DDESB-KT 2 November 2000

MEMORANDUM FOR ARMY BOARD MEMBER, COLONEL JAMES C. KING
NAVY BOARD MEMBER, CAPTAIN MIKE HERB
AIR FORCE BOARD MEMBER, MR. PAUL PRICE
MARINE CORPS BOARD MEMBER, MR. JERRY MAZZA

SUBJECT: Approved Change to DoD 6055.9-STD, Chapter 9, Section C9.6 – Energetic Liquids

References: (a) DDESB-KT Memorandum dated 21 June 2000, Subject: Vote by Correspondence on Proposed Revision to DoD 6055.9-STD Chapter 9 C9.6 – Energetic Liquids

(b) PM Ammo, MARCORSYSCOM Memorandum 1000 AM-EES dated 27 June 2000, same subject as above

(c) HQ AFSC/SEW Memorandum dated 30 June 2000, Subject: Vote by Correspondence on Proposed Revision to DoD 6055.9-STD Chapter 9 C9.6 – Energetic Liquids (Your Memorandum, dated 21 June 2000)

(d) CNO Memorandum 8020 Ser N411C1/OU591221 dated 25 July 2000, Subject: Modifications to Proposed Changes to DoD Standard 6055.9-STD Chapter 9 C9.6 – Energetic Liquids

(e) DALO-AMA (DDESB-KT/21 June 2000) 1st Col J.C. King 227-8455 dated 04 October 2000, Subject: Vote by Correspondence on Proposed Revision to DoD 6055.9-STD Chapter 9 C9.6 – Energetic Liquids—Action Memorandum

(f) DDESB-KT E-mail (Ward, Dr. Jerry M. – DDESB Secretariat) dated Friday, 13 October 2000 7:52 AM, Subject: FW: Energetic Liquids change to the STD

The subject change to DoD 6055.9-STD submitted by reference (a) was approved by references (b) through (e) as modified by editorial changes proposed by references (c) and (e) and discussed in reference (f).

The approved change to DoD 6055.9-STD is attached.

The two editorial modifications to the change referenced above are summarized as follows:

a. The editorial comment from reference (c) resulted in a change to the last sentence in paragraph C9.6.5.6.

- Change -- "For example, if a new liquid oxygen pressure vessel configuration is hazard classified: "(10)2.2(LA)", a minimum distance of 1000 feet would apply, rather than the minimum distance specified in Table C9.T17."

- To read -- "For example, if a new liquid oxygen pressure vessel configuration is hazard classified: "(10)2.2(LA)," a minimum distance of 1000 feet would apply for inhabited building distance and public traffic route distance, rather than the minimum distance specified in Table C9.T17."

b. The editorial comment from reference (e) as modified by the Secretariat resulted in a note to be added to the end of paragraph C9.6.1.

"C9.6.1.1. This section applies to the storage of energetic liquids (listed in Table C9.T17.) in all types of containers, to include rocket and missile tankage. Laboratory Quantities of energetic liquids will be stored and handled as prescribed by the controlling DoD Component. (Note: The required Q-D are only based on the energetic liquids' energetic reaction (blast overpressure and container fragmentation). These Q-D requirements do not consider the toxicity or potential down-wind hazard. Therefore, Q-D may not be the only factor that needs to be considered when selecting a location for storage and operations of energetic liquids.)"

This approval with attachments will be posted on the Department of Defense Explosives Safety Board (DDESB) webpage: http://www.hqda.army.mil/ddesb/esb.html.

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/s/Daniel T. Tompkins
DANIEL T. TOMPKINS
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USADAC/SMAAC-ES (Mr. Johnnie Cook)
NOSSA/N711 (Mr. Richard T. Adams)

APPROVED CHANGE[1]

C9.6. Energetic Liquids

C9.6.1. Scope and application

C9.6.1.1. This section applies to the storage of energetic liquids (listed in Table C9.T17.) in all types of containers, including rocket and missile tankage. Laboratory Quantities shall be stored and handled as prescribed by the controlling Department of Defense (DoD) Component. (Note: The required quantity-distance (Q-D) are only based on the energetic liquids' energetic reaction (blast overpressure and container fragmentation). These Q-D requirements do not consider the toxicity or potential down-wind hazard. Therefore, Q-D may not be the only factor that needs to be considered when selecting a location for storage and operations of energetic liquids.)

C9.6.1.2. Exclusion. This section 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 ammunition items.

C9.6.2. Concept

C9.6.2.1. These Q-D standards were developed on the premise that the controlling DoD Component will 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 (such as nitrogen padding, blanketing, and tank cooling) are used when required.

C9.6.2.2. When additional hazards associated with ammunition or explosives are involved, the safety distances prescribed in other sections of this Chapter shall be applied, as appropriate.

C9.6.2.3. These standards are based upon the estimated credible damage resulting from an incident, without considering probabilities or frequency of occurrence.

C9.6.3. Determination of energetic liquids quantity

C9.6.3.1. 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.

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[1] 10/13/00

C9.6.3.2. When the quantities of energetic liquids are given in gallons, the conversion factors given in Table C9.T18. may be used to determine the quantity in pounds.

C9.6.4. Measurement of separation distances

C9.6.4.1. Separation distances shall be measured from the closest hazard source (containers, buildings, segment, or positive cutoff point in piping, whichever is controlling).

C9.6.4.2 When buildings containing a small number of cylinders or drums are present or when quantities of energetic liquids are subdivided effectively, distances may be measured from the nearest container or controlling subdivision.

C9.6.5. Hazard Classification of Energetic Liquids. Replacement of the old Hazard Group (I - IV)/Compatibility Group (A - F) classification scheme (referenced in previous editions of DoD 6055.9-STD) for liquid propellants with United Nations (UN) hazard classification nomenclature as defined in Recommendations on the Transport of Dangerous Goods (Reference (d)) has been approved. Thus, the main hazard classification designator for energetic liquids is either Class 1 (explosives), Class 2 (compressed or liquefied gases), Class 3 (flammable liquids), Class 4 (flammable solids, self-reactive materials), Class 5 (oxidizers), Class 6 (toxic/infectious substances), Class 8 (corrosive), or Class 9 (miscellaneous). 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 ammunition components. Since two energetic liquids might each be compatible with certain explosive ammunition stores, but incompatible with each other, a two-part compatibility group designation is assigned to an energetic liquid.

C9.6.5.1. The first element is the standard storage and transportation Compatibility Group (CG) designation. The alpha designations are the same as the CG designations for UN Hazard Class 1, with the same definitions. However, for storage and handling on DoD facilities, a CG may also be assigned to an energetic liquid in a Hazard Class other than Class 1. The absence of a CG indicates incompatibility with solid explosives.

C9.6.5.2. The second element is a new Energetic Liquid Compatibility Group (ELCG) designation. The ELCG applies to mixed storage of energetic liquids or ammunition components containing energetic liquids. The ELCG is specified in parentheses as the last element of the hazard classification. The ELCG designations and definitions are:

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, nitrogen tetroxide and mixed oxides of nitrogen (MON), inhibited red fuming nitric acid (IRFNA), liquid oxygen (LO_2), hydrogen peroxide (H_2O_2), and gels, slurries, or emulsions of the above.

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 kerosene's and strained ring ramjet fuels; liquid hydrogen (LH_2); and gels, slurries, or emulsions of the above.

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, hydrazine's and other amines; and gels, slurries, or emulsions of the above.

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 ethylene and propylene oxides, and boranes.

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 hydroxyl ammonium nitrate (HAN), halogen fluorides (ClF_3 and ClF_5) and fluorine, and gels, slurries, or emulsions of the above.

C9.6.5.3. Different energetic liquids in the same ELCG may be stored together with the exception of dissimilar liquids of Group LE. Mixed storage is prohibited between energetic liquids of different ELCG designations, with one exception: liquids of groups LB and LC should not be stored together if possible, especially for storage areas containing primarily materials of group LB; however, mixed storage is permitted if circumstances require. This compatibility scheme is reflected in the hazard classification for the hydroxyl ammonium nitrate based liquid gun propellant XM-46:

1.3C(LE)

This hazard classification reflects CG "C" which indicates the propellant can be stored in the same magazine with CG "C" solid propellants, and since CG "C" can be mixed in storage with CG "D" (reference Table C3.T1., DoD 6055.9-STD), CG "D" high explosive projectiles could also be present. On the other hand, hydrocarbon fuel such as JP-10 would not be permitted in this storage scenario, because its ELCG (LB) indicates incompatibility with the liquid gun propellant (LE).

C9.6.5.4. Complete DoD hazard classification assignments for current energetic liquids are shown in Table C9.T17.

C9.6.5.5. 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 in accordance with the process described in Department of Defense Ammunition and Explosives Hazard Classification Procedures (reference (e)).

C9.6.5.6. The Q-D criteria described below include separation requirements for bulk quantities, and in some cases, minimum distances for pressure vessels and other commercial packagings. If the hazards of a particular new packaging configuration are not adequately addressed by the separations prescribed in the following tables, a different minimum distance may be assigned during the hazard classification process, and indicated parenthetically, in hundreds of feet, as the first element of the hazard classification. For example, if a new liquid oxygen pressure vessel configuration is hazard classified: For example, if a new liquid oxygen pressure vessel configuration is hazard classified: "(10)2.2(LA)," a minimum distance of 1,000 feet would apply for inhabited building distance and public traffic route distance, rather than the minimum distance specified in Table C9.T17.

C9.6.6. Specific hazardous locations. Aside from the fact that the energetic liquids differ from each other, as explained for the above groups, the predominant hazard of the individual energetic liquids can vary depending upon the location of the energetic liquid storage and the operations involved. In order of decreasing hazard, these conditions are:

C9.6.6.1. Launch pads. These involve research, development, testing, space exploration, and operational launchings, as well as defense- or combat-type operations that may well be one-time events. 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. Launch vehicle tankage is involved and explosive equivalents must be used (Table C9.T19.) with the combined energetic liquids weight subject to mixing except as provided in paragraph C9.6.6.4., below.

C9.6.6.2. Static test stands. Although these can involve experimental operations, the units remain static and are subject to better control than launch vehicles. Except when run tankage for fuel and oxidizer are mounted one above the other, it may be possible to separate the tankage to reduce the hazard over that for the rocket or missile on the launch pad. Explosive equivalents shall be used (Table C9.T19.) 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 the following criteria:

C9.6.6.2.1. All tanks are American Society of Mechanical Engineers (ASME) certified (reference (ab)) and designed and maintained in accordance with section VIII division 1 or division 2 of the ASME Code.

C9.6.6.2.2. For cryogenic propellants, all tanks are constructed with double wall jacketing.

C9.6.6.2.3. The configuration of the test stand is such that the thrust measuring structure load cell (heavily built structure) is between the engine and the run tanks so as to prevent fragments from puncturing the tanks in case of engine malfunction.

C9.6.6.2.4. The fuel line contains two remotely operated valves to shut off energetic liquids flow in the event of a malfunction.

C9.6.6.3. Ready storage. This 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 explosive equivalents shall be used (Table C9.T19.) 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 a mishap 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 C9.T17., C9.T20., C9.T21., C9.T22., and C9.T23.).

C9.6.6.4. Cold-flow test operations. Fire and fragment hazards govern (Tables C9.T17., C9.T20., C9.T21., C9.T22., and C9.T23.) 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, explosive equivalents (Table C9.T19.) shall be used with the combined energetic liquids weight.

C9.6.6.5. Bulk storage. This 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 C9.T17., C9.T20., C9.T21., C9.T22., and C9.T23.) except in special cases as indicated in Tables C9.T17. and C9.T19.

C9.6.6.6. Rest storage. This 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 C9.T17., C9.T20., C9.T21., C9.T22., and C9.T23.) except in special cases as indicated in Tables C9.T17. and C9.T19. The transporter becomes a part of that storage to which it is connected during energetic liquids transfer.

C9.6.6.7. Run tankage (operating tankage). This 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. HE equivalents shall be used (Table C9.T19.) for quantities of such materials subject to mixing unless provisions of paragraphs C9.6.6.2.1. through C9.6.6.2.4. are satisfied.

C9.6.6.8. Pipelines. A 25-foot 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 C9.T17., C9.T21., C9.T22., and C9.T23. apply, as appropriate.

C9.6.7. Q-D standards. Since many energetic liquids are not classified as UN Class 1 explosives, conventional Q-D 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 Q-D 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.

C9.6.7.1. Tables C9.T17., C9.T20., C9.T21., C9.T22., and C9.T23. provide minimum distance requirements for storage of bulk quantities, and in some cases, pressure vessels and other commercial packagings of energetic liquids. In general, storage of different energetic liquids shall be separated by the minimum distance required by the material requiring the greatest distance. 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 Sections C9.6.6.1., C9.6.6.2., C9.6.6.3., and C9.6.6.7. above). Explosives equivalence applies for some materials as indicated in Tables C9.T17. and C9.T19. 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, Q-D standards are adopted from Occupational Safety and Health Administration (OSHA) and/or National Fire Protection Association (NFPA) guidelines to account for normal fire protection principles.

C9.6.7.2. For specific hazardous locations as defined in Paragraph C9.6.6. above, explosives equivalency may apply. If so, consult Tables C9.T17. and C9.T19. with the combined energetic liquids weight subject to mixing and use distances found in Tables C9.T1. or C9.T3. Enter weight of explosives equivalent in Tables C9.T1. or C9.T3. Q-D standards for

other conditions and explosive equivalents for any combination not contained in Tables C9.T17. or C9.T19. shall be determined by the controlling DoD Component.

C9.6.8. Contaminated energetic liquids

C9.6.8.1. 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.

C9.6.8.2. 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.

Table C9.T17. Hazard Classifications and Minimum Q-D for Energetic Liquids

Energetic Liquid	OSHA/NFPA Fuel[1] or Oxidizer[2] Class	DoD Storage Hazard Class	Minimum Q-D[3]
Hydrogen Peroxide, > 60%	3 or 4[4]	5.1 (LA)	800[5] ft or Table C9.T21.
IRFNA	3	8 (LA)	Table C9.T21.
Nitrogen Tetroxide/MON	2	2.3 (LA)	Table C9.T21.
Liquid Oxygen	N/A	2.2 (LA)	Table C9.T22.
RP-1	II	3 (LB)	Table C9.T20.
JP-10	II	3J (LB)	Table C9.T20.
Liquid Hydrogen	N/A	2.1 (LB)	Table C9.T23.
Hydrazine, > 64%	II	8 (LC)	800[5] or 300[6] ft or Note 7
Aerozine 50 (50%N_2H_4/50% UDMH)	I B	6.1 (LC)	800[5] or 300[6] ft or Note 7
Methylhydrazine	I B	6.1 (LC)	800[5] or 300[6] ft or Note 7
UDMH	I B	6.1 (LC)	Table C9.T20.
Ethylene Oxide	I A	2.3 (LD)	H/D 1.1 Q-D[8] with TNT Equiv = 100%, or 800[5] or 300[6] ft
Propylene Oxide	I A	3 (LD)	H/D 1.1 Q-D[8] with TNT Equiv. = 100%, or 800[5] or 300[6] ft
Nitromethane	I C	3 (LE)	Use H/D 1.1 Q-D with TNT Equiv. = 100%[9] or Table C9.T20.
Hydroxylammonium Nitrate (HAN)	2	8 (LE)	800[5] ft or Table C9.T21.
XM-46 (HAN Monopropellant)	N/A	1.3C (LE)	800[5] ft or use H/D 1.3 Q-D
Otto Fuel II	III B	9 (LE)	Use H/D 1.1 Q-D[10] with TNT Equiv. = 100%, or 150[11] ft, or Table C9.T20.
Halogen Fluorides (ClF_3/ClF_5)	4	2.3 (LE)	Table C9.T21.
Liquid Fluorine	4	2.3 (LE)	Table C9.T21.
Nitrogen Trifluoride	4	2.2 (LE)	Table C9.T21.
Nitrate esters (NG, TMETN, DEGDN, TEGDN, BTTN)	N/A	1.1 D (LE)	Use H/D 1.1 Q-D with TNT Equiv. = 100%

Notes:

1. Flammable or combustible liquid classification index based on flash point and boiling point versus criteria as specified in 29 CFR 1910.106 (OSHA) (Reference (ac)) and NFPA 30 Flammable and Combustible Liquids Code (Reference (j)). Primary descriptor is a Roman numeral, possibly with an additional letter.

2. NFPA oxidizer classification index as described in NFPA 430 Code for the Storage of Liquid and Solid Oxidizers (Reference (ad)). Descriptor is an ordinary number.

3. 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 C9.T20. through C9.T22.). For flammable energetic liquids and liquid oxidizers where only minimum blast or fragment distances are specified, applicable OSHA and/or NFPA guidance referenced in Table C9.T20. and C9.T21., respectively, should also be used.

4. Hydrogen peroxide solutions of concentration greater than 91% are NFPA Class 4 oxidizers.

5. 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).

6. Should be used as a default value, unless otherwise hazard classified, when the material is packaged in small (non-bulk) shipping containers (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) 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/PTR Protected Distance column of Table C9.T23.

7. For large ready, bulk, or rest storage tanks (as defined in Paragraphs C9.6.6.3., C9.6.6.5., and C9.6.6.6.), use Table C9.T23.

8. Where there is a reasonable risk of vapor cloud explosion of large quantities (for example, in bulk tank storage).

9. Technical grade nitromethane in unit quantities of 55 gallons or less in DOT approved containers listed in 49CFR173.202 (reference (b)) may be stored as flammable liquids (Table C9.T20.) provided the following apply:

    a. Packages are stored only one tier high.
    b. Packages are protected from direct rays of sun.
    c. Maximum storage life of two years, unless storage life tests indicate product continues to meet purchase specification. Such tests are to be repeated at one-year intervals thereafter.

10. For underwater static test stands, when operated at hydrostatic pressure above 50 psig, or for propellant tanks or other vessels having burst pressures of greater than 100 psig without acceptable pressure relief devices (unless otherwise hazard classified). For underwater test stands, the TNT equivalence (MCE) should include the total propellant weight in all pumps and plumbing, as well as the weight of propellant 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).

11. 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) without acceptable pressure relief devices.

Table C9.T18. Factors to Use When Converting Gallons of Energetic liquids into Pounds. [1]

Item	Pounds per gallon	At Temperature °F
Chlorine Pentafluoride	14.8	77
Chlorine trifluoride	15.1	77
Ethyl alcohol	6.6	68
Ethylene oxide	7.4	51
Fluorine (liquid)	12.6	-306
HAN Monopropellants	11.9	77
HAN solution (25 to 95 wt %)	10.0 to 13.4	68
Hydrazine	8.4	68
Hydrogen peroxide (90 percent)	11.6	77
JP-10	7.8	60
Liquid hydrogen	0.59	-423
Liquid oxygen	9.5	-297
Monomethyl hydrazine	7.3	68
Nitrogen tetroxide	12.1	68
Nitrogen trifluoride	12.8	-200
Nitromethane	9.5	68
Otto Fuel II	10.3	77
Propylene oxide	7.2	32
Red fuming nitric acid (IRFNA)	12.9	77
RP-1	6.8	68
UDMH	6.6	68
UDMH/hydrazine	7.5	77

1. Conversion of quantities of energetic liquids from gallons to pounds: Pounds of energetic liquids = gallons X density of energetic liquids in pounds per gallon.

Table C9.T19. Energetic Liquid Explosive Equivalents [1,2, 3, 4, 5]

ENERGETIC LIQUIDS	TNT EQUIVALENCE	
	STATIC TEST STANDS	RANGE LAUNCH
LO_2/LH_2	See Note 6	See Note 6
LO_2/LH_2 + LO_2/RP-1	Sum of (see Note 6 for LO_2/LH_2) + (10% for LO_2/RP-1)	Sum of (see Note 6 for LO_2/LH_2) + (20% for LO_2/RP-1)
LO_2/RP-1	10 %	20% up to 500,000 pounds plus 10% over 500,000 pounds
IRFNA/UDMH [7]	10%	10%
N_2O_4/UDMH + N_2H_4 [7]	5%	10%
N_2O_4 liquid oxidizer + PBAN solid fuel (Hybrid propellants)	15% [8]	15% [8]
Nitromethane (alone or in combination)	100%	100%
Otto Fuel II	100% [9]	
Ethylene Oxide	100% [10]	100% [10]

Notes:

1. The percentage factors given in the table are to be used to determine equivalencies 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 equivalencies.

2. The explosives equivalent 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 C9.T1. and C9.T3.

3. These equivalencies apply also for the following substitutions:

   a. Alcohol's or other hydrocarbons for RP-1.

   b. H_2O_2 for LO_2 (only when LO_2 is in combination with RP-1 or equivalent hydrocarbon fuel).

   c. MMH for N_2H_4, UDMH, or combinations of the two.

4. For quantities of energetic liquids up to but not over the equivalent of 100 pounds of explosives, 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.

5. 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.

6. For siting launch vehicles and static test stands, explosive equivalent weight is the larger of:

   (1) The weight equal to $8W^{2/3}$ where W 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 mishaps. When it can be reliably demonstrated that the maximum credible event involves a lesser quantity of energetic liquids subject to involvement in a single reaction, the lesser quantity may be used in determining the explosive equivalent yield. When siting is based on a quantity less than the total energetic liquids present, the maximum credible event and associated explosive yield analysis must be documented in an approved site plan (Chapter 5, section 6.).

7. These are hypergolic combinations.

8. Explosive equivalency of the hybrid rocket system N_2O_4 liquid oxidizer combined with PBAN solid fuel was evaluated in 200-pound tests (reference (ae)). These tests indicate a maximum TNT equivalency of 15% for an explosive donor accident scenario, 5% for a high velocity impact scenario, and less than 0.01% (negligible) for static mixing (tower drop) failures.

9. See Note 10 of Table C9.T17.

10. See Note 8 of Table C9.T17.

Table C9.T20. Q-D Criteria for OSHA/NFPA Class I – III Flammable and Combustible Energetic Liquids Storage in Detached Buildings or Tanks[1,2]

Quantity	IBD/PTR (ft)	ILD/Aboveground Intermagazine Distance (IMD) (ft)
Unlimited[3]	50 [4,5]	Note 6

Notes:

1. 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 29 CFR 1910.106 (reference (ac)) and NFPA 30 Flammable and Combustible Liquids Code (reference (j)) for further guidance on liquid storage and fire protection.

2. Refer to 29 CFR 1910.106 (reference (ac)) and NFPA 30 Flammable and Combustible Liquids Code (reference (j)) for definition and explanation of OSHA/NFPA classification of flammable and combustible liquids.

3. Guidelines on interior storage configuration (for container storage inside buildings) also apply with the following exceptions: (a) If the storage building is located at least 100 ft from any exposed building (under the direct jurisdiction of a fire protection organization) or property line; or (b) If the storage building is located at least 200 ft from any exposed building (not under the direct jurisdiction of a fire protection organization) or property line; or (c) for combustible liquids that will not exhibit sustained burning in bulk form, e.g. Otto Fuel II, as determined through ASTM D 92 Standard Test Method for Flash and Fire Points by Cleveland Open Cup or comparable testing. Refer to 29 CFR 1910.106 (reference (ac)) and NFPA 30 Flammable and Combustible Liquids Code (reference (j)) for further guidance on liquid storage and fire protection.

4. For container storage inside of a building, IBD/PTR distances may be less than 50 ft (to a minimum of 10 ft) if the storage building is constructed of fire resistive exterior walls having an NFPA Fire Resistance rating of two hours or more according to NFPA 251 (reference (af)).

5. For large tank storage, Q-D may be 25 feet for tank capacities up to 100,000 gallons, and 37.5 feet for capacities between 100,001 and 500,000 gallons.

6. For flammable liquids container storage inside of a building, ILD/Aboveground Intermagazine Distance (IMD) is 50 feet (accept as in Note 4), or for adjacent incompatible oxidizer storage, distances specified for energetic liquid oxidizers (Table C9.T21) or oxygen (Table C9.T22). 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 Note 5 for adjacent container storage inside of a building; or (2) for adjacent incompatible oxidizer storage, distances specified for energetic liquid oxidizers (Table C9.T21) or oxygen (Table C9.T22) . Earth-covered magazines may be used to their physical capacity for storing flammable energetic liquids provided they comply with the construction and siting requirements of Chapter 5 and Chapter 9, respectively for Hazard Division 1.1. The earth-covered magazines must be sited for a minimum of 100 lbs of Hazard Division 1.1 items using Tables C9.T4. and C9.T5.

Table C9.T21. Q-D Criteria for Energetic Liquid Oxidizer (excluding Liquid Oxygen) Storage in Detached Buildings or Tanks[1, 2]

NFPA Oxidizer Class[3]	Quantity (lbs)	IBD/PTR/ILD/Aboveground IMD (ft)
2	up to 600,000	50
3	up to 400,000	75
4[4,5]	≤ 50	75
	70	76
	100	79
	150	84
	200	89
	300	98
	500	114
	700	128
	1,000	147
	1,500	175
	2,000 [6]	200
	3,000	246
	5,000	328
	7,000	404
	10,000	510
	15,000	592
	20,000	651
	30,000	746
	50,000	884
	70,000	989
	100,000	1114
	150,000	1275
	200,000	1404
	300,000	1607
	500,000	1905

Notes:

1. Quantity-distance requirements do not apply to storage of NFPA Class 2 and 3 oxidizers (reference (ad)) in approved fixed tanks.

2. Other requirements for interior storage configuration, building construction, diking, container materials, facility venting, etc. also apply. Refer to NFPA 430 Code for the Storage of Liquid and Solid Oxidizers (reference (ad)) for further guidance on oxidizer storage and fire protection.

3. Refer to NFPA 430 Code for the Storage of Liquid and Solid Oxidizers (reference (ad)) for definition and explanation of NFPA classification of oxidizers.

4. Multiple tanks containing NFPA Class 4 oxidizers may be located at distances less than those specified in the 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.

5. Notes for NFPA Oxidizer Class 4:

   (a) $W \leq 10{,}000$ lbs, Distance $= 149.3*W^{(-0.41+0.059*\ln(W))}$

   (b) $W > 10{,}000$ lbs, Distance $= 24*W^{1/3}$

   (c) Use of equations given in (a) and (b) to determine distances for other quantities (W) is allowed.

6. NFPA 430 requires sprinkler protection to be provided for storage of greater than 2,000 pounds of NFPA Class 4 oxidizers inside of a building (reference (ad)).

Table C9.T22. Q-D Criteria for Liquid Oxygen[1, 2]

	IBD/PTR (ft)	ILD/Aboveground IMD (ft)
Unlimited[3]	100	100 [4]

Notes:

1. Distances do not apply where a protective structure having an NFPA fire resistance rating of at least two hours according to NFPA 251 (reference (af)) interrupts the line of sight between the oxygen system and the exposure. Refer to 29 CFR 1910.104 (reference (ac)) and NFPA 50 Standard for Bulk Oxygen Systems at Consumer Sites (reference (ag)) for further guidance.

2. Additional guidelines relating to equipment assembly and installation, facility design (diking), and other fire protection issues also apply. Refer to 29 CFR 1910.104 (reference (ac)) and NFPA 50 Standard for Bulk Oxygen Systems at Consumer Sites (reference (ag)) for further guidance.

3. Q-D is independent of oxygen quantity.

4. Minimum ILD/IMD distance between adjacent compatible energetic liquids storage is 50 feet.

Table C9.T23. Q-D Criteria for Liquid Hydrogen and Bulk Quantities of Hydrazines[1]

Propellant Weight (pounds)	IBD/PTR		ILD/Aboveground IMD (ft) [6,7]
	Unprotected (ft)[2, 3]	Protected (ft) [4,5]	
0--100	600	80	30
200	600	100	37
300	600	113	42
400	600	122	46
500	600	130	49
600	600	136	51
700	600	141	53
800	600	145	54
900	600	149	56
1,000	600	153	57
2,000	600	176	66
3,000	600	191	72
4,000	600	202	76
5,000	600	211	79
6,000	600	218	82
7,000	600	224	84
8,000	600	230	86
9,000	600	235	88
10,000	603	239	90
15,000	691	258	97
20,000	760	272	102
25,000	819	283	106
30,000	870	292	110
35,000	916	301	113
40,000	958	308	116
45,000	996	315	118
50,000	1,032	321	120
60,000	1,096	332	124
70,000	1,154	341	128
80,000	1,206	349	131
90,000	1,255	357	134
100,000	1,300	364	136
125,000	1,400	379	142
150,000	1,488	391	147
175,000	1,566	403	151
200,000	1,637	412	155
250,000	1,764	429	161

300,000	1,800	444	166
350,000	1,800	457	171
400,000	1,800	468	175
450,000	1,800	478	179
500,000	1,800	487	183
600,000	1,800	503	189
700,000	1,800	518	194
800,000	1,800	530	199
900,000	1,800	542	203
1,000,000[8]	1,800	552	207
2,000,000	1,800	626	235
3,000,000	1,800	673	252
4,000,000	1,800	708	266
5,000,000	1,800	737	276
6,000,000	1,800	761	285
7,000,000	1,800	782	293
8,000,000	1,800	800	300
9,000,000	1,800	817	306
10,000,000	1,800	832	312

Notes:

1. Positive measures shall be taken to prevent mixing of hydrogen or hydrazine's and adjacent oxidizers in the event of a leak or spill.

2. 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.

3. 10,000 <W ≤ 265,000 lbs, Unprotected Distance = $28*W^{1/3}$. Also W = $(\text{Unprotected Distance}/28)^3$.

4. The term "protected" means that protection from fragments is provided by terrain, effective barricades, nets, or other physical means.

5. Distances are based on the recommended inhabited building distances given in the Bureau of Mines, Department of the Interior Report No. 5707, dated 1961 (reference (ah)), and extrapolation thereof (2 cal/cm^2 on 1 percent water vapor curve). Curve fit of the data yields Protected Distance = $-154.1 + 72.89*[\ln(W)] - 6.675*[\ln(W)]^2 + 0.369*[\ln(W)]^3$.

   Also W = $\exp[311.367 - 215.761*[\ln(\text{protected distance})] + 55.1828*[\ln(\text{protected distance})]^2 - 6.1099*[\ln(\text{protected distance})]^3 + 0.25343*[\ln(\text{protected distance})]^4]$.

6. 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. Earth-covered magazines may be used to their physical capacity for storing hydrogen provided they comply with the construction and siting requirements of Chapter 5 and Chapter 9, respectively for Hazard Division 1.1. The earth-covered magazines must be sited for a minimum of 100 lbs of Hazard Division 1.1 items using Tables C9.T4 and C9.T5.

7. Distances are an average of 37.5 percent of “protected” column.

8. Extrapolations above 1,000,000 pounds extend well outside data included in reference (ah) from which the original Q-D tables were derived; however, they are supported by independent calculations and knowledge of like phenomena.

References

(ab) American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels, Division 1/Division 2, American Society of Mechanical Engineers, New York, NY, 1995

(ac) Title 29 Code of Federal Regulations, Part 1910, Subpart H – Hazardous Materials, current edition

(ad) National Fire Protection Association (NFPA) 430, "Code for the Storage of Liquid and Solid Oxidizers," National Fire Protection Association, Batterymarch Park, Quincy Massachusetts, 1995

(ae) Wilton, C., "Investigation of the Explosive Potential of the Hybrid Propellant Combinations N_2O_4/PBAN and CTF/PBAN," AFRPL-TR-67-124, 1967).

(af) National Fire Protection Association (NFPA) 251, "Standard Methods of Tests of Fire Endurance of Building Construction and Materials," National Fire Protection Association, Batterymarch Park, Quincy Massachusetts, 1995

(ag) National Fire Protection Association (NFPA) 50, "Standard for Bulk Oxygen Systems at Consumer Sites," National Fire Protection Association, Batterymarch Park, Quincy Massachusetts, 1996

(ah) Zabetakis, M. G. and Burgess, D. S., Research on the Hazards Associated With the Production and Handling of Liquid Hydrogen, US Department of the Interior, Bureau of Mines Report 5707, 1961.

Definitions

Energetic Liquid – A liquid, slurry, or gel, consisting of or containing an explosive, oxidizer, fuel, or combination of the above, that may undergo, contribute to, or cause rapid exothermic decomposition, deflagration, or detonation.

Hybrid Propellants – A propellant charge utilizing a combination of physically separated solid and liquid (or gelled) substances as fuel and oxidizer.