directives.

V5.8. EFFECTIVE DATE. This Volume is effective upon its publication to the DoD Issuances Website.

Enclosures

1. References
2. Responsibilities
3. Areas Used for Intentional Burns and Detonations
4. Energetic Liquids
5. Underground Storage of AE

Glossary

TABLE OF CONTENTS

FIGURES

ENCLOSURE 1

REFERENCES

(a) DoD 6055.09-STD, "DoD Ammunition and Explosives Safety Standards," February 29, 2008 (cancelled by Volume 1 of this Manual)
(b) DoD Directive 5134.01, Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L))," December 9, 2005
(c) DoD Directive 6055.9E, "Explosives Safety Management and the DoD Explosives Safety Board," August 19, 2005
(d) Department of Defense Explosives Safety Board, Technical Paper 16, "Methodologies for Calculating Primary Fragment Characteristics," April 1, 2009[1]
(e) Part 1910.106 of title 29, Code of Federal Regulations
(f) National Fire Protection Association 30, "Flammable and Combustible Liquids Code," current version[2]
(g) National Fire Protection Association 430, "Code for the Storage of Liquid and Solid Oxidizers," current version[2]
(h) Parts 171-177 of title 49, Code of Federal Regulations, current edition
(i) Army Technical Bulletin 700-2, Naval Sea Systems Command Instruction 8020.8B, Technical Order 11A-1-47, Defense Logistics Agency Regulations 8220.1, "Department of Defense Ammunition and Explosives Hazard Classification Procedures," January 5, 1998[1]
(j) American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, "Section VIII, Rules for Construction of Pressure Vessels, Division 1/Division 2," current version[3]
(k) Wilton, C., "Investigation of the Explosive Potential of the Hybrid Propellant Combinations N_2O_4/PBAN and CTF/PBAN," AFRPL-TR-67-124, 1967 (AD A003 595)[4]
(l) National Fire Protection Association 251, "Standard Methods of Tests of Fire Resistance of Building Construction and Materials," current version[2]
(m) National Fire Protection Association 50, "Standard for Bulk Oxygen Systems at Consumer Sites," current version[2]
(n) Zabetakis, M. G. and Burgess, D. S., "Research on the Hazards Associated With the Production and Handling of Liquid Hydrogen," U.S. Department of the Interior, Bureau of Mines Report 5707, 1961[5]

---

[1] Available from DDESB, Room 856C, Hoffman Building I, 2461 Eisenhower Avenue, Alexandria, VA 22331-0600; Phone: 703-325-0891; Fax: 703-325-6227
[2] NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471; Phone: 617-770-3000; Fax: 617-770-0700
[3] ASME International, 22 Law Drive, Box 2900, Fairfield, NJ 07007-2900; Phone: 800-843-2763; International: 973-882-1167; Fax: 973-882-1717
[4] Defense Technical Information Center, Fort Belvoir, VA; Phone: 800-225-3842
[5] Chemical Propulsion Information Agency (CPIA) Accession Number 1964-0291, CPIA, The Johns Hopkins University, 10630 Little Patuxent Parkway, Suite 202, Columbia, MD 21044-3204; Phone: 410-992-7300; Fax: 410-730-4969

ENCLOSURE 2

RESPONSIBILITIES

V5.E2.1. UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY, AND LOGISTICS (USD(AT&L)). The USD(AT&L) shall provide overall policy guidance for the DoD Explosives Safety Management Program.

V5.E2.2. CHAIRMAN, DDESB. The Chairman, DDESB, shall report to the Deputy Under Secretary of Defense for Installations and Environment (DUSD(I&E)) and, on behalf of the USD(AT&L) and the DUSD(I&E), shall collaborate with the Military Service-appointed voting DDESB members to maintain explosives safety standards.

V5.E2.3. HEADS OF THE DoD COMPONENTS. The Heads of the DoD Components shall:

V5.E2.3.1. Implement these DoD explosives safety standards.

V5.E2.3.2. Comply with applicable Federal and State laws and regulations. Where this Volume conflicts with such laws and regulations, ensure the safety of DoD personnel and the public while complying and notify the Chairman, DDESB, through the Component's board member, of the conflict. These standards are not intended to be so rigid as to prevent the DoD Components from accomplishing their assigned missions.

V5.E2.3.3. Issue DoD Component guidance that implements these standards and provides DoD Component unique requirements.

V5.E2.3.4. Send a copy of any implementing and supplementary guidance to these standards to the Chairman, DDESB.

V5.E2.3.5. Document the exceptions described in paragraph V5.2.2. in permanent records. These records must include:

V5.E2.3.5.1. The effective date the applicable DoD explosives safety standards were first published.

V5.E2.3.5.2. The date the deviant facility was either approved, from an explosives safety viewpoint, for use or was first used in a manner deviating from the standard.

ENCLOSURE 3

AREAS USED FOR INTENTIONAL BURNS AND DETONATIONS

V5.E3.1. AREAS FOR BURNING AE. Use the QD formula described in paragraph V1.E7.5.1. and the requirements in paragraphs V5.E3.1.1. through V5.E3.1.3. to determine safe locations for burning AE.

V5.E3.1.1. Use K24 [9.52] in the QD formula to determine the minimum safe distance for either personnel burning AE or those conducting unrelated AE operations.

V5.E3.1.2. Use K40 [15.87] in the QD formula to determine the safe distance for persons not performing AE operations. However, if the net explosive weight for quantity-distance (NEWQD) of burn material is more than 450 lbs [204 kg], the minimum safe distance shall be at least 1,250 ft [381 m]. If the NEWQD of burn material is ≤ 450 lbs [204 kg], use the minimum hazardous fragment distance given in Table V3.E3.T2.

V5.E3.1.3. Locate burning grounds at intraline distance (ILD) from other potential explosion sites (PESs).

V5.E3.2. AREAS USED FOR INTENTIONAL DETONATIONS

V5.E3.2.1. General

V5.E3.2.1.1. Protective structures for personnel or measures to suppress blast or fragment effects may be used to reduce the required withdrawal distances.

V5.E3.2.1.2. Control sites for intentional detonations for AE disposals, live-fire demonstrations, and explosive ordnance disposal (EOD) non-emergency operations must be at ILD from other PESs, based on the PES's NEWQD.

V5.E3.2.2. Separation Distances. The minimum separation distances between areas used for intentional detonation (excluding hands-on training) and nonessential personnel are determined by application of the criteria given in subparagraphs V5.E3.2.2.1. through V5.E3.2.2.2.2.3.3. If the minimum separation distance requirements for previously approved DDESB sitings or those prescribed in subparagraphs V5.E3.2.2.1. through V5.E3.2.2.2.2.3.3. cannot be met, then personnel shall be provided the protection specified in paragraph V1.E9.3.2.

V5.E3.2.2.1. For non-fragmenting AE, use $d = 328W^{1/3}$ but not less than 200 ft [$d = 130.1Q^{1/3}$, but not less than 61 m].

V5.E3.2.2.2. For fragmenting AE use the larger of the two distances given in subparagraphs V5.E3.2.2.2.1. and V5.E3.2.2.2.2.

V5.E3.2.2.2.1. The distance determined from the equation $d = 328W^{1/3}$ but not less than 200 ft [$d = 130.1Q^{1/3}$ but not less than 61 m].

V5.E3.2.2.2.2. The distances given in Tables V5.E3.T1. or V5.E3.T2. A calculated (using DDESB Technical Paper 16 (Reference (d))) or measured maximum fragment throw distance (including the interaction effects for stacks of items or single items, whichever applies), with a safety factor determined by the DoD Component, may be used to replace these distances. Calculated case fragment maximum throw distances for selected munitions are given in the Fragmentation Database that is located on the DDESB secure Web page. A snapshot of this database is included in Reference (d). (Tables V5.E3.T1. and V5.E3.T2., as well as the Fragmentation Database and its snapshot in Reference (d), are for individual items. These distances do not directly apply to stacks of munitions. Further, these throw distances do not consider fragments that are produced by sections of nose plugs, base plates, boattails, or lugs. These fragments are sometimes referred to as "rogue" fragments. In addition, shaped charge jets or slugs from directed energy munitions can travel significantly greater distances than case fragments; therefore, these munitions require specific analysis.)

V5.E3.2.2.2.2.1. "Rogue" fragments can travel significantly greater distances (> 10,000 ft [3,048 m]) than those shown in Tables V5.E3.T1. and V5.E3.T2, the Fragmentation Database, and its snapshot in Reference (d). Care must be taken either to properly orient the munition (e.g., lugs or strongbacks and nose or tail plate sections oriented away from personnel locations), or to minimize or eliminate the hazard of rogue fragments (e.g., sandbagging the munition prior to detonation).

V5.E3.2.2.2.2.2. For multiple munitions' detonation, the preferred approach is:

V5.E3.2.2.2.2.2.1. Place the munitions in a single layer with their sides touching such that their axis is horizontal.

V5.E3.2.2.2.2.2.2. Place the munitions so that the nose of each munition is pointing in the same direction.

V5.E3.2.2.2.2.2.3. Orient the munitions so that lugs or strongbacks and nose or tail plate sections are facing away from areas to be protected.

V5.E3.2.2.2.2.2.4. Initiate the stack detonation so that all munitions detonate simultaneously.

V5.E3.2.2.2.2.3. Use the following when the procedures outlined in subparagraphs V5.E3.2.2.2.2.2.1. through V5.E3.2.2.2.2.2.4. cannot be met:

V5.E3.2.2.2.2.3.1. If the orientation of potential rogue fragments cannot be controlled, fragment ranges must be evaluated on a case-by-case basis.

V5.E3.2.2.2.2.3.2. If the orientation of the potential rogue fragments can be controlled, then the ranges given in the Fragmentation Database and its snapshot in Reference (d) shall be increased by 33 percent to account for the interaction effects and/or non-design mode initiation.

V5.E3.2.2.2.2.3.3. If detonations involve stacks of mixed munitions, evaluate the distance for each munition separately using the procedures in subparagraph V5.E3.2.2.2.2. and select the largest distance.

Table V5.E3.T1. Default Maximum Case Fragment Distances Versus Diameter for Intentional Detonations[a, b]

Diameter	Maximum Fragment Distance (MFD)[c]		
	Robust[d]	Extremely Heavy Case[e]	Non-robust[f]
(in)	(ft)	(ft)	(ft)
[mm]	*[m]*	*[m]*	*[m]*
0.1	100	178	131
2.54	*30.5*	*54.2*	*40.0*
0.2	136	285	248
5.08	*41.4*	*86.9*	*75.6*
0.3	214	376	349
7.62	*65.1*	*114.6*	*106.4*
0.4	290	458	439
10.16	*88.5*	*139.5*	*133.7*
0.5	365	533	519
12.70	*111.3*	*162.4*	*158.4*
0.6	438	603	593
15.24	*133.5*	*183.9*	*180.9*
0.7	509	670	661
17.78	*155.1*	*204.3*	*201.7*
0.8	578	734	725
20.32	*176.1*	*223.8*	*221.0*
0.9	645	796	784
22.86	*196.6*	*242.5*	*239.1*
1.0	711	855	840
25.40	*216.5*	*260.5*	*256.1*
1.5	1,016	1,127	1,079
38.10	*309.4*	*343.5*	*328.9*
2.0	1,290	1,371	1,270
50.80	*392.8*	*418.0*	*387.3*
2.5	1,539	1,597	1,430
63.50	*468.7*	*486.7*	*436.2*
3.0	1,769	1,808	1,568
76.20	*538.6*	*551.1*	*478.2*
3.5	1,983	2,009	1,688
88.90	*603.5*	*612.2*	*514.9*
4.0	2,182	2,200	1,795
101.60	*664.2*	*670.6*	*547.6*
4.5	2,369	2,384	1,892
114.30	*721.1*	*726.7*	*576.9*
5.0	2,546	2,562	1,979
127.00	*774.9*	*780.9*	*603.5*

Table V5.E3.T1. Default Maximum Case Fragment Distances Versus Diameter for Intentional Detonations,[a, b] Continued

Diameter	Maximum Fragment Distance (MFD)[c]		
	Robust[d]	Extremely Heavy Case[e]	Non-robust[f]
(in)	(ft)	(ft)	(ft)
[mm]	*[m]*	*[m]*	*[m]*
5.5	2,713	2,734	2,058
139.70	*825.8*	*833.3*	*627.7*
6.0	2,872	2,901	2,131
152.40	*874.2*	*884.2*	*650.0*
6.5	3,024	3,064	2,198
165.10	*920.3*	*933.9*	*670.5*
7.0	3,169	3,223	2,261
177.80	*964.4*	*982.3*	*689.5*
7.5	3,307	3,378	2,319
190.50	*1,006.6*	*1,029.6*	*707.3*
8.0	3,440	3,530	2,373
203.20	*1,047.1*	*1,075.9*	*723.8*
8.5	3,568	3,679	2,424
215.90	*1,086.0*	*1,121.3*	*739.3*
9.0	3,691	3,825	2,472
228.60	*1,123.4*	*1,165.9*	*753.9*
9.5	3,810	3,969	2,517
241.30	*1,159.5*	*1,209.7*	*767.6*
10.0	3,924	4,110	2,559
254.00	*1,194.4*	*1,252.8*	*780.6*
10.5	4,035	4,249	2,599
266.70	*1,228.0*	*1,295.2*	*792.9*
11.0	4,142	4,386	2,637
279.40	*1,260.6*	*1,336.9*	*804.5*
11.5	4,246	4,521	2,674
292.10	*1,292.2*	*1,378.1*	*815.5*
12.0	4,347	4,654	2,708
304.80	*1,322.8*	*1,418.6*	*826.0*
12.5	4,444	4,786	2,741
317.50	*1,352.5*	*1,458.7*	*836.0*
13.0	4,539	4,916	2,772
330.20	*1,381.3*	*1,498.2*	*845.5*
13.5	4,631	5,044	2,802
342.90	*1,409.4*	*1,537.3*	*854.6*
14.0	4,721	5,170	2,830
355.60	*1,436.7*	*1,575.9*	*863.3*

Table V5.E3.T1. Default Maximum Case Fragment Distances Versus Diameter for Intentional Detonations,[a, b] Continued

Diameter	Maximum Fragment Distance (MFD)[c]		
	Robust[d]	Extremely Heavy Case[e]	Non-robust[f]
(in)	(ft)	(ft)	(ft)
[mm]	*[m]*	*[m]*	*[m]*
14.5	4,808	5,296	2,857
368.30	*1,463.2*	*1,614.1*	*871.6*
15.0	4,893	5,419	2,883
381.00	*1,489.1*	*1,651.8*	*879.6*
16.0	5,057	5,663	2,933
406.40	*1,538.9*	*1,726.2*	*894.5*
18.0	5,362	6,137	3,020
457.20	*1,631.5*	*1,870.5*	*921.1*
20.0	5,640*	6,594*	3,095*
508.00	*1,716.2**	*2,009.9**	*944.0**
22.0	5,896*	7,037*	3,160*
558.80	*1,794.0**	*2,144.9**	*963.9**
24.0	6,133*	7,467*	3,217*
609.60	*1,866.0**	*2,276**	*981.4**
26.0	6,353*	7,886*	3,268*
660.40	*1,932.8**	*2,403.7**	*996.8**
28.0	6,558*	8,295*	3,312*
711.20	*1,995.2**	*2,528.3**	*1,010.5**
30.0	6,750*	8,695*	3,352*
762.00	*2,053.6**	*2,650.1**	*1,022.7**
35.0	7,182*	9,659*	3,435*
889.00	*2,184.9**	*2,943.9**	*1,047.9**
40.0	7,557*	10,580*	3,499*
1,016.00	*2,298.9**	*3,224.6**	*1,067.4**
45.0	7,887*	11,465*	3,549*
1,143.00	*2,399.2*	*3,494.3**	*1,082.7**
50.0	8,180*	12,319*	3,588*
1,270.00	*2,488.3**	*3,754.7**	*1,094.7**
55.0	8,443*	13,146*	3,619*
1,397.00	*2,568.2*	*4,006.8**	*1,104.2**
60.0	8,680*	13,950*	3644*
1,524.00	*2,640.3**	*4,251.8**	*1,111.7**
* = Extrapolated			

a	Use of equations given in footnotes d, e, and f to determine other diameter/MFD combinations is allowed.
b	See subparagraph V5.E3.2.2.2.2. for ranges associated with multiple munitions detonation.

Table V5.E3.T1. Default Maximum Case Fragment Distances Versus Diameter for Intentional Detonations,[a, b] Continued

c	These calculated fragment throw distances are for individual munitions and do not apply to stacks. They also do not address "rogue" (non-case) fragments that can be produced from sections of nose plugs, base plates, boattails, or lugs. Rogue fragments can travel to significantly greater distances (i.e., > 10,000 ft [3,048 m]) than those shown. Care must be taken to properly orient the munition or take other measures to minimize rogue fragment hazards.
d	Robust munitions are defined in Volume 8.
	English Equations (EQNs) (MFD in ft, Diameter (D) in inches; ln is natural logarithm, exp [x] is e^x)
	$MFD = 711*D^{(0.91 - 0.073*\ln(D))}$ EQN V5.E3.T1-1
	$D = \exp[6.233 – \{128.804 – 13.699*\ln(MFD)\}^{1/2}]$ EQN V5.E3.T1-2
	Metric EQNs (MFD in m, Diameter (D) in millimeters (mm); ln is natural logarithm, exp [x] is e^x)
	$MFD = 5.318*D^{(1.382 - 0.073*\ln(D))}$ *EQN V5.E3.T1-3*
	$D = \exp[9.467 – \{112.531 – 13.699*\ln(MFD)\}^{1/2}]$ *EQN V5.E3.T1-4*
e	Extremely heavy case munitions are defined in Volume 8.
	English EQNs (MFD in ft, Diameter (D) in inches)
	$MFD = 854.8*D^{0.682}$ EQN V5.E3.T1-5
	$D = (5.0243E-05)*MFD^{1.4663}$ EQN V5.E3.T1-6
	Metric EQNs (MFD in m, Diameter (D) in mm)
	$MFD = 28.693*D^{0.682}$ *EQN V5.E3.T1-7*
	$D = (7.2862E-03)*MFD^{1.4663}$ *EQN V5.E3.T1-8*
f	Non-robust munitions are defined in Volume 8.
	English EQNs (MFD in ft, Diameter (D) in inches; ln is natural logarithm, exp [x] is e^x)
	$MFD = 840*D^{(0.645 - 0.07*\ln(D))}$ EQN V5.E3.T1-9
	$D = \exp[4.607 – \{117.417 – 14.286*\ln(MFD)\}^{1/2})]$ EQN V5.E3.T1-10
	Metric EQNs (MFD in m, Diameter (D) in mm; ln is natural logarithm, exp [x] is e^x)
	$MFD = 15.278*D^{(1.098 - 0.07*\ln(D))}$ *EQN V5.E3.T1-11*
	$D = \exp[7.842 – \{100.448 – 13.699*\ln(MFD)\}^{1/2}]$ *EQN V5.E3.T1-12*

Table V5.E3.T2. Default Maximum Case Fragment Distances Versus Net Explosive Weight (NEW) for Intentional Detonations[a, b]

NEW	MFD[c]		
	Robust[d]	Extremely Heavy Case[e]	Non-robust[f]
(lbs)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*
0.01	587	150	678
0.005	*179.2*	*45.6*	*206.9*
0.015	747	379	756
0.007	*228.0*	*115.6*	*230.7*
0.02	861	542	811
0.009	*262.5*	*165.2*	*247.5*
0.03	1,021	772	889
0.014	*311.3*	*235.1*	*271.2*
0.04	1,134	934	944
0.018	*345.9*	*284.8*	*288.0*
0.05	1,222	1,061	987
0.023	*372.7*	*323.3*	*301.1*
0.06	1,294	1,164	1,022
0.027	*394.6*	*354.7*	*311.8*
0.07	1,355	1,251	1,051
0.032	*413.1*	*381.3*	*320.8*
0.08	1,408	1,327	1,077
0.036	*429.2*	*404.3*	*328.6*
0.09	1,454	1,393	1,099
0.041	*443.3*	*424.7*	*335.5*
0.1	1,496	1,453	1,120
0.045	*456.0*	*442.8*	*341.7*
0.15	1,656	1,682	1,197
0.068	*504.7*	*512.8*	*365.4*
0.2	1,769	1,845	1,253
0.091	*539.3*	*562.4*	*382.2*
0.3	1,929	2,075	1,330
0.14	*588.1*	*632.3*	*405.9*
0.4	2,043	2,237	1,386
0.18	*622.6*	*682.0*	*422.7*
0.5	2,131	2,364	1,428
0.23	*649.5*	*720.5*	*435.8*
0.6	2,202	2,467	1,463
0.27	*671.4*	*751.9*	*446.5*
0.7	2,263	2,554	1,493
0.32	*689.9*	*778.5*	*455.5*

Table V5.E3.T2. Default Maximum Case Fragment Distances Versus Net Explosive Weight (NEW) for Intentional Detonations,[a, b] Continued

NEW	MFD[c]		
	Robust[d]	Extremely Heavy Case[e]	Non-robust[f]
(lbs)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*
0.8	2,316	2,630	1,519
0.36	*706.0*	*801.5*	*463.3*
0.9	2,362	2,696	1,541
0.41	*720.1*	*821.9*	*470.2*
1.0	2,404	2,756	1,561
0.45	*732.8*	*840.0*	*476.4*
1.5	2,564	2,985	1,639
0.68	*781.5*	*910.0*	*500.1*
2	2,677	3,148	1,694
0.91	*816.1*	*959.6*	*516.9*
3	2,837	3,378	1,772
1.36	*864.8*	*1,029.5*	*540.6*
4	2,951	3,541	1,827
1.81	*899.4*	*1,079.2*	*557.5*
5	3,039	3,667	1,870
2.27	*926.2*	*1,117.7*	*570.5*
6	3,111	3,770	1,905
2.72	*948.1*	*1,149.1*	*581.2*
7	3,172	3,857	1,935
3.18	*966.7*	*1,175.7*	*590.2*
8	3,224	3,933	1,960
3.63	*982.7*	*1,198.7*	*598.0*
9	3,271	3,999	1,983
4.08	*996.9*	*1,219.0*	*604.9*
10	3,312	4,059	2,003
4.54	*1,009.5*	*1,237.2*	*611.1*
15	3,472	4,288	2,081
6.80	*1,058.3*	*1,307.2*	*634.8*
20	3,586	4,451	2,136
9.07	*1,092.9*	*1,356.8*	*651.6*
30	3,746	4,681	2,214
13.61	*1,141.6*	*1,426.7*	*675.3*
50	3,947	4,970	2,312
22.68	*1,203.0*	*1,514.9*	*705.2*
70	4,080	5,160	2,376
31.75	*1,243.4*	*1,572.9*	*724.9*

Table V5.E3.T2. Default Maximum Case Fragment Distances Versus Net Explosive Weight (NEW) for Intentional Detonations,[a, b] Continued

NEW	MFD[c]		
	Robust[d]	Extremely Heavy Case[e]	Non-robust[f]
(lbs)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*
100	4,221	5,362	2,445
45.36	*1,286.3*	*1,634.4*	*745.8*
150	4,381	5,592	2,522
68.04	*1,335.1*	*1,704.4*	*769.5*
200	4,494	5,754	2,578
90.72	*1,369.6*	*1,754.0*	*786.3*
300	4,654	5,984	2,655
136.08	*1,418.4*	*1,823.9*	*810.0*
500	4,856	6,273	2,753
226.80	*1,479.8*	*1,912.0*	*839.9*
700	4,988	6,463	2,818
317.51	*1,520.2*	*1,970.1*	*859.6*
1,000	5,129	6,665	2,886
453.59	*1,563.1*	*2,031.6*	*880.5*
1,500	5,289*	6,895*	2,964*
680.39	*1,611.8**	*2,101.6**	*904.2**
2,000	5,403*	7,057*	3,019*
907.18	*1,646.4**	*2,151.2**	*921.0**
3,000	5,563*	7,287*	3,097*
1,360.8	*1,695.1**	*2,221.1**	*944.7**
5,000	5,764*	7,576*	3,195*
2,268.0	*1,756.5**	*2,309.2**	*974.6**
7,000	5,897*	7,766*	3,259*
3,175.1	*1,797.0**	*2,367.3**	*994.3**
10,000	6,037*	7,968*	3,328*
4,535.9	*1,839.9**	*2,428.8**	*1,015.2**
15,000	6,197*	8,198*	3,406*
6,803.9	*1,888.6**	*2,498.8**	*1,038.9**
20,000	6,311*	8,360*	3,461*
9,071.8	*1,923.2**	*2,548.4**	*1,055.7**

* = Extrapolated

a	Use of equations given in footnotes d, e, and f to determine other NEW/MFD combinations is allowed.
b	See subparagraph V5.E3.2.2.2.2. for ranges associated with multiple munitions detonation.

Table V5.E3.T2. Default Maximum Case Fragment Distances Versus Net Explosive Weight (NEW) for Intentional Detonations,[a, b] Continued

c	These calculated fragment throw distances are for individual munitions and do not apply to stacks. They also do not address "rogue" (non-case) fragments that can be produced from sections of nose plugs, base plates, boattails or lugs. Rogue fragments can travel to significantly greater distances (i.e., > 10,000 ft [3,048 m]) than those shown. Care must be taken to properly orient the munition or take other measures to minimize rogue fragment hazards.	
d	Robust munitions are defined in Volume 8.	
	English EQNs (MFD in ft, NEW (W) in lbs; ln is natural logarithm, exp [x] is e^x)	
	MFD = 2404 + 394.5*ln(W)	EQN V5.E3.T2-1
	W = exp[(MFD – 2404)/394.5]	EQN V5.E3.T2-2
	Metric EQNs (MFD in m, NEW (W) in kg; ln is natural logarithm, exp [x] is e^x)	
	*MFD = 827.8 + 120.2*ln(W)*	*EQN V5.E3.T2-3*
	W = exp[(MFD – 827.8)/120.2]	*EQN V5.E3.T2-4*
e	Extremely heavy case munitions are defined in Volume 8.	
	English EQNs (MFD in ft, NEW (W) in lbs; ln is natural logarithm, exp [x] is e^x)	
	MFD = 2756 + 565.9*ln(W)	EQN V5.E3.T2-5
	W = exp[(MFD – 2756)/565.9]	EQN V5.E3.T2-6
	Metric EQNs (MFD in m, NEW (W) in kg; ln is natural logarithm, exp [x] is e^x)	
	*MFD = 976.4 + 172.5*ln(W)*	*EQN V5.E3.T2-7*
	W = exp[(MFD – 976.4)/172.5]	*EQN V5.E3.T2-8*
f	Non-robust munitions are defined in Volume 8.	
	English EQNs (MFD in ft, NEW (W) in lbs; ln is natural logarithm, exp [x] is e^x)	
	MFD = 1561.3 + 191.8*ln(W), with a minimum distance of 100 ft	EQN V5.E3.T2-9
	W = exp[(MFD – 1561.3)/191.8]	EQN V5.E3.T2-10
	Metric EQNs (MFD in m, NEW (W) in kg; ln is natural logarithm, exp [x] is e^x)	
	*MFD = 522.6 + 58.5*ln(W), with a minimum distance of 30.5 m*	*EQN V5.E3.T2-11*
	W = exp[(MFD – 522.6)/58.5]	*EQN V5.E3.T2-12*

V5.E3.2.3. EOD Operations

V5.E3.2.3.1. Nonessential Personnel

V5.E3.2.3.1.1. EOD operational responses require the application of public withdrawal distances to all nonessential personnel per Table V1.E10.T4*10*.

V5.E3.2.3.1.2. EOD operations or demonstrations conducted on ranges require minimum separation distances (see paragraph V5.E3.2.2.) for nonessential personnel.

V5.E3.2.3.2. Essential Personnel. EOD training operations, or operations involving demolition of AE, do not require minimum separation distances for essential personnel. The onsite DoD authority shall determine adequate protection for essential personnel.

V5.E3.2.3.3. EOD Proficiency Training Ranges. EOD proficiency-training ranges are limited to a maximum of 5 lbs [2.27 kg] of demolition explosives (e.g., bare charges or items without a fragment hazard).

V5.E3.2.3.3.1. Separation Distances. Facilities that require inhabited building distance (IBD), public traffic route distance (PTRD), and ILD protection must be located at the following minimum distances from the destruction point:

V5.E3.2.3.3.1.1. If the destruction point is at least 500 ft [152.4 m] from these facilities, a 5-lb [2.27 kg] NEWQD limit applies.

V5.E3.2.3.3.1.2. If the destruction point is less than 500 ft [152.4 m], but 300 ft [91.4 m] or more from these facilities, a 2.5-lb [1.13-kg] NEWQD limit applies.

V5.E3.2.3.3.1.3. If the destruction point is less than 300 ft [91.4 m], but 200 ft [61 m] or more from these facilities, a 1.25-lb [0.57-kg] NEWQD limit applies.

V5.E3.2.3.3.2. Barricading of Destruction Point. If the EOD Proficiency Training Range provides the 500-ft [152.4-m] protection distance specified in subparagraph V5.E3.2.3.3.1.1., then no barricading of the destruction point is required. If the EOD Proficiency Training Range provides less than 500-ft [152.4-m] protection distance, then the range's destruction point shall be constructed to control ejection of debris by:

V5.E3.2.3.3.2.1. Constructing a barricade with two entrances, which surrounds the destruction point, that is the equivalent of at least two side-to-side sandbags, is at least 6-ft [1.83-m] high, and is constructed within about 10 ft [3.05 m] of the destruction point.

V5.E3.2.3.3.2.2. Locating the barricade entrances at 180 degrees separation. These entrances shall be barricaded, as described in subparagraph V5.E3.2.3.3.2.1, to effectively block all debris.

V5.E3.2.3.3.3. Use of Items With a Fragment Hazard. EOD proficiency training ranges used with other than bare charges or non-fragment producing items shall meet the requirements of paragraphs V5.E3.2.1. and V5.E3.2.2.

V5.E3.2.3.3.4. Use of Explosively Operated Tool Kits. EOD proficiency training ranges on which explosively operated tool kits are used on inert AE only require 100-ft [30.5-m] separation distance between the destruction point and facilities that require IBD, PTRD, and ILD protection. The site shall be barricaded per subparagraph V5.E3.2.3.3.2.

V5.E3.2.4. Live-fire Demonstrations and Disposal Operations. The appropriate DoD authority shall determine, on a case-by-case basis:

V5.E3.2.4.1. Essential personnel required for the live-fire demonstrations or disposal operations.

V5.E3.2.4.2. Other range safety considerations (e.g., personnel withdrawal distances and acceptable exposures).

ENCLOSURE 4

ENERGETIC LIQUIDS

V5.E4.1. SCOPE AND APPLICATION

V5.E4.1.1. This enclosure applies to the storage of energetic liquids, listed in Table V5.E4.T~~1~~*3*., in all types of containers, including rocket and missile tankage. Laboratory quantities shall be stored and handled as prescribed by the controlling DoD Component. The required QD in this enclosure are only based on the energetic liquids' energetic reaction (blast overpressure and container fragmentation). These QD requirements do not consider the toxicity or potential down-wind hazard. Therefore, QD may not be the only factor that needs to be considered when selecting a location for storage and operations of energetic liquids.

V5.E4.1.2. This enclosure does not govern the storage or handling of energetic liquids for uses other than in space launch vehicles, rockets, missiles, associated static test apparatus, and AE.

V5.E4.2. CONCEPT

V5.E4.2.1. These QD standards were developed on the premise that the controlling DoD Component shall ensure that the materials of construction are compatible with the energetic liquids, facilities are of appropriate design, fire protection and drainage control techniques are employed, and other specialized controls (e.g., nitrogen padding, blanketing, and tank cooling) are used, when required.

V5.E4.2.2. When additional hazards associated with AE are involved, the safety distances prescribed in other enclosures of this volume, as well as other volumes of this Manual, shall be applied, as required.

V5.E4.2.3. These standards are based upon the estimated credible damage resulting from an incident, without considering probabilities or frequency of occurrence.

V5.E4.3. DETERMINATION OF ENERGETIC LIQUIDS QUANTITY

V5.E4.3.1. The total quantity of energetic liquids in a tank, drum, cylinder, or other container shall be the net weight of the energetic liquids contained therein. Quantity of energetic liquids in the associated piping must be included to the points that positive means are provided for interrupting the flow through the pipe, or interrupting a reaction in the pipe in the event of an incident.

V5.E4.3.2. When the quantities of energetic liquids are given in gallons [liters], the conversion factors given in Table V5.E4.T~~2~~*4*. may be used to determine the quantity in pounds [kg].

V5.E4.4. MEASUREMENT OF SEPARATION DISTANCES

V5.E4.4.1. Measure from the closest controlling hazard source (e.g., containers, buildings, segment, or positive cutoff point in piping).

V5.E4.4.2. Measure from the nearest container or controlling subdivision, when buildings containing a small number of cylinders or drums are present or when quantities of energetic liquids are subdivided effectively.

Table V5.E4.T~~1~~*3*. Hazard Classifications and Minimum QD For Energetic Liquids

Energetic Liquid	OSHA/NFPA Fuel[a] or Oxidizer[b] Class	DoD Storage Hazard Class	Minimum QD[c]
H_2O_2, > 60%	3 or 4[d]	5.1 (LA)	800[e] ft or Table V5.E4.T~~5~~*7*. *243.8[e] m or Table V5.E4.T~~5~~7.*
IRFNA	3	8 (LA)	Table V5.E4.T~~5~~*7*.
N_2O_4/MON	2	2.3 (LA)	Table V5.E4.T~~5~~*7*.
LO_2	N/A	2.2 (LA)	Table V5.E4.T~~6~~*8*.
RP-1	II	3 (LB)	Table V5.E4.T~~4~~*6*.
JP-10	II	3J (LB)	Table V5.E4.T~~4~~*6*.
LH_2	N/A	2.1 (LB)	Table V5.E4.T~~7~~*9*.
N_2H_4, > 64%	II	8 (LC)	800[e] ft or 300[f] ft or footnote g *243.8[e] m or 91.4[f] m or footnote g*
Aerozine 50 (50% N_2H_4/50% UDMH)	I B	6.1 (LC)	800[e] ft or 300[f] ft or footnote g *243.8[5] m or 91.4[f] m or footnote g*
Methylhydrazine	I B	6.1 (LC)	800[e] ft or 300[f] ft or footnote g *243.8[e] m or 91.4[f] m or footnote g*
UDMH	I B	6.1 (LC)	Table V5.E4.T~~4~~*6*.
Ethylene Oxide	I A	2.3 (LD)	HD 1.1 QD[h] with TNT Equiv = 100%, or 800[e] ft or 300[f] ft *HD 1.1 QD[h] with TNT Equiv = 100%, or 243.8[e] m or 91.4[f] m*
Propylene Oxide	I A	3 (LD)	HD 1.1 QD[h] with TNT Equiv = 100%, or 800[e] ft or 300[f] ft *HD 1.1 QD[h] with TNT Equiv = 100%, or 243.8[e] m or 91.4[f] m*
Nitromethane	I C	3 (LE)	HD 1.1 QD with TNT Equiv = 100%[i], or Table V5.E4.T~~4~~*6*.
HAN	2	8 (LE)	800[e] ft or Table V5.E4.T~~5~~*7*. *243.8[e] m or Table V5.E4.T~~5~~7.*
XM-46 (HAN Monopropellant)	N/A	1.3C (LE)	800[e] ft or use HD 1.3 QD *243.8[e] m or use HD 1.3 QD*

Table V5.E4.T~~1~~3. Hazard Classifications and Minimum QD For Energetic Liquids, Continued

Energetic Liquid	OSHA/NFPA Fuel[a] or Oxidizer[b] Class	DoD Storage Hazard Class	Minimum QD[c]
Otto Fuel II	III B	9 (LE)	HD 1.1 QD[j] with TNT Equiv = 100%, or 150[k] ft or Table V5.E4.T~~4~~6. *HD 1.1 QD[j] with TNT Equiv = 100%, or 45.7[k] m or Table V5.E4.T~~4~~6.*
Halogen Fluorides (ClF_3/ClF_5)	4	2.3 (LE)	Table V5.E4.T~~5~~7.
Liquid Fluorine	4	2.3 (LE)	Table V5.E4.T~~5~~7.
Nitrogen Trifluoride	4	2.2 (LE)	Table V5.E4.T~~5~~7.
Nitrate Esters (e.g. NG, TMETN, DEGDN, TEGDN, BTTN)	N/A	1.1 D (LE)	HD 1.1 QD with TNT Equiv = 100%

OSHA = Occupational Safety and Health Administration; NFPA = National Fire Protection Association; H_2O_2 = hydrogen peroxide; IRFNA = inhibited red fuming nitric acid; N_2O_4 = nitrogen tetroxide; MON = mixed oxides of nitrogen; LO_2 = liquid oxygen; RP = rocket propellant; JP = jet propellant; LH_2 = liquid hydrogen; N_2H_4 = hydrazine; UDMH = unsymmetrical dimethylhydrazine; HD = hazard division; TNT = trinitrotoluene; HAN = hydroxyl ammonium nitrate; ClF_3 = chlorine trifluoride; ClF_5 = chlorine pentafluoride; NG = nitroglycerin; TMETN = trimethylolethane trinitrate; DEGDN = diethylene glycol dinatrate; TEGDN = triethylene glycol dinitrate; BTTN = butane-trio-trinitrate

a	Flammable or combustible liquid classification index based on flash point and boiling point versus criteria as specified in subpart 1910.106 of title 29, Code of Federal Regulations (CFR) (Reference (e)) and NFPA 30 (Reference (f)). Primary descriptor is a Roman numeral, possibly with an additional letter.
b	NFPA oxidizer classification index as described in NFPA 430 (Reference (g)). Descriptor is an ordinary number.
c	Positive measures for spill containment/control shall be taken for isolated storage of energetic liquids in accordance with applicable OSHA and NFPA guidance (referenced in Tables V5.E4.T~~4~~6. through V5.E4.T~~6~~8.). For flammable energetic liquids and liquid oxidizers where only minimum blast or fragment distances are specified, applicable OSHA and/or NFPA guidance referenced in Tables V5.E4.T~~4~~6. and V5.E4.T~~5~~7., respectively, should also be used.
d	H_2O_2 solutions of concentration greater than 91 percent are NFPA Class 4 oxidizers.
e	Should be used as a default value, unless otherwise hazard classified, when the material is packaged in small (non-bulk) shipping containers, portable ground support equipment, small aerospace flight vehicle propellant tanks, or similar pressure vessels that provide heavy confinement (burst pressure greater than 100 psi [690 kPa]).
f	Should be used as a default value, unless otherwise hazard classified, when the material is packaged in small (non-bulk) shipping containers (Department of Transportation (DoT) 5C or equivalent), portable ground support equipment, small aerospace flight vehicle propellant tanks, or similar pressure vessels providing a lower level of confinement (burst pressure less than or equal to 100 psi [690 kPa]) and if adequate protection from fragments is not provided from terrain, effective barricades, nets, or other physical means (lightweight building construction is not adequate). If protection from fragments is provided, use the IBD/PTRD "Protected" column of Table V5.E4.T~~7~~9.
g	For large ready, bulk, or rest storage tanks (as defined in paragraphs V5.E4.5.7., V5.E4.5.9., and V5.E4.5.10.), use Table V5.E4.T~~7~~9.
h	Where there is a reasonable risk of vapor cloud explosion of large quantities (for example, in bulk tank storage).

Table V5.E4.T~~1~~*3*. Hazard Classifications and Minimum QD For Energetic Liquids, Continued

i	Technical grade nitromethane in unit quantities of 55 gallons [208.2 liters] or less in DoT-approved containers listed in subpart 173.202 of title 49, CFR (Reference (h)) may be stored as flammable liquids (Table V5.E4.T4*6*.) provided the following apply: 1. Packages are stored only one tier high. 2. Packages are protected from direct rays of the sun. 3. Maximum storage life of 2 years, unless storage life tests indicate product continues to meet purchase specification. Such tests are to be repeated at 1-year intervals thereafter.
j	For underwater static test stands, when operated at hydrostatic pressure above 50 pounds per square inch gauge (psig) [345 kPa], or for propellant tanks or other vessels having burst pressures of greater than 100 psig [690 kPa] without acceptable pressure relief devices (unless otherwise hazard classified). For underwater test stands, the TNT equivalence (i.e., maximum credible event (MCE)) should include the total energetic liquids weight in all pumps and plumbing, as well as the weight of energetic liquids held in tankage (under the test cell hydrostatic pressure) unless acceptable mitigation measures such as fuel line detonation arrestors and/or fuel tank isolation/barricading are used (as determined by hazard analysis).
k	Should be used as a default value, unless otherwise hazard classified, when the material is packaged in small vehicle propellant tanks, small (non-bulk) shipping containers, portable ground support equipment, or similar pressure vessels that provide relatively heavy confinement (burst pressure between 50 – 100 psig [345 – 690 kPa]) without acceptable pressure relief devices.

Table V5.E4.T~~2~~*4*. Factors to Use When Converting Energetic Liquid Densities[a]

Item	Density (lb/gallon) *[kg/liter]*	Temperature degrees Fahrenheit (°F) *degrees Celsius [°C]*
ClF_5	14.8 *1.77*	77 *25.0*
ClF_3	15.1 *1.81*	77 *25.0*
Ethyl alcohol	6.6 *0.79*	68 *20.0*
Ethylene oxide	7.4 *0.89*	51 *10.6*
Fluorine (liquid)	12.6 *1.51*	-306 *-187.8*
HAN Monopropellants	11.9 *1.43*	77 *25.0*
HAN solution (25 to 95 wt %)	10.0 to 13.4 *1.20 to 1.61*	68 *20.0*
N_2H_4	8.4 *1.01*	68 *20.0*
H_2O_2 (90%)	11.6 *1.39*	77 *25.0*
JP-10	7.8 *0.93*	60 *15.6*
LH_2	0.59 *0.07*	-423 *-252.8*
LO_2	9.5 *1.14*	-297 *-182.8*
Monomethyl hydrazine (MMH)	7.3 *0.87*	68 *20.0*
N_2O_4	12.1 *1.45*	68 *20.0*
Nitrogen trifluoride	12.8 *1.53*	-200 *-128.9*
Nitromethane	9.5 *1.14*	68 *20.0*
Otto Fuel II	10.3 *1.23*	77 *25.0*
Propylene oxide	7.2 *0.86*	32 *0.0*
IRFNA	12.9 *1.55*	77 *25.0*

Table V5.E4.T~~2~~*4*. Factors to Use When Converting Energetic Liquid Densities,[a] Continued

Item	Density (lb/gallon) *[kg/liter]*	Temperature (°F) *[°C]*
RP-1	6.8 *0.81*	68 *20.0*
UDMH	6.6 *0.79*	68 *20.0*
UDMH/ N_2H_4	7.5 *0.90*	77 *25.0*

a Conversion of quantities of energetic liquids:

English EQNs

From gallons to lbs: lbs of energetic liquid = gallons*density of energetic liquid (lbs/gallon) EQN V5.E4.T~~2~~*4*-1

From lb/gallon to kg/liter: 1 lb/gallon = 8.345 kg/liter EQN V5.E4.T~~2~~*4*-2

Metric EQNs

*From liters to kg: kg of energetic liquid = liters*density of energetic liquid (kg/liter) EQN V5.E4.T~~2~~4-3*

From kg/liter to lb/gallon: 1 kg/liter = 0.11983 lb/gallon EQN V5.E4.T~~2~~4-4

V5.E4.5. HAZARD CLASSIFICATION OF ENERGETIC LIQUIDS

V5.E4.5.1. The main United Nations (UN) hazard classification designators for energetic liquids are indicated in subparagraph V5.E4.5.1.1. through V5.E4.5.1.8. The original liquid propellant hazard groups I - IV and compatibility groups (CGs) A - F are no longer used.

V5.E4.5.1.1. Class 1: Explosives.

V5.E4.5.1.2. Class 2: Compressed or liquefied gases.

V5.E4.5.1.3. Class 3: Flammable liquids.

V5.E4.5.1.4. Class 4: Flammable solids and self-reactive materials.

V5.E4.5.1.5. Class 5: Oxidizers.

V5.E4.5.1.6. Class 6: Toxic/infectious substances.

V5.E4.5.1.7. Class 8: Corrosive.

V5.E4.5.1.8. Class 9: Miscellaneous.

V5.E4.5.2. Because two energetic liquids might each be compatible with certain explosive AE stores, but incompatible with each other, a two-part CG designation is assigned to an energetic liquid. The design and logistics of modern weapons sometimes require that consideration be given to permitting storage or operations involving energetic liquids in a storage structure containing solid explosives. For example, it may be necessary to store hydrocarbon-fueled cruise missiles having high explosive warheads with fueled configurations not containing explosive warheads. Another example is the storage of liquid gun propellant with explosive AE components.

V5.E4.5.2.1. The first element is the standard storage and transportation CG designation. The alpha designations are the same as the CG designations for UN Class 1 as given in Enclosure 6 of Volume 1. However, for storage and handling on DoD facilities, a CG may also be assigned to an energetic liquid in a Class other than Class 1. The absence of a CG indicates incompatibility with solid explosives.

V5.E4.5.2.2. The second element is a new energetic liquid compatibility group (ELCG) designation. The ELCG applies to mixed storage of energetic liquids or AE containing energetic liquids. The ELCG is specified in parentheses as the last element of the hazard classification. The ELCG designations and definitions are:

V5.E4.5.2.2.1. LA: Energetic liquids that are strong oxidizers, mainly of acidic character. These materials may cause or contribute to the combustion of other material, possibly resulting in serious flare fires or explosions. Includes, but is not limited to, N_2O_4 and MON, IRFNA, LO_2, H_2O_2, and gels, slurries, or emulsions of these chemicals.

V5.E4.5.2.2.2. LB: Energetic liquids that are readily combustible when exposed to, or ignited in the presence of an oxidizing agent, but that are not strong reducing agents. Some may be hypergolic with group LA materials. Includes, but is not limited to, hydrocarbons such as kerosenes and strained ring ramjet fuels; LH_2; and gels, slurries, or emulsions of these chemicals.

V5.E4.5.2.2.3. LC: Energetic liquids that are readily combustible when exposed to, or ignited in the presence of an oxidizing agent, and are also strong reducing agents. These will likely be hypergolic with group LA substances. Includes, but is not limited to, hydrazines and other amines; and gels, slurries, or emulsions of these chemicals.

V5.E4.5.2.2.4. LD: Energetic liquids that act mainly as combustible fuels, similar to groups LB and LC, when exposed to or ignited in the presence of oxidizing agents but that may act as oxidizers in some combinations. They may be a monopropellant with the right catalyst, or may be pyrophoric and ignite upon release to the atmosphere. Examples are boranes and ethylene and propylene oxides.

V5.E4.5.2.2.5. LE: Energetic liquids having characteristics that do not permit storage with any other energetic liquid. They may react adversely with either fuels (reducing agents) or oxidizers. Examples are nitromethane, nitrate ester-based formulations such as Otto Fuel II, liquid monopropellants containing HAN, halogen fluorides (ClF_3 and ClF_5) and fluorine, and gels, slurries, or emulsions of these chemicals.

V5.E4.5.2.3. For mixing of energetic liquids:

V5.E4.5.2.3.1. Different energetic liquids in the same ELCG may be stored together.

V5.E4.5.2.3.2. ELCG-LE may not be mixed with other ELCG or dissimilar ELCG-LE.

V5.E4.5.2.3.3. Mixed storage is prohibited between energetic liquids of different ELCG designations with one exception. ELCG-LB and -LC should not be stored together, particularly when the majority of the material stored is ELCG-LB; however, mixed storage of ELCG-LB and -LC is permitted when operationally necessary.

V5.E4.5.2.4. As an example, for the 1.3C(LE) hazard classification for HAN-based liquid gun propellant XM-46:

V5.E4.5.2.4.1. "C": indicates the propellant can be stored in the same magazine with CG-C solid propellants. Because CG-C and CG-D can be mixed, CG-D high explosive projectiles could also be stored with the energetic liquid gun propellant.

V5.E4.5.2.4.2. "LE": indicates that hydrocarbon fuel (e.g., JP-10), which is an ELCG-LB, would not be permitted in this storage scenario, because its ELCG-LB indicates incompatibility with ELCG-LE.

V5.E4.5.3. Complete DoD hazard classification assignments for current energetic liquids are shown in Table V5.E4.T~~1~~*3*. (Conversions for gallons of energetic liquids to pounds are provided in Table V5.E4.T~~2~~*4*.)

V5.E4.5.4. Each new energetic liquid, or new non-bulk packaging configuration of an energetic liquid, developed by a DoD Component or adopted for DoD use, must be examined and assigned a hazard classification per Army Technical Bulletin 700-2/Naval Sea Systems Command Instruction 8020.8B/Technical Order 11A-1-47/Defense Logistics Agency Regulations 8220.1 (Reference (i)).

V5.E4.5.5. A different minimum distance may be assigned during the hazard classification process when the hazards of a particular new packaging configuration are not adequately addressed. This distance shall be indicated parenthetically, in hundreds of feet, as the first element of the hazard classification. For example, if a new liquid oxidizer pressure vessel configuration is hazard classified as (04)2.2(LA), then a minimum distance of 400 ft [122 m] would apply for IBD and PTRD, otherwise the prescribed liquid oxidizer QD criteria would apply.

V5.E4.5.6. The predominant hazard of the individual energetic liquids at specific hazardous locations can vary depending upon the location of the energetic liquid storage and the operations involved. These locations are listed in subparagraphs V5.E4.5.6.1. and V5.E4.5.6.2. in the order of decreasing hazards.

V5.E4.5.6.1. Launch Pads. Operations at these facilities are very hazardous because of the proximity of fuel and oxidizer to each other, the frequency of launchings, lack of restraint of the vehicle after liftoff, and the possibility of fallback with resultant dynamic mixing on impact. To compute the equivalent explosive weight for the launch pad, use Table V5.E4.T~~3~~*5*. with the combined energetic liquids weight in the launch vehicle tanks and any energetic liquids in piping that are subject to mixing, except as indicated in subparagraph V5.E4.5.8.

V5.E4.5.6.2. Static Test Stands. Operations at these facilities are less hazardous because test items are restrained and subject to better control than launch vehicles. As with launch pads, the proximity of fuel and oxidizer presents a significant hazard. To reduce this hazard, tankage should be separated and remotely located from the static test stand. The equivalent explosive weights of Table V5.E4.T~~3~~*5*. shall be used, with the combined energetic liquids weight subject to mixing as determined by hazard analysis. The amount of energetic liquids held in run tanks can be excluded from consideration if the test stand meets all the following criteria, if applicable:

V5.E4.5.6.2.1. All tanks are American Society of Mechanical Engineers (ASME) certified and maintained per ASME Boiler and Pressure Vessel Code, section VIII, Division 1 or Division 2 (Reference (j)).

V5.E4.5.6.2.2. For cryogenic propellants, all tanks are constructed with double wall jacketing.

V5.E4.5.6.2.3. Run tankage is protected from fragments produced by an engine malfunction.

V5.E4.5.6.2.4. Both the fuel and oxidizer lines contain two (redundant), remotely-operated valves to shut off flow in the event of a malfunction.

Table V5.E4.T~~3~~*5*. Energetic Liquid Equivalent Explosive Weights[a, b, c, d, e]

Energetic Liquids	TNT Equivalence	
	Static Test Stands	Range Launch
LO_2/LH_2	See footnote f	See footnote f
LO_2/LH_2 + LO_2/RP-1	Sum of (see footnote f for LO_2/LH_2) + (10% for LO_2/RP-1)	Sum of (see footnote f for LO_2/LH_2) + (20% for LO_2/RP-1)
LO_2/RP-1	10%	20% up to 500,000 lbs plus 10% over 500,000 lbs *20% up to 226,795 kg* *plus 10% over 226,795 kg*
IRFNA/UDMH[g]	10%	10%
N_2O_4/UDMH + N_2H_4[g]	5%	10%
N_2O_4 liquid oxidizer + polybutadiene-acrylic acid-acrolyonitrile (PBAN) solid fuel (Hybrid propellants)	15%[h]	15%[h]
Nitromethane (alone or in combination)	100%	100%
Otto Fuel II	100%[i]	
Ethylene Oxide	100%[j]	100%[j]

a	The percentage factors given in this table are to be used to determine equivalent explosive weights of energetic liquids mixtures at static test stands and range launch pads when such energetic liquids are located aboveground and are unconfined except for their tankage. Other configurations shall be considered on an individual basis to determine equivalent explosive weights.
b	The equivalent explosive weight calculated by the use of this table shall be added to any non-nuclear explosive weight aboard before distances can be determined from Tables V3.E3.T1. and V3.E3.T5.
c	These equivalent explosive weights apply also for these substitutions: 1. Alcohols or other hydrocarbons for RP-1. 2. H_2O_2 for LO_2 (only when LO_2 is in combination with RP-1 or equivalent hydrocarbon fuel). 3. MMH for N_2H_4, UDMH, or combinations of the two.
d	For quantities of energetic liquids up to but not over the equivalent explosive weight of 100 lbs [45.4 kg] of AE, the distance shall be determined on an individual basis by the DoD Component. All personnel and facilities, whether involved in the operation or not, shall be protected by operating procedures, equipment design, shielding, barricading, or other suitable means.
e	Distances less than intraline are not specified. Where a number of prepackaged energetic liquid units are stored together, separation distance to other storage facilities shall be determined on an individual basis by the DoD Component, taking into consideration normal hazard classification procedures.

Table V5.E4.T~~3~~*5*. Energetic Liquid Equivalent Explosive Weights,[a, b, c, d, e] Continued

f	For siting launch vehicles and static test stands, equivalent explosive weight is the larger of: 1. The weight equal to $8W^{2/3}$ [$4.13Q^{2/3}$] where W [Q] is the weight of LO_2/LH_2; or 2. 14 percent of the LO_2/LH_2 weight. For these calculations, use the total weight of LO_2/LH_2 present in the launch vehicle, or the total weight in test stand run tankage and piping for which there is no positive means to prevent mixing in credible accidents. When it can be reliably demonstrated that the MCE involves a lesser quantity of energetic liquids subject to involvement in a single reaction, the lesser quantity may be used in determining the equivalent explosive weight. When siting is based on a quantity less than the total energetic liquids present, the MCE and associated explosive yield analysis must be documented in an approved site plan (section V1.E5.1.).
g	These are hypergolic combinations.
h	The equivalent explosive weight of the hybrid rocket system N_2O_4 liquid oxidizer combined with PBAN solid fuel was evaluated as 15 percent for an explosive donor accident scenario, 5 percent for a high-velocity impact scenario, and less than 0.01 percent (negligible) for static mixing (tower drop) failures (Air Force Rocket Propulsion Laboratory AFRPL-TR-67-124 (Reference (k))).
i	See footnote j of Table V5.E4.T~~1~~*3*.
j	See footnote h of Table V5.E4.T~~1~~*3*.

V5.E4.5.7. Ready storage is relatively close to the launch and static test stands; normally it is not involved directly in feeding the engine as in the case with run tankage, which is an integral part of all launch and test stand operations. The equivalent explosive weights of Table V5.E4.T~~3~~*5*. shall be used with the combined energetic liquids weight subject to mixing if the facility design does not guarantee against fuel and oxidizer mixing and against detonation propagation to, or initiation at, the ready storage facility when an accident occurs at the test stand, on the ground at the launch pad, or at the ready storage areas. Otherwise, fire and fragment hazards shall govern (Tables V5.E4.T~~1~~*3*., V5.E4.T4*6*., V5.E4.T~~5~~*7*., V5.E4.T~~6~~*8*., and V5.E4.T~~7~~*9*.).

V5.E4.5.8. For cold-flow test operations, fire and fragment hazards govern (Tables V5.E4.T~~1~~*3*., V5.E4.T4*6*., V5.E4.T~~5~~*7*., V5.E4.T~~6~~*8*., and V5.E4.T~~7~~*9*.) if the design is such that the system is closed except for approved venting; is completely airtight; fuel and oxidizer never are employed concurrently; and each has a completely separate isolated system and fitting types to preclude intermixing, and the energetic liquids are of required purity. Otherwise, equivalent explosive weights (Table V5.E4.T~~3~~*5*.) shall be used with the combined energetic liquids weight.

V5.E4.5.9. Bulk storage is the most remote storage with respect to launch and test operations. It consists of the area, tanks, and other containers therein, used to hold energetic liquids for supplying ready storage and, indirectly, run tankage where no ready storage is available. Fire and fragment hazards govern (Tables V5.E4.T~~1~~*3*., V5.E4.T4*6*., V5.E4.T~~5~~*7*., V5.E4.T~~6~~*8*., and V5.E4.T~~7~~*9*.) except in special cases as indicated in Tables V5.E4.T~~1~~*3*. and V5.E4.T~~3~~*5*.

V5.E4.5.10. Rest storage is temporary-type storage and most closely resembles bulk storage. It is a temporary parking location for barges, trailers, tank cars, and portable hold tanks used for topping operations when these units actually are not engaged in the operation, and for such vehicles when they are unable to empty their cargo promptly into the intended storage container. Fire and fragment hazards govern (Tables V5.E4.T~~1~~*3*., V5.E4.T4*6*., V5.E4.T~~5~~*7*., V5.E4.T~~6~~*8*., and V5.E4.T~~7~~*9*.) except in special cases as indicated in Tables V5.E4.T~~1~~*3*. and V5.E4.T~~3~~*5*. The transporter becomes a part of that storage to which it is connected during energetic liquids transfer.

V5.E4.5.11. Run tankage (operating tankage) consists of the tank and other containers and associated piping used to hold the energetic liquids for direct feeding into the engine or device during operation. The contents of properly separated “run tanks” (operating tankage) and piping are normally considered on the basis of the pertinent hazards for the materials involved, except for quantities of incompatible materials that are or can be in a position to become mixed. Equivalent explosive weights shall be used (Table V5.E4.T~~3~~*5*.) for quantities of such materials subject to mixing unless provisions of subparagraphs V5.E4.5.6.2.1. through V5.E4.5.6.2.4. are satisfied.

V5.E4.5.12. A 25-ft [7.6-m] clear zone to inhabited buildings shall be maintained, as a minimum, on each side of pipelines used for energetic liquids (excluding flammable or combustible liquids that exhibit normal fire hazards such as RP-1, JP-10, and Otto Fuel II). Tables V5.E4.T~~1~~*3*., V5.E4.T~~5~~*7*., V5.E4.T~~6~~*8*., and V5.E4.T~~7~~*9*. apply, as appropriate.

Table V5.E4.T~~4~~*6*. QD Criteria for OSHA/NFPA Class I-III Flammable and Combustible Energetic Liquids Storage in Detached Buildings or Tanks[a, b]

Quantity	IBD/PTRD	ILD/Aboveground Intermagazine Distance (IMD)
	(ft)	(ft)
	[m]	*[m]*
Unlimited[c]	50[d, e]	Footnote f
	15.2[d, e]	

a	Other guidelines for diking, tank or container construction, tank venting, and facility construction apply (except for Class III B combustible liquids, e.g., Otto Fuel II). Refer to References (e) and (f) for further guidance on liquid storage and fire protection.
b	Refer to References (e) and (f) for definition and explanation of OSHA/NFPA classification of flammable and combustible liquids.
c	Guidelines on interior storage configuration (for container storage inside buildings) also apply with these exceptions: 1. If the storage building is located at least 100 ft [30.5 m] from any exposed building (under the direct jurisdiction of a fire protection organization) or property line; or 2. If the storage building is located at least 200 ft [61 m] from any exposed building (not under the direct jurisdiction of a fire protection organization) or property line; or 3. For combustible liquids that will not exhibit sustained burning in bulk form, e.g., Otto Fuel II, as determined through American Society for Testing and Materials D 92 Standard Test Method for Flash and Fire Points by Cleveland Open Cup or comparable testing. Refer to References (e) and (f) for further guidance on liquid storage and fire protection.
d	For container storage inside of a building, IBD/PTRD may be less than 50 ft [15.2 m] (to a minimum of 10 ft [3.05 m]) if the storage building is constructed of fire-resistive exterior walls having an NFPA fire resistance rating of 2 hours or more, according to NFPA 251 (Reference (l)).
e	For large tank storage, QD may be 25 ft [7.6 m] for tank capacities up to 100,000 gallons [378,541 liters], and 37.5 ft [11.4 m] for capacities between 100,001 gallons [378,545 liters] and 500,000 gallons [1,892,706 liters].
f	For flammable liquids container storage inside of a building, ILD/aboveground IMD is 50 ft [15.2 m] (except as in footnote d), or for adjacent incompatible oxidizer storage, distances specified for energetic liquid oxidizers (Table V5.E4.T~~5~~*7*.) or oxygen (Table V5.E4.T~~6~~*8*.). For flammable liquids storage in fixed or large portable tanks, ILD/aboveground IMD is either (1) for compatible energetic liquids, equal to one-sixth of the sum of the diameters of the two adjacent tanks, or distances specified in footnote e for adjacent container storage inside of a building; or (2) for adjacent incompatible oxidizer storage, distances specified for energetic liquid oxidizers (Table V5.E4.T~~5~~*7*.) or oxygen (Table V5.E4.T~~6~~*8*.). Earth-covered magazines (ECMs) may be used to their physical capacity for storing flammable energetic liquids provided they comply with the construction and siting requirements of Volume 2, Enclosure 5, and Volumes 3, 4, and 5, respectively, for HD 1.1. ECMs must be sited for a minimum of 100 lbs [45.4 kg] of HD 1.1 items using Tables V3.E3.T4. and V3.E3.T6.

Table V5.E4.T~~5~~7. QD Criteria for Energetic Liquid Oxidizer (Excluding LO_2) Storage in Detached Buildings or Tanks[a, b]

NFPA Oxidizer Class[c]	Quantity	IBD/PTRD/ILD/ Aboveground IMD
	(lbs)	(ft)
	[kg]	*[m]*
2	up to 600,000	50
	up to 227,154	*15.2*
3	up to 400,000	75
	up to 181,436	*22.9*
4[d, e, f]	≤ 50	75
	≤ 22.7	*15.2*
	70	76
	31.8	*23.1*
	100	79
	45.4	*24.1*
	150	84
	68.0	*25.7*
	200	89
	90.7	*27.2*
	300	98
	136.1	*29.9*
	500	114
	226.8	*34.8*
	700	128
	317.5	*39.0*
	1,000	147
	453.6	*44.7*
	1,500	175
	680.4	*53.2*
	2,000	200
	907.2	*60.9*
	3,000	246
	1,360.8	*74.9*
	5,000	328
	2,268.0	*100.0*
	7,000	404
	3,175.1	*123.0*
	10,000	510
	4,535.9	*155.4*

Table V5.E4.T~~5~~*7*. QD Criteria for Energetic Liquid Oxidizer (Excluding LO_2) Storage in Detached Buildings or Tanks,[a, b] Continued

NFPA Oxidizer Class[c]	Quantity	IBD/PTRD/ILD/ Aboveground IMD
	(lbs)	(ft)
	[kg]	*[m]*
4[d, e, f]	15,000	592
	6,803.9	*180.4*
	20,000	651
	9,071.8	*198.5*
	30,000	746
	13,607.7	*227.3*
	50,000	884
	22,679.5	*269.5*
	70,000	989
	31,751.3	*301.5*
	100,000	1,114
	45,359.0	*339.5*
	150,000	1,275
	68,038.5	*388.6*
	200,000	1,404
	90,718.0	*427.8*
	300,000	1,607
	136,077.0	*489.7*
	500,000	1,905
	226,795.0	*580.6*

a	QD requirements do not apply to storage of NFPA Class 2 and 3 oxidizers (see Reference (g)) in approved fixed tanks.
b	Other requirements for interior storage configuration, building construction, diking, container materials, facility venting, etc. also apply. Refer to Reference (g) for further guidance on oxidizer storage and fire protection.
c	Refer to Reference (g) for definition and explanation of NFPA classification of oxidizers.
d	Multiple tanks containing NFPA Class 4 oxidizers may be located at distances less than those specified in this table; however, if the tanks are not separated from each other by 10 percent of the distance specified for the largest tank, then the total contents of all tanks shall be used to calculate distances to other exposures.
e	The following equations may be used to determine distance/weights for other quantities:
	English EQNs (Quantity (W) in lbs, distance in ft; ln is natural logarithm, exp [x] is e^x)
	$W \le 10,000$ lbs: Distance $= 149.3 * W^{(-0.41+0.059*\ln(W))}$ EQN V5.E4.T~~5~~*7*-1
	$W > 10,000$ lbs: Distance $= 24 * W^{1/3}$ EQN V5.E4.T~~5~~*7*-2

Table V5.E4.T~~5~~*7*. QD Criteria for Energetic Liquid Oxidizer (Excluding LO_2) Storage in Detached Buildings or Tanks,[a, b] Continued

e	English EQNs (Quantity (W) in lbs, distance in ft; ln is natural logarithm, exp [x] is e^x) Distance > 75 ft: W = exp[-313.18 + 206.53*(ln(Distance)) – 49.968*$(ln(Distance))^2$ + 5.5354*$(ln(Distance))^3$ – 0.2119*$(ln(Distance))^4$] EQN V5.E4.T~~5~~7-3 *Metric EQNs (Quantity (W) in kg, distance in m; ln is natural logarithm, exp [x] is e^x)* *W ≤ 4,535.9 kg: Distance = 34.2*$W^{(-0.317+0.059*ln(W))}$ EQN V5.E4.T~~5~~7-4* *W > 4,535.9 kg: Distance = 9.52*$W^{1/3}$ EQN V5.E4.T~~5~~7-5* *Distance > 22.9 m: W = exp[-130.32 + 108.79*(ln(Distance)) – 32.587*$(ln(Distance))^2$ + 4.3313*$(ln(Distance))^3$ – 0.21111*$(ln(Distance))^4$] EQN V5.E4.T~~5~~7-6*
f	Reference (g) requires sprinkler protection to be provided for storage of greater than 2,000 lbs [907.2 kg] of NFPA Class 4 oxidizers inside of a building.

Table V5.E4.T~~6~~*8*. QD Criteria for LO_2 Storage in Detached Buildings or Tanks[a, b]

Quantity	IBD/PTRD (ft) *[m]*	ILD/Aboveground IMD (ft) *[m]*
Unlimited[c]	100 *30.5*	100[d] *30.5[d]*

a	Per Reference (l), distances do not apply where a protective structure having an NFPA fire resistance rating of at least 2 hours interrupts the line of sight between the oxygen system and the exposure. Refer to Reference (e) and NFPA 50 (Reference (m)) for further guidance.
b	Additional guidelines relating to equipment assembly and installation, facility design (diking), and other fire protection issues also apply. Refer to Reference (e) and Reference (m) for further guidance.
c	QD is independent of oxygen quantity.
d	Minimum ILD/IMD distance between adjacent compatible energetic liquids storage is 50 ft [15.2 m].

Table V5.E4.T~~7~~*9*. QD Criteria for LH_2 and Bulk Quantities of Hydrazines[a]

Propellant Weight (W)	IBD/PTRD		ILD/Aboveground IMD[f, g]
	Unprotected[b, c]	Protected[d, e]	
(lbs)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*
≤ 100	600	80	30
≤ 45.4	*182.9*	*24.4*	*9.1*
150	600	90	34
68.0	*182.9*	*27.4*	*10.3*
200	600	100	37
90.7	*182.9*	*30.4*	*11.2*
300	600	113	42
136.1	*182.9*	*34.4*	*12.7*
500	600	130	49
226.8	*182.9*	*39.5*	*14.6*
700	600	141	53
317.5	*182.9*	*42.9*	*15.9*
1,000	600	153	57
453.6	*182.9*	*46.5*	*17.2*
1,500	600	166	62
680.4	*182.9*	*50.7*	*19.0*
2,000	600	176	66
907.2	*182.9*	*53.7*	*19.9*
3,000	600	191	72
1,360.8	*182.9*	*58.2*	*21.5*
5,000	600	211	79
2,268.0	*182.9*	*64.1*	*23.7*
7,000	600	224	84
3,175.1	*182.9*	*68.3*	*25.3*
10,000	603	239	90
4,535.9	*183.9*	*72.9*	*27.0*
15,000	691	258	97
6,803.9	*210.5*	*78.5*	*29.0*
20,000	760	272	102
9,071.8	*231.7*	*82.7*	*30.6*
30,000	870	292	110
13,607.7	*265.2*	*89.0*	*32.9*
50,000	1,032	321	120
22,679.5	*314.5*	*97.6*	*36.1*
70,000	1,154	341	128
31,751.3	*351.8*	*103.8*	*38.4*
100,000	1,300	364	136
45,359.0	*396.2*	*110.7*	*41.0*

Table V5.E4.T~~7~~*9*. QD Criteria for LH_2 and Bulk Quantities of Hydrazines,[a] Continued

Propellant Weight (W)	IBD/PTRD		ILD/Aboveground IMD[f, g]
	Unprotected[b, c]	Protected[d, e]	
(lbs)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*
150,000	1,488	391	147
68,038.5	*453.6*	*119.1*	*44.1*
200,000	1,637	412	155
90,718.0	*499.2*	*125.5*	*46.4*
300,000	1,800	444	166
136,077.0	*548.6*	*135.1*	*50.0*
500,000	1,800	487	183
226,795.0	*548.6*	*148.2*	*54.8*
700,000	1,800	518	194
317,513.0	*548.6*	*157.6*	*58.3*
1,000,000[h]	1,800	552	207
453,590.0[h]	*548.6*	*168.1*	*62.2*
1,500,000[h]	1,800	594	223
680,385.0[h]	*548.6*	*180.8*	*67.8*
2,000,000[h]	1,800	626	235
907,180.0[h]	*548.6*	*190.4*	*70.5*
3,000,000[h]	1,800	673	252
1,360,770.0[h]	*548.6*	*204.7*	*75.8*
5,000,000[h]	1,800	737	276
2,267,950.0[h]	*548.6*	*224.2*	*83.0*
7,000,000[h]	1,800	782	293
3,175,130.0[h]	*548.6*	*237.9*	*88.0*
10,000,000[h]	1,800	832	312
4,535,900.0[h]	*548.6*	*253.3*	*93.7*

a	Positive measures shall be taken to prevent mixing of hydrogen or hydrazines and adjacent oxidizers in the event of a leak or spill.
b	Distances are necessary to provide reasonable protection from fragments of tanks or equipment that are expected to be thrown in event of a vapor phase explosion.
c	English EQNs (W in lbs, Distance in ft) $W \leq 10,000$ lbs: Unprotected Distance = 600 ft $10,000 < W \leq 265,000$ lbs: Unprotected Distance = $28 * W^{1/3}$ EQN V5.E4.T~~7~~*9*-1 $W > 265,000$ lbs: Unprotected Distance = 1,800 ft 603 ft $\leq$ Unprotected Distance < 1,798 ft: $W = (\text{Unprotected Distance}/28)^3$ EQN V5.E4.T~~7~~*9*-2

Table V5.E4.T~~7~~9. QD Criteria for LH_2 and Bulk Quantities of Hydrazines,[a] Continued

	Metric EQNs (W in kg, Distance in m) *W ≤ 4,535.9 kg:* — *Unprotected Distance = 182.9 m* *4,535.9 kg <W ≤ 120,201.4 kg:* — *Unprotected Distance = 11.11*W$^{1/3}$* — *EQN V5.E4.T~~7~~9-3* *W > 120,201.4 kg:* — *Unprotected Distance = 548.6 m* *183.9 m ≤ Unprotected Distance < 548.2 m:* — *W = (Unprotected Distance/11.11)^3* — *EQN V5.E4.T~~7~~9-4*
d	The term "protected" means that protection from fragments is provided by terrain, effective barricades, nets, or other physical means.
e	Distances are based on the recommended IBD given in U.S. Department of the Interior, Bureau of Mines Report 5707 (Reference (n)), and extrapolation of the 2 calories/square centimeter data on the 1 percent water vapor curve.
	English EQNs (W in lbs, Distance in ft; ln is natural logarithm, exp [x] is e^x) W ≤ 100 lbs: — Protected Distance = 80 ft 100 lbs <W: — Protected Distance = -154.1 + 72.89*[ln(W)] – 6.675*[ln(W)]^2 + 0.369*[ln(W)]^3 — EQN V5.E4.T~~7~~9-5 80 ft ≤ Protected Distance: — W = exp [311.367 – 215.761*(ln(protected distance)) + 55.1828*(ln(protected distance))^2 – 6.1099*(ln(protected distance))^3 + 0.25343*(ln(protected distance))^4] — EQN V5.E4.T~~7~~9-6
	Metric EQNs (W in kg, Distance in m; ln is natural logarithm, exp [x] is e^x) *W ≤ 45.4 kg:* — *Protected Distance = 24.4 m* *45.4 kg <W:* — *Protected Distance = -30.62 + 19.211*[ln(W)] –1.7678*[ln(W)]^2 + 0.1124*[ln(W)]^3* — *EQN V5.E4.T~~7~~9-7* *24.4 m ≤ Protected Distance:* — *W = exp [122.38 – 108.8094*(ln(protected distance)) + 35.5517*(ln(protected distance))^2 – 4.9055*(ln(protected distance))^3 + 0.25343*(ln(protected distance))^4]* — *EQN V5.E4.T~~7~~9-8*
f	ILD/aboveground IMD distances in this column apply for adjacent compatible (ELCG LB or LC) storage; for adjacent incompatible (other ELCG) storage, use IBD distances shown in previous columns. ECMs may be used to their physical capacity for storing hydrogen provided they comply with the construction and siting requirements of Volume 2, Enclosure 5, and Volumes 3, 4, and 5, respectively for HD 1.1. ECMs must be sited for a minimum of 100 lbs [45.4 kg] of HD 1.1 items using Tables V3.E3.T4. and V3.E3.T6.
g	Distances are 37.5 percent of "protected" column.
h	Extrapolations above 1,000,000 lbs [453,590 kg] extend well outside data included in Reference (n) from which the original QD tables were derived; however, they are supported by independent calculations and knowledge of like phenomena.

V5.E4.6. QD STANDARDS. Since many energetic liquids are not classified as UN Class 1 explosives, conventional QD storage criteria do not generally apply to these materials. At the same time, the (non-Class 1) UN transportation hazard classifications for many energetic liquids appear to be inappropriate and/or inadequate for application to storage safety (based on available accident and test data). For example, hydrazine has a UN hazard classification of 8 (corrosive), while it also is subject to dangerous fire and explosive behavior. Thus, the implementation of QD criteria for energetic liquids is based on an independent determination of the predominant hazard presented by the material in the storage environment. The following standards are applicable to energetic liquids used for propulsion or operation of missiles, rockets, and other related devices.

V5.E4.6.1. Tables V5.E4.T~~1~~*3*., V5.E4.T~~4~~*6*., V5.E4.T~~5~~*7*., V5.E4.T~~6~~*8*., and V5.E4.T~~7~~*9*. provide minimum distance requirements for storage of bulk quantities, and in some cases, pressure vessels and other commercial packagings of energetic liquids. In general, the minimum distance required by the material requiring the greatest distance shall separate storage of different energetic liquids. In addition, positive measures shall be taken to control the flow of energetic liquids in the event of a leak or spill, in order to prevent possible fire propagation or accumulation of flammable liquids near other storage, and/or to prevent mixing of incompatible energetic liquids (except for specific hazardous locations as identified in paragraph V5.E4.5.6.). Equivalent explosive weights apply for some materials as indicated in Tables V5.E4.T~~1~~*3*. and V5.E4.T~~3~~*5*. Fragment hazards govern for some materials in certain packaging configurations. For the more conventional fuels and oxidizers, and also where minimum blast and/or fragment criteria are not required due to low confinement packaging, QD standards are adopted from OSHA and NFPA guidelines to account for normal fire protection principles.

V5.E4.6.2. For specific hazardous locations as defined in paragraph V5.E4.5.6., equivalent explosive weights may apply. If so, consult Tables V5.E4.T~~1~~*3*. and V5.E4.T~~3~~*5*. with the combined energetic liquids weight subject to mixing and use distances found in Table V3.E3.T1. or V3.E3.T5. Enter the equivalent explosive weight in Table V3.E3.T1. or V3.E3.T5. QD standards for other conditions and equivalent explosive weights for any combination not contained in Table V5.E4.T~~1~~*3*. or V5.E4.T~~3~~*5*. shall be determined by the controlling DoD Component.

V5.E4.7. CONTAMINATED ENERGETIC LIQUIDS

V5.E4.7.1. Caution shall be exercised in the storage and handling of contaminated energetic liquids. Such contamination may increase the degree of hazard associated with the energetic liquids.

V5.E4.7.2. Energetic liquids known to be contaminated or in a suspect condition shall be isolated and provided separate storage from all other energetic liquids pending laboratory analysis for verification of contamination and disposition requirements, if any.

ENCLOSURE 5

UNDERGROUND STORAGE OF AE

V5.E5.1. GENERAL

V5.E5.1.1. This enclosure provides QD standards for underground storage (e.g., natural caverns and below grade, excavated chambers) and storage facilities providing the overpressure confinement effects typically encountered in underground storage.

V5.E5.1.2. These criteria are only applicable when the minimum distance from the perimeter of a storage chamber to an exterior surface exceeds $0.25W^{1/3}$ [$0.10Q^{1/3}$]. (This minimum distance normally, but not always, equals the thickness of the earth cover.)

V5.E5.1.3. Use aboveground siting criteria when minimum distance criteria of paragraph V5.E5.1.2. cannot be met.

V5.E5.1.4. This enclosure addresses explosives safety criteria both with and without rupture of the earth cover.

V5.E5.1.5. QD siting requirements of this enclosure may be determined from the applicable equations or by interpolating between the table and figure entries.

V5.E5.1.6. Expected ground shock, debris, and airblast hazards from an accidental explosion in an underground storage facility depend on several variables, including the local geology and site-specific parameters. These parameters vary significantly from facility to facility. Siting distances other than those listed may be used when validated by approved experimental or analytical results showing equivalent protection to that required.

V5.E5.2. EXTERNAL QD DETERMINATIONS

V5.E5.2.1. QD Dependence on HD. (See section V1.E7.2. to determine the explosive weight for mixed HDs.)

V5.E5.2.1.1. HD 1.1. Distances shall be determined from the total quantity of HD 1.1 in the individual chambers, unless the total quantity is subdivided to prevent rapid communication of an incident from one subdivision to another. Connected chambers containing HD 1.1 shall be treated as a single chamber site, unless explosion communication is prevented by adequate subdivision or chamber separation.

V5.E5.2.1.2. HD 1.2. Except for primary fragments from openings to underground storage, external explosives safety hazards are not normally significant for HD 1.2. The safe distance for both IBD and PTRD is the IBD in Tables V3.E3.T9. through V3.E3.T13. for locations within 10 degrees to either side of the centerline of a tunnel opening. These criteria apply only to those detonations that occur where a line-of-sight path exists from the detonation point to any portion of the tunnel opening. For detonations that do not have a line-of-sight path to the tunnel opening, or where the line-of-sight path is intercepted by a barricade beyond the opening, the IBD and PTRD are zero.

V5.E5.2.1.3. HD 1.3. HD 1.3 shall be treated as HD 1.1 with an explosive equivalence of 100 percent for QD purposes. Any significant and validated differences in energy release per unit mass of HD 1.3 from that of TNT may be considered.

V5.E5.2.1.4. HD 1.4. External explosives safety hazards are not normally significant for HD 1.4. Accordingly, external QD criteria do not apply for HD 1.4.

V5.E5.2.1.5. HD 1.5. HD 1.5 shall be treated as HD 1.1 with an explosive equivalence of 100 percent for QD purposes.

V5.E5.2.1.6. HD 1.6. HD 1.6 shall be treated as HD 1.2.

V5.E5.2.2. QD Reference Points

V5.E5.2.2.1. Distances determined by blast or debris exiting from tunnel openings is the minimum distance measured from the openings to the nearest wall or point of the location to be protected. Use extended centerlines of the openings as reference lines for directional effects.

V5.E5.2.2.2. Distances determined for airblast and debris produced by breaching of the chamber cover shall be the minimum distance from an exterior point defined by chamber cover thickness, on the ground surface above the storage chamber to the nearest wall or point of the location to be protected. For configurations where the storage chambers are not distinct from the access tunnel**,** the distance is the shortest distance from the tunnel roof directly above the charge to the surface.

V5.E5.2.2.3. Distances determined for ground shock shall be the minimum distance measured from the nearest wall of the storage chamber to the location to be protected.

V5.E5.2.3. IBD. IBD for HD 1.1 shall be the largest of those distances required for protection against ground shock, debris, and airblast as defined subparagraphs V5.E5.2.3.1. through V5.E5.2.3.3.6.

V5.E5.2.3.1. Ground Shock

V5.E5.2.3.1.1. For protection of residential buildings against significant structural damage by ground shock, the maximum particle velocity induced in the ground at the building site shall not exceed:

V5.E5.2.3.1.1.1. 2.4 inches per second (ips) [6.1 centimeters (cm)/second (s)] in soil.

V5.E5.2.3.1.1.2. 4.5 ips [11.4 cm/s] in weak rock.

V5.E5.2.3.1.1.3. 9.0 ips [22.9 cm/s] in strong rock.

V5.E5.2.3.1.2. The values in subparagraphs V5.E5.2.3.1.1.1. through V5.E5.2.3.1.1.3. form the basis for the following equations (D_{ig} is in ft and W is the explosive quantity in lbs [D_{ig} is in m and Q is the explosive quantity in kg]):

V5.E5.2.3.1.2.1. For sitings in moderately strong to strong rock with chamber loading densities (NEWQD/chamber internal volume), w, of 3.0 lb/cubic feet (ft^3) [48.1 kg/cubic meters (m^3)] or less, the IBD for ground shock, D_{ig}, is as shown in Figure V5.E5.F1.

Figure V5.E5.F1. D_{ig}, Moderately Strong to Strong Rock ($w \le 3.0$ lb/ft^3 [48.1 kg/m^3])

$D_{ig} = 5.8*W^{1/3}$	English EQN V5.E5.2-1
$D_{ig} = 2.30*Q^{1/3}$	*Metric EQN V5.E5.2-2*

V5.E5.2.3.1.2.2. For higher loading densities in chambers sited in moderately strong to strong rock, and for all loading densities in other materials, the IBD for ground shock, D_{ig}, is as shown in Figure V5.E5.F2. (See subparagraph V5.E5.2.3.1.2.3. for values of decoupling factor, f_g.)

Figure V5.E5.F2. D_{ig}, Moderately Strong to Strong Rock ($w > 3.0$ lb/ft^3 [48.1 kg/m^3]) and Other Materials

$D_{ig} = 12.5*f_g*W^{4/9}$ (Moderately strong to strong rock)	English EQN V5.E5.2-3
$D_{ig} = 5.41*f_g*Q^{4/9}$ (Moderately strong to strong rock)	*Metric EQN V5.E5.2-4*
$D_{ig} = 11.1*f_g*W^{4/9}$ (Weak rock)	English EQN V5.E5.2-5
$D_{ig} = 4.81*f_g*Q^{4/9}$ (Weak rock)	*Metric EQN V5.E5.2-6*
$D_{ig} = 2.1*f_g*W^{4/9}$ (Soil)	English EQN V5.E5.2-7
$D_{ig} = 0.91*f_g*Q^{4/9}$ (Soil)	*Metric EQN V5.E5.2-8*

V5.E5.2.3.1.2.3. The dimensionless decoupling factor, f_g, depends on chamber loading density, w (lb/ft^3 [kg/m^3]), and is as shown in Figure V5.E5.F3. Values of D_{ig} and D_{ig}/f_g are given in Table V5.E5.T~~1~~*10*.; values of f_g are shown in Table V5.E5.T~~2~~*11*.; alternate values for D_{ig} may be used only when justified by site-specific ground shock data.

Figure V5.E5.F3. Decoupling Factor, f_g

$f_g = 0.267*w^{0.3}$	English EQN V5.E5.2-9
$f_g = 0.11604*w^{0.3}$	*Metric EQN V5.E5.2-10*

V5.E5.2.3.2. Debris. (See section V2.E5.8. for special design considerations.)

V5.E5.2.3.2.1. A minimum IBD of 1,800 ft [548.6 m] for debris throw from an opening shall apply within 10 degrees to either side of the centerline axis of that opening, unless positive means are used to prevent or control the debris throw.

V5.E5.2.3.2.2. The distance D_{id} that is required for protection of inhabited areas against the effects of debris thrown from breaching of the cover material over a detonation depends on the thickness of the cover (C) over the storage chamber. The critical cover thickness, C_c, is defined as $2.5W^{1/3}$ [$1.0Q^{1/3}$].

V5.E5.2.3.2.2.1. When $C_c \geq 2.5W^{1/3}$ [$1.0Q^{1/3}$], debris from a surface breach need not be considered.

V5.E5.2.3.2.2.2. When $C_c < 2.5W^{1/3}$ [$1.0Q^{1/3}$], then the debris distance, D_{id}, shall be calculated using the equations in Figure V5.E5.F4.

Figure V5.E5.F4. D_{id}, $C_c < 2.5W^{1/3}$ [$1.0Q^{1/3}$])

$D_{id} = f_d * f_c * W^{0.41}$	English EQN V5.E5.2-11
$D_{id} = f_d * f_c * Q^{0.41}$	*Metric EQN V5.E5.2-12*

V5.E5.2.3.2.2.3. The dimensionless, decoupling factor, f_d, depends on chamber loading density, w (lb/ft^3 [kg/m^3]), and is as shown in Figure V5.E5.F5.

Figure V5.E5.F5. Decoupling Factor, f_d

$f_d = 0.6 * w^{0.18}$	English EQN V5.E5.2-13
$f_d = 0.3615 * w^{0.18}$	*Metric EQN V5.E5.2-14*

V5.E5.2.3.2.2.4. Values of f_d are shown in Table V5.E5.T~~2~~*11*. The coupling factor, f_c, is related to the type of rock around the storage chamber and the scaled cover thickness, C. Values of f_c are given in Table V5.E5.T~~3~~*12*.

Table V5.E5.T~~1~~*10*. Distances to Protect Against Ground Shock

NEWQD	Soil	Weak Rock	Moderately Strong to Strong Rock	All Rock $w \leq 3$ lb/ft^3 *[$w \leq 48.1$ kg/m^3]*
	D_{ig}/f_g			D_{ig}
(lbs)	(ft)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*	*[m]*
1,000	45	239	269	58
453.6	*13.8*	*72.9*	*82.0*	*17.7*
1,500	54	286	322	66
680.4	*16.5*	*87.3*	*98.2*	*20.2*
2,000	62	325	366	73
907.2	*18.8*	*99.2*	*111.6*	*22.3*
3,000	74	390	439	84
1,361	*22.5*	*118.8*	*133.7*	*25.5*
5,000	93	489	551	99
2,268	*28.2*	*149.1*	*167.7*	*30.2*
7,000	107	568	640	111
3,175	*32.8*	*173.2*	*194.8*	*33.8*
10,000	126	665	749	125
4,536	*38.4*	*345.3*	*228.2*	*38.1*
15,000	151	797	897	143
6,804	*46.0*	*243.0*	*273.3*	*43.6*
20,000	171	906	1,020	157
9,072	*52.2*	*276.1*	*528.4*	*48.0*
30,000	205	1,084	1,221	180
13,608	*62.6*	*330.7*	*371.9*	*54.9*
50,000	257	1,361	1,532	214
22,680	*78.5*	*414.9*	*466.7*	*65.1*
70,000	299	1,580	1,779	239
31,751	*91.2*	*481.9*	*542.0*	*72.8*
100,000	350	1,852	2,085	269
45,359	*106.8*	*564.6*	*635.1*	*82.0*
150,000	419	2,217	2,497	308
68,039	*127.9*	*676.1*	*760.5*	*93.9*
200,000	477	2,520	2,837	339
90,718	*145.4*	*768.4*	*864.2*	*103.3*
300,000	571	3,017	3,398	388
136,077	*174.1*	*920.1*	*1,034.9*	*118.3*
500,000	716	3,786	4,264	460
226,795	*218.4*	*1,154.6*	*1,298.6*	*140.3*

Table V5.E5.T~~1~~*10*. Distances to Protect Against Ground Shock, Continued

NEWQD	Soil	Weak Rock	Moderately Strong to Strong Rock	All Rock $w \leq 3$ lb/ft^3 *[$w \leq 48.1$ kg/m^3]*
	D_{ig}/f_g			D_{ig}
(lbs)	(ft)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*	*[m]*
700,000	832	4,397	4,951	515
317,513	*253.7*	*1,340.8*	*1,508.1*	*156.9*
1,000,000	975	5,152	5,802	580
453,590	*297.2*	*1,571.2*	*1,767.1*	*176.7*

Table V5.E5.T~~2~~*11*. Functions of Loading Density

Loading Density, w (lb/ft^3) *[kg/m^3]*	Ground Shock f_g	Debris f_d
1 *16.0*	0.267	0.600
1.5 *24.0*	0.301	0.645
2 *32.0*	0.328	0.680
3 *48.1*	0.371	0.730
5 *80.1*	0.432	0.800
7 *112.1*	0.481	0.850
10 *160.2*	0.532	0.910
15 *240.3*	0.601	0.977
20 *320.3*	0.655	1.030
30 *480.5*	0.740	1.110
50 *800.9*	0.862	1.210
70 *1,121.2*	0.954	1.290
100 *1,601.7*	1.062	1.370

Table V5.E5.T~~3~~*12*. Debris Dispersal Function

Scaled Earth Cover (C)	Earth Cover Function, f_c	
	Hard Rock[a]	Soft Rock[a]
$(ft/lb^{1/3})$	$(ft/lb^{0.41})$	$(ft/lb^{0.41})$
$[m/kg^{1/3}]$	*$[m/kg^{0.41}]$*	*$[m/kg^{0.41}]$*
0.3	9.51	9.80
0.12	*4.01*	*4.13*
0.4	10.25	10.69
0.16	*4.32*	*4.51*
0.5	10.94	11.52
0.20	*4.61*	*4.85*
0.6	11.49	12.08
0.24	*4.84*	*5.09*
0.7	11.89	12.28
0.28	*5.01*	*5.17*
0.8	12.09	12.09
0.32	*5.10*	*5.10*
0.9	12.11	11.55
0.36	*5.10*	*4.87*
1	11.95	10.72
0.40	*5.04*	*4.52*
1.25	10.91	7.99
0.50	*4.60*	*3.37*
1.5	9.31	5.38
0.60	*3.92*	*2.27*
1.75	7.58	3.68
0.69	*3.20*	*1.55*
2	6.04	2.79
0.79	*2.54*	*1.18*
2.25	4.78	2.13
0.89	*2.01*	*0.90*
2.5	3.76	1.54
0.99	*1.58*	*0.65*

a English EQNs (Scaled earth cover, C in $ft/lb^{1/3}$, f_c in $ft/lb^{0.41}$)

$0.25\ ft/lb^{1/3} < C \leq 2.5\ ft/lb^{1/3}$

Hard Rock:

$$f_c = 8.0178 - 0.1239*C + 27.1578*C^2 - 40.1461*C^3 + 21.9018*C^4 - 5.3529*C^5 + 0.4948*C^6$$ EQN V5.E5.T~~3~~*12*-1

Soft Rock:

$$f_c = 10.8116 - 25.0685*C + 113.9591*C^2 - 168.1092*C^3 + 107.1033*C^4 - 31.5032*C^5 + 3.5251*C^6$$ EQN V5.E5.T~~3~~*12*-2

Table V5.E5.T~~3~~*12*. Debris Dispersal Function, Continued

	Metric EQNs (Scaled earth cover, C in m/kg$^{1/3}$, f_c in m/kg$^{0.41}$) *0.10 m/kg$^{1/3}$ < C < 1.0 m/kg$^{1/3}$* *Hard Rock:* $f_c = 3.3794 - 0.1316*C + 72.7376*C^2 - 271.0478*C^3 + 372.7526*C^4 - 229.651*C^5 + 53.5115*C^6$	*EQN V5.E5.T~~3~~12-3*
	Soft Rock: $f_c = 4.5570 - 26.6351*C + 305.2201*C^2 - 1134.995*C^3 + 1822.82*C^4 - 1351.556*C^5 + 381.2317*C^6$	*EQN V5.E5.T~~3~~12-4*

V5.E5.2.3.3. Airblast. (See section V2.E5.8. for special design considerations.)

V5.E5.2.3.3.1. An explosion in an underground storage chamber may produce external airblast from two sources; the exit of blast from existing openings (tunnel entrances, ventilation shafts, etc.) and the rupture or breach of the chamber cover by the detonation. Required IBD is independently determined for each of these airblast sources, with the maximum IBD used for siting. If the chamber cover thickness is less than C_c given in subparagraph V5.E5.2.3.2., some external airblast will be produced depending on the cover thickness. Use the following to determine IBD for airblast produced by breaching of the chamber cover:

V5.E5.2.3.3.1.1. $C \leq 0.25W^{1/3}$ ft [$0.10Q^{1/3}$ m]: Use IBD for surface burst of bare explosives charge (Table V3.E3.T1., footnote d).

V5.E5.2.3.3.1.2. $0.25W^{1/3} < C \leq 0.50W^{1/3}$ ft [$0.10Q^{1/3} < C \leq 0.20Q^{1/3}$ m]: Use 1/2 of IBD for surface burst of bare explosives charge.

V5.E5.2.3.3.1.3. $0.50W^{1/3} < C \leq 0.75W^{1/3}$ ft [$0.20Q^{1/3} < C \leq 0.30Q^{1/3}$ m]: Use 1/4 of IBD for surface burst of bare explosives charge.

V5.E5.2.3.3.1.4. $0.75W^{1/3}$ ft [$0.30Q^{1/3}$ m] < C: Airblast hazards from blast through the earth cover are negligible relative to ground shock or debris hazards.

V5.E5.2.3.3.2. Overpressure and debris hazards must be determined for each facility opening whose cross-section area is 5 percent or more of that of the largest opening.

V5.E5.2.3.3.2.1. Distance versus overpressure along the centerline axis of a single opening is as shown in Figure V5.E5.F6.

Figure V5.E5.F6. Distance Versus Overpressure Along the Centerline Axis

$R(\theta=0) = 149.3*D_{HYD}*((W/V_E)^{0.5}/P_{SO})^{1/1.4}$ English EQN V5.E5.2-15

$R(\theta=0) = 220.191*D_{HYD}*((W/V_E)^{0.5}/P_{SO})^{1/1.4}$ Metric EQN V5.E5.2-16

where:

- $R(\theta=0)$: Distance from opening (ft) [m] along the centerline axis
- D_{HYD}: Effective hydraulic diameter that controls dynamic flow issuing from the opening (ft) [m] (compute D_{HYD}, using the minimum cross-sectional area of the tunnel that is located within five tunnel diameters of the opening, as $D_{HYD} = 4*A/P$, where A is the area (square feet) [square meter] and P is the perimeter (ft) [m])
- P_{SO}: Overpressure at distance R (psi) [kPa]
- W: MCE in lb [kg]
- $V_{E:}$ Total volume engulfed by the blast wavefront within the tunnel system at the time the wavefront arrives at the point of interest (ft^3) [m^3]

V5.E5.2.3.3.2.2. Distance versus overpressure off the centerline axis of the opening is as shown in Figure V5.E5.F7.

Figure V5.E5.F7. Distance Versus Overpressure Off the Centerline Axis

$R(\theta) = R(\theta=0)/(1 + (\theta/56)^2)^{1/1.4}$ (EQN V5.E5.2-17)

where:

- $R(\theta=0)$: Distance along the centerline axis, and θ is the horizontal angle from the centerline (degrees)

V5.E5.2.3.3.3. English EQN V5.E5.2-15 [Metric EQN V5.E5.2-16] and EQN V5.E5.2-17 show that the distance providing protection from an overpressure exceeding P_{SO} depends on the D_{HYD}, and the angle from the centerline axis for the location of interest. Table V5.E5.T4*13*. gives the ratio of off-axis to on-axis distances.

V5.E5.2.3.3.4. Find required IBD distances for airblast using the appropriate equations discussed in subparagraph V5.E5.2.3.3.1., English EQN V5.E5.2-15 [Metric EQN V5.E5.2-16] and EQN V5.E5.2-17, with the criteria that the total incident overpressure at IBD shall not exceed that shown in Figure V5.E5.F8.

Figure V5.E5.F8. Overpressure at IBD

$P_{SO} = 1.2$ psi	for W ≤ 100,000 lbs	
$P_{SO} = 8.27$ kPa	*for W ≤ 45,359 kg*	
$P_{SO} = 44.57*W^{-0.314}$ psi	for 100,000 <W ≤ 250,000 lbs	English EQN V5.E5.2-18
$P_{SO} = 239.8*W^{-0.314}$ kPa	*for 45,359 < W ≤ 113,397.5 kg*	*Metric EQN V5.E5.2-19*
$P_{SO} = 0.9$ psi	for W > 250,000 lbs	
$P_{SO} = 6.21$ kPa	*for W > 113,397.5 kg*	

V5.E5.2.3.3.5. For the overpressure of subparagraph V5.E5.2.3.3.4., on-axis IBD is as shown in Figure V5.E5.F9.

Figure V5.E5.F9. On-axis IBD

$R(\theta=0) = 131.1*D_{HYD}*(W/V_E)^{1/2.8}$	for W ≤ 100,000 lbs	English EQN V5.E5.2-20
$R(\theta=0) = 48.683*D_{HYD}*(W/V_E)^{1/2.8}$	*for W ≤ 45,359 kg*	*Metric EQN V5.E5.2-21*
$R(\theta=0) = 9.91*D_{HYD}*W^{0.581}/V_E^{0.357}$	for 100,000 < W ≤ 250,000 lbs	English EQN V5.E5.2-22
$R(\theta=0) = 4.395*D_{HYD}*W^{0.581}/V_E^{0.357}$	*for 45,359 < W ≤ 113,397.5 kg*	*Metric EQN V5.E5.2-23*
$R(\theta=0) = 161.0*D_{HYD}*(W/V_E)^{1/2.8}$	for W > 250,000 lbs	English EQN V5.E5.2-24
$R(\theta=0) = 59.787*D_{HYD}*(W/V_E)^{1/2.8}$	*for W > 113,397.5 kg*	*Metric EQN V5.E5.2-25*

V5.E5.2.3.3.6. QD distances for IBD for airblast from openings may be determined from the equations in Figure V5.E5.F9. or from entries in Tables V5.E5.T~~5~~*14*. and V5.E5.T~~6~~*15*.

Table V5.E5.T4*13*. Off-axis Distance Ratios

Angle Off-axis (θ) (degrees)	Distance Ratio[a] (R(θ)/R(θ=0))
0	1.000
5	0.994
10	0.978
15	0.952
20	0.918
25	0.878
30	0.835
35	0.790
40	0.745
45	0.701
50	0.658
55	0.617
60	0.579
65	0.544
70	0.511
75	0.480
80	0.452
85	0.426
90	0.402
100	0.359
110	0.323
120	0.292
130	0.266
140	0.243
150	0.223
160	0.206
170	0.190
180	0.177
a $R(\theta)/R(\theta=0) = [1+(\theta/56)^2]^{(-1/1.4)}$	EQN V5.E5.T4*13*-1

Table V5.E5.T~~5~~*14*. Values for Ratio, $D_{HYD}/V_E^{1/2.8}$

V_E	$D_{HYD}/V_E^{1/2.8}$ (D_{HYD} in ft [m], V_E in ft^3 [m^3])					
(ft^3)	10	15	20	25	30	35
[m^3]	*3.05*	*4.57*	*6.10*	*7.62*	*9.14*	*10.67*
1,000	0.8483	1.2725	1.6967	2.1209	2.5450	2.9692
28.32	*3.0298*	*4.5447*	*6.0596*	*7.5745*	*9.0894*	*10.6043*
1,500	0.7340	1.1010	1.4680	1.8349	2.2019	2.5689
42.48	*2.6213*	*3.9320*	*5.2427*	*6.5533*	*7.8640*	*9.1747*
2,000	0.6623	0.9935	1.3246	1.6558	1.9869	2.3181
56.63	*2.3654*	*3.5481*	*4.7308*	*5.9135*	*7.0962*	*8.2788*
3,000	0.5730	0.8595	1.1460	1.4326	1.7191	2.0056
84.95	*2.0465*	*3.0698*	*4.0930*	*5.1163*	*6.1395*	*7.1628*
5,000	0.4775	0.7162	0.9549	1.1937	1.4324	1.6711
141.58	*1.7052*	*2.5578*	*3.4104*	*4.2630*	*5.1157*	*5.9683*
7,000	0.4234	0.6351	0.8468	1.0585	1.2702	1.4819
198.22	*1.5121*	*2.2682*	*3.0243*	*3.7803*	*4.5364*	*5.2925*
10,000	0.3728	0.5591	0.7455	0.9319	1.1183	1.3047
283.17	*1.3313*	*1.9969*	*2.6626*	*3.3282*	*3.9938*	*4.6595*
15,000	0.3225	0.4838	0.6450	0.8063	0.9675	1.1288
424.75	*1.1518*	*1.7277*	*2.3036*	*2.8795*	*3.4554*	*4.0313*
20,000	0.2910	0.4365	0.5820	0.7275	0.8731	1.0186
566.34	*1.0393*	*1.5590*	*2.0787*	*2.5984*	*3.1180*	*3.6377*
30,000	0.2518	0.3777	0.5036	0.6295	0.7554	0.8812
849.51	*0.8992*	*1.3488*	*1.7985*	*2.2481*	*2.6977*	*3.1473*
50,000	0.2098	0.3147	0.4196	0.5245	0.6294	0.7343
1,415.84	*0.7493*	*1.1239*	*1.4985*	*1.8732*	*2.2478*	*2.6224*
70,000	0.1860	0.2791	0.3721	0.4651	0.5581	0.6511
1,982.18	*0.6644*	*0.9966*	*1.3289*	*1.6611*	*1.9933*	*2.3255*
100,000	0.1638	0.2457	0.3276	0.4095	0.4914	0.5733
2,831.68	*0.5850*	*0.8774*	*1.1699*	*1.4624*	*1.7549*	*2.0474*
150,000	0.1417	0.2126	0.2834	0.3543	0.4251	0.4960
4,247.53	*0.5061*	*0.7592*	*1.0122*	*1.2653*	*1.5183*	*1.7714*
200,000	0.1279	0.1918	0.2557	0.3197	0.3836	0.4476
5,663.37	*0.4567*	*0.6850*	*0.9134*	*1.1417*	*1.3701*	*1.5984*
300,000	0.1106	0.1660	0.2213	0.2766	0.3319	0.3872
8,495.05	*0.3951*	*0.5927*	*0.7902*	*0.9878*	*1.1854*	*1.3829*
500,000	0.0922	0.1383	0.1844	0.2305	0.2766	0.3226
14,158.42	*0.3292*	*0.4938*	*0.6585*	*0.8231*	*0.9877*	*1.1523*
700,000	0.0817	0.1226	0.1635	0.2044	0.2452	0.2861
19,821.79	*0.2919*	*0.4379*	*0.5839*	*0.7299*	*0.8758*	*1.0218*

Table V5.E5.T~~5~~*14*. Values for Ratio, $D_{HYD}/V_E^{1/2.8}$, Continued

V_E	$D_{HYD}/V_E^{1/2.8}$ (D_{HYD} in ft [m], V_E in ft^3 [m^3])					
(ft^3)	10	15	20	25	30	35
[m^3]	*3.05*	*4.57*	*6.10*	*7.62*	*9.14*	*10.67*
1,000,000	0.0720	0.1080	0.1439	0.1799	0.2159	0.2519
28,316.84	*0.2570*	*0.3855*	*0.5141*	*0.6426*	*0.7711*	*0.8996*
1,500,000	0.0623	0.0934	0.1245	0.1557	0.1868	0.2179
42,475.27	*0.2224*	*0.3336*	*0.4448*	*0.5559*	*0.6671*	*0.7783*
2,000,000	0.0562	0.0843	0.1124	0.1405	0.1686	0.1967
56,633.69	*0.2007*	*0.3010*	*0.4013*	*0.5017*	*0.6020*	*0.7023*
3,000,000	0.0486	0.0729	0.0972	0.1215	0.1458	0.1701
84,950.53	*0.1736*	*0.2604*	*0.3472*	*0.4340*	*0.5208*	*0.6076*
5,000,000	0.0405	0.0608	0.0810	0.1013	0.1215	0.1418
141,584.22	*0.1447*	*0.2170*	*0.2893*	*0.3617*	*0.4340*	*0.5063*

Table V5.E5.T~~6~~*15*. Values for Ratio, $R(\theta)/(D_{HYD}/V_E^{1/2.8})$, Without Mitigating Devices[a, b]

NEWQD	$R(\theta)/(D_{HYD}/V_E^{1/2.8})$[c]					
	Horizontal Angle from Centerline Axis (Degrees)					
(lbs) *[kg]*	0	30	60	90	120	180
1,000	1,545	1,290	895	621	452	273
453.6	*432.8*	*361.4*	*250.7*	*173.9*	*126.6*	*76.4*
1,500	1,786	1,491	1,034	718	522	315
680.4	*500.2*	*417.7*	*289.7*	*201.0*	*146.3*	*88.3*
2,000	1,979	1,653	1,146	795	579	349
907.2	*554.3*	*462.9*	*321.1*	*222.8*	*162.1*	*97.9*
3,000	2,287	1,910	1,325	919	669	404
1,361	*640.7*	*535.0*	*371.1*	*257.5*	*187.4*	*113.1*
5,000	2,745	2,292	1,590	1,103	803	485
2,268	*768.9*	*642.1*	*445.4*	*309.0*	*224.9*	*135.8*
7,000	3,096	2,585	1,793	1,244	905	547
3,175	*867.1*	*724.1*	*502.2*	*348.5*	*253.6*	*153.1*
10,000	3,516	2,936	2,037	1,413	1,028	621
4,536	*984.9*	*822.5*	*570.5*	*395.8*	*288.0*	*173.9*
15,000	4,064	3,394	2,354	1,633	1,188	718
6,804	*1,138.4*	*950.6*	*659.4*	*457.5*	*332.9*	*201.0*
20,000	4,504	3,761	2,609	1,810	1,317	795
9,072	*1,261.5*	*1,053.5*	*730.7*	*507.0*	*368.9*	*222.8*
30,000	5,206	4,347	3,015	2,092	1,522	919
13,608	*1,458.1*	*1,217.6*	*844.6*	*586.0*	*426.4*	*257.5*
50,000	6,247	5,217	3,619	2,511	1,827	1,103
22,680	*1,749.9*	*1,461.3*	*1,013.6*	*703.3*	*511.7*	*309.0*
70,000	7,045	5,883	4,081	2,831	2,060	1,244
31,751	*1,973.4*	*1,647.9*	*1,143.0*	*793.1*	*577.1*	*348.5*
100,000	8,002	6,683	4,635	3,216	2,340	1,413
45,359	*2,241.5*	*1,871.8*	*1,298.3*	*900.8*	*655.5*	*395.8*
150,000	9,249	7,724	5,357	3,717	2,705	1,633
68,039	*2,837.8*	*2,369.8*	*1,643.7*	*1,140.5*	*829.9*	*501.1*
200,000	11,977	10,002	6,937	4,813	3,502	2,115
90,718	*3,354.9*	*2,801.6*	*1,943.2*	*1,348.3*	*981.1*	*592.4*
300,000	14,550	12,150	8,427	5,848	4,255	2,569
136,077	*4,071.9*	*3,400.4*	*2,358.5*	*1,636.5*	*1,190.8*	*719.0*
500,000	17,462	14,582	10,114	7,018	5,106	3,083
226,795	*4,886.9*	*4,081.0*	*2,830.5*	*1,964.0*	*1,429.1*	*862.9*
700,000	19,691	16,444	11,406	7,914	5,759	3,477
317,513	*5,510.9*	*4,602.1*	*3,192.0*	*2,214.8*	*1,611.6*	*973.1*
1,000,000	22,367	18,678	12,955	8,989	6,541	3,949
453,590	*6,259.5*	*5,227.3*	*3,625.6*	*2,515.7*	*1,830.5*	*1,105.3*

Table V5.E5.T~~6~~*15*. Values for Ratio, $R(\theta)/(D_{HYD}/V_E^{1/2.8})$, Without Mitigating Devices,[a, b] Continued

a	IBD for airblast from openings, without airblast mitigating devices, is determined by multiplying the ratio $R(\theta)/(D_{HYD}/V_E^{1/2.8})$ in this table (for a given NEWQD and horizontal angle from the centerline axis) by the ratio $D_{HYD}/V_E^{1/2.8}$ (as determined from Table V5.E5.T~~5~~*14*. for a given D_{HYD} and V_E).
b	For IBD reductions with mitigating devices, see paragraph V2.E5.8.3.
c	English EQNs (See English EQN V5.E5.2-15 for variable units) $R(\theta)/(D_{HYD}/V_E^{1/2.8}) = 149.3*\{W^{0.5}/[P_{SO}(1+(\theta/56)^2)]\}^{1/1.4}$ EQN V5.E5.T~~6~~*15*-1 where: $P_{SO} = 1.2$ psi $W \leq 100{,}000$ lbs $P_{SO} = 44.57*W^{-0.314}$ psi $100{,}000 < W \leq 250{,}000$ lbs EQN V5.E5.T~~6~~*15*-2 $P_{SO} = 0.9$ psi $W > 250{,}000$ lbs *Metric EQNs (See Metric EQN V5.E5.2-16 for variable units)* $R(\theta)/(D_{HYD}/V_E^{1/2.8}) = 149.3*\{W^{0.5}/[P_{SO}(1+(\theta/56)^2)]\}^{1/1.4}$ *EQN V5.E5.T~~6~~15-3* *where:* $P_{SO} = 8.27$ kPa $W \leq 45{,}359$ kg $P_{SO} = 239.8*W^{-0.314}$ kPa $45{,}359 < W \leq 113{,}397.5$ kg *EQN V5.E5.T~~6~~15-4* $P_{SO} = 6.21$ kPa $W > 113{,}397.5$ kg

V5.E5.2.4. PTRD. PTRD for HD 1.1 is 60 percent of IBD for ground shock, debris, or airblast, whichever is greater.

V5.E5.2.5. ILD. ILD for HD 1.1 is the greater of the following:

V5.E5.2.5.1. Ground Shock. Does not apply.

V5.E5.2.5.2. Debris. For locations within 10 degrees of either side of the centerline of a tunnel opening, site intraline facilities at IBD (see paragraph V5.E5.2.3.). QD criteria for debris are not applicable to locations outside 10 degrees of either side of the centerline axis of an opening.

V5.E5.2.5.3 Airblast. Overpressure at barricaded and unbarricaded ILD shall not exceed 12 psi [82.7 kPa] and 3.5 psi [24.1 kPa], respectively.

V5.E5.2.6. Distance to Aboveground Magazines (AGMs) for HD 1.1

V5.E5.2.6.1. Ground Shock. Does not apply.

V5.E5.2.6.2. Debris. For locations within 10 degrees of either side of the centerline of an opening, site aboveground magazines at IBD (see paragraph V5.E5.2.3.). QD criteria for debris from rupture of the chamber cover are not applicable.

V5.E5.2.6.3. Airblast. Overpressure at barricaded and unbarricaded AGM distance shall not exceed 27 and 8 psi [186.2 and 55.2 kPa], respectively.

V5.E5.2.7. Distance to ECMs for HD 1.1

V5.E5.2.7.1. Ground Shock. Does not apply.

V5.E5.2.7.2. Debris. QD criteria for debris from rupture of the chamber cover are not applicable. QD criteria for debris exiting from an opening are not applicable, if the magazine is oriented for side-on or rear-on exposures to the debris; however, the criteria do apply for frontal exposures. Site ECM that are located within 10 degrees of either side of the centerline of an opening and oriented for a frontal debris exposure at IBD (see paragraph V5.E5.2.3.).

V5.E5.2.7.3. Airblast. These sitings are based on the strength of the ECM's headwall and doors that are under consideration, and the overpressures calculated using English EQN V5.E5.2-15 [Metric EQN V5.E5.2-16], and EQN V5.E5.2-17.

V5.E5.2.7.3.1. Head-on Exposure Criteria

V5.E5.2.7.3.1.1. 7-Bar ECM: Site where p_{SO} is $\leq$ 29 psi [200 kPa].

V5.E5.2.7.3.1.2. 3-Bar ECM: Site where p_{SO} is $\leq$ 16 psi [110.3 kPa].

V5.E5.2.7.3.1.3. Undefined ECM: Site where p_{SO} is $\leq$ 3.5 psi [24.1 kPa].

V5.E5.2.7.3.2. Other Than Head-on Exposure. Site all ECMs where p_{SO} is $\leq$ 45 psi [310.3 kPa].

GLOSSARY

ABBREVIATIONS AND ACRONYMS

AE	ammunition and explosives
AGM	aboveground magazine
ASME	American Society of Mechanical Engineers
°C	degrees Celsius
CG	compatibility group
CFR	Code of Federal Regulations
ClF_3	chlorine trifluoride
ClF_5	chlorine pentafluoride
cm	centimeter
DDESB	Department of Defense Explosives Safety Board
DoT	Department of Transportation
DUSD(I&E)	Deputy Under Secretary of Defense for Installations and Environment
ECM	earth-covered magazine
ELCG	energetic liquid compatibility group
EOD	explosive ordnance disposal
EQN	equation
°F	degrees Fahrenheit
ft	foot or feet
ft^3	cubic feet
H_2O_2	hydrogen peroxide
HAN	hydroxyl ammonium nitrate
HD	hazard division
IBD	inhabited building distance
ILD	intraline distance
IMD	intermagazine distance
ips	inches per second
IRFNA	inhibited red fuming nitric acid
JP	jet propellant
kg	kilogram
kPa	kilopascal
LH_2	liquid hydrogen
LO_2	liquid oxygen

lbs	pounds
m	meter
m^3	cubic meter
MCE	maximum credible event
MFD	maximum fragment distance
mm	millimeter
MMH	monomethylhydrazine
MON	mixed oxides of nitrogen
N_2H_4	hydrazine
N_2O_4	nitrogen tetroxide
NEW	net explosive weight
NEWQD	net explosive weight for quantity-distance
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PBAN	polybutadiene-acrylic acid-acrolyonitrile
PES	potential explosion site
psi	pounds per square inch
PTRD	public traffic route distance
QD	quantity-distance
RP	rocket propellant
s	second
TNT	trinitrotoluene
UDMH	unsymmetrical dimethylhydrazine
UN	United Nations
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics