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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

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(6) ORIGIN AND SUBSEQUENT MODIFICATIONS OF EXPLOSIVE SAFETY QUANTITY-DISTANCE (ESQD) STANDARDS FOR MASS DETONATING EXPLOSIVES WITH SPECIAL REFERENCE TO NAVAL VESSELS.

VOLUME I.

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By

(10) David Freund

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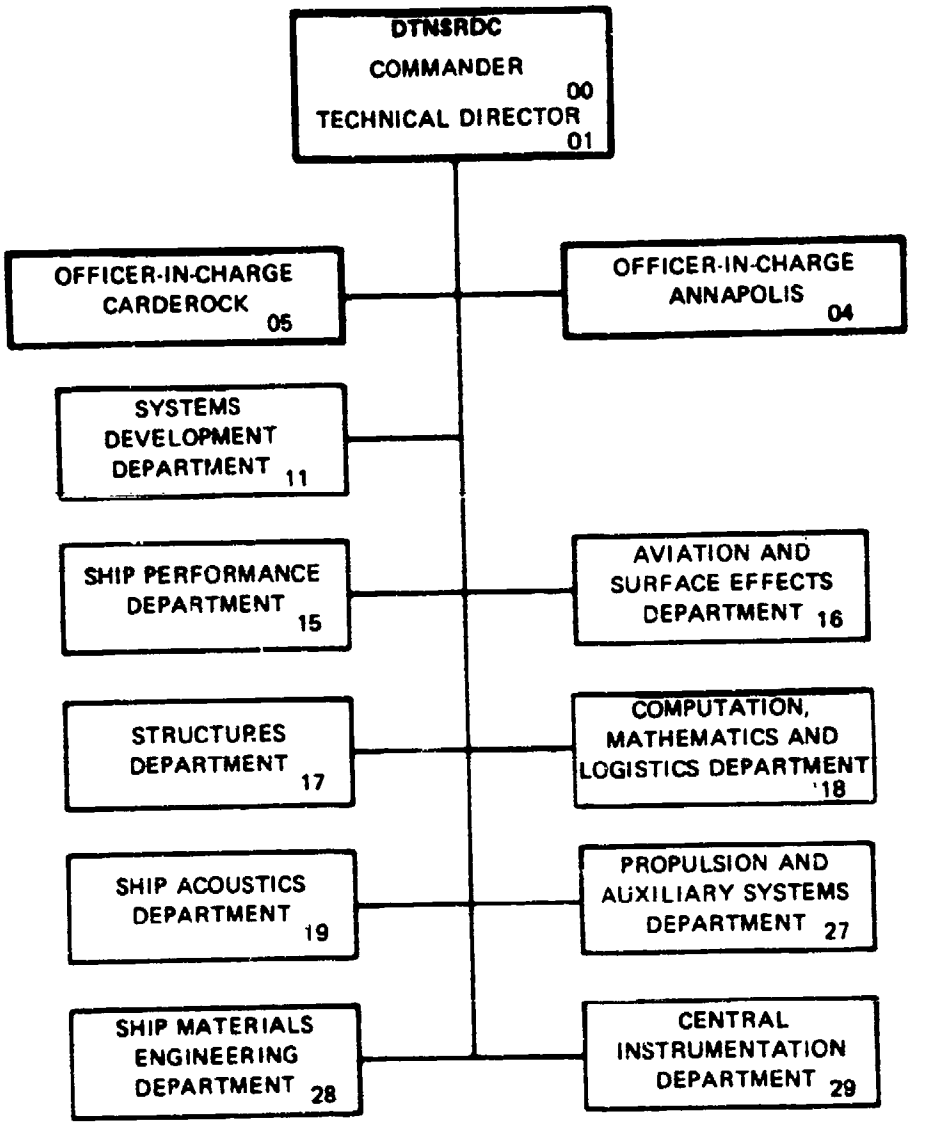

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From: Commander, David W. Taylor Naval Ship R&D Center
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Subj: Report on the Basis of DOD Explosives Safety Standards; forwarding of

Ref: (a) Chairman DDESB ltr DDESB-KT of 28 Nov 1977
(b) FONECON between J. Petes (NSWC WR-10) and F. J. Fisch (DTNSRDC 1740.2) of 1 May 1978

Encl: (1) "Origin and Subsequent Modifications of Explosive Safety Quantity-Distance (ESQD) Standards for Mass Detonating Explosives, With Special Reference to Naval Vessels, Volume I"
(2) "Origin and Subsequent Modifications of Explosive Safety Quantity-Distance (ESQD) Standards for Mass Detonating Explosives, With Special Reference to Naval Vessels, Volume II - Appendices"

1. Enclosures (1) and (2) present the results of a study to determine the history of the development of the Department of Defense Explosive Safety Quantity-Distance Standards for mass detonating explosives from their origins to those currently in use. This study was conducted by the David W. Taylor Naval Ship R&D Center for the Naval Surface Weapons Center in support of the Navy Explosive Safety Improvement Program.

2. This report is being forwarded at the request of the Chairman of the Department of Defense Explosive Safety Board (reference (a)), with the concurrence of the study sponsor (reference (b)).

W.W. MURRAY
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Prepared with the cooperation of the Department of Defense Explosives Safety Board during a 6-month temporary assignment at their offices, wherein are located their library and archives which formed the underlying data for this study.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report details the origin and subsequent modifications made over time to the Department of Defense Explosive Safety Quantity-Distance (ESQD) Standards for mass detonating explosives, especially those related to submarine tender operations. These standards are based upon the reasoned deliberations of the Department of Defense Explosives Safety Board (DDESB) since its inception in 1928 to the present. Investigation of these ESQD Board standards was accomplished primarily by studying the official historical volumes at the

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20. ABSTRACT (continued)

DDESB which detailed the technical data, administrative and military constraints, and accidental and test explosions experience upon which the judgments of Board members were based.

Volume I summarized the overall ESQD problem, including its background. A brief overview and summary is given therein of (1) the materials investigated and reported upon, and (2) the origins and modifications to the ESQD standards. Conclusions drawn and references studied are also included.

Volume II consists solely of the appendices referred to in Volume I.

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* These materials appear in Volume II.

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DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD
WASHINGTON, D.C. 20314

28 November 1977

DDESB-KT

SUBJECT: Report on the Basis of DoD Explosives Safety Standards

Commander
David W. Taylor Naval Ship R&D Center
Bethesda, MD 20034

1. Mr. David Freund of your command has spent considerable time reviewing the past minutes of the Department of Defense Explosives Safety Board. A detailed report is being prepared by Mr. Freund which summarizes, abstracts, and analyzes these minutes with regard to the development of DoD Explosives Safety Standards.

2. Mr. Freund's work is considered to be very important and much needed. It is therefore requested that additional distribution be made of this report in accordance with the attached list.

Incl
as

P. G. KELLEY, JR.
Colonel, USA
Chairman

01127724

ABSTRACT

This report details the origin and subsequent modifications made over time to the Department of Defense Explosive Safety Quantity-Distance (ESQD) Standards for mass detonating explosives, especially those related to submarine tender operations. These standards are based upon the reasoned deliberations of the Department of Defense Explosives Safety Board (DDESB) since its inception in 1928 to the present. Investigation of these ESQD Board standards was accomplished primarily by studying the official historical volumes at the DDESB which detailed the technical data, administrative and military constraints, and accidental and test explosions experience upon which the judgments of Board members were based.

Volume I summarized the overall ESQD problem, including its background. A brief overview and summary is given therein of (1) the materials investigated and reported upon, and (2) the origins and modifications to the ESQD standards. Conclusions drawn and references studied are also included.

Volume II consists solely of the appendices referred to in Volume I.

ADMINISTRATIVE INFORMATION

This study was performed for the Naval Surface Weapons Center White Oak Laboratory (NSWC/WOL) in support of the Naval Sea Systems Command Program for Test and Evaluation of Explosive Safety Criteria. Funding support was furnished by NSWC/WOL Purchase Order N60921-77-PO W00062 of 1 Dec 1976, and Work Request WR N60921-78-WR-W0059 of 28 Oct 1978.

DISCLAIMER

Irrespective of the copious assistance of Board personnel during the performance of this study, it should be clearly understood that any data paraphrased or conclusions stated in this report solely reflect the views of the author. Errors of summation or interpretation of the facts as read and understood are the responsibility of the author and the statements made in this report do not necessarily reflect the views, agreement, or endorsement of the DDESB.

INTRODUCTION

The explosive safety quantity-distance standards set forth in OP-5, Vol. 1,[1*] which is based on DOD Standard 5154.4S[2], as they apply to Navy ships, particularly submarine and destroyer tenders, during in-port munitions handling operations, are becoming increasingly difficult to satisfy. Improvement of private property bordering federal lands places increasing pressure on the perimeters of explosive safety quantity-distance (ESQD) arcs and on utilization of federal property as safety buffer zones. Operations under waivers of these standards which were necessary during the Southeast Asia hostilities are now either unacceptable to, or the subject of continuous and increasingly less sympathetic review by, DOD and other federal, state, and local authorities. New construction of military facilities is subject to Department of Defense Explosive Safety Board (DDESB) review for conformance with ESQD requirements prior to submission for funding. Failure to find a solution to these difficulties will either delay or prevent the construction of needed facilities, require abandonment of existing tender support facilities with concurrent loss of operational flexibility or the outlay of large sums of money to acquire the necessary additional real estate to permit continued operations or required facilities construction. In many cases, land acquisition may not be possible.

The current physical criteria which form the limits of the ESQD arc are: (1) blast overpressure of 1 psi (6.9 KNm^{-2}); (2) hazardous fragments having impact energies of 58 ft-lb (78.6J) or greater, and (3) hazardous fragment densities of one or more per 600 sq ft ($55.7m^2$). These criteria form the underlying basis for the specified 1245 ft (379m) ESQD arc which applies to munitions handling operations involving any quantity of fragmenting munitions with explosive weights from 50 lbs to 30,000 lbs (13,608 Kg).** These ESQD arcs are not supposed to be absolutely safe distances but represent distances of relatively acceptable hazard to personnel and material at risk.[3] Navy ammunition-handling evolutions have historically been determined by review of relevant empirical data derived from accidental explosions and from various types of explosives/munitions tests.[3] The hazards recognized in studies of these data have included fire, explosion and missiles. There have been virtually no controlled experiments for the in-port shipboard munitions handling scenario to evaluate the suitability of the ESQD tables contained in References 1 and 2 in terms of the physical criteria which form their basis. Rather, the rationale on which the current ESQD arc limits are based appear to relate to general acceptance, established usage and typical environmental situations.

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* References are indicated by a superscript number. A complete listing of references is given beginning on page 22.

**See Reference 1, Table 5-4, pp 5-33 to 5-36; and Reference 2, Table 5-3.1, pp 5-4 and 5.5.

Because of the urgency of this problem, the Chief of Naval Operations requested a program of testing/evaluation to accomplish the following objectives: (a) reduction of the 1245-ft (379m) handling arc in the pier/berthed ship scenario to release additional real estate for facility development; (b) definition of essential persons within the ESQD arc; (c) probability of sympathetic detonation of adjacent magazine/shops from radiating magazine/shops; (d) ESQD arc struck from magazine bulkhead/skin or ship vice junction of pier and land; (e) reasonable safety quantifiable in discrete terms of overpressure, fragment density and probability of injury; (f) analyses of ESB standards in terms of Defense Conditions I through V.

Consequently, the Naval Sea Systems Command established a program to provide the Navy with a technical basis for seeking relief from the present ESQD arcs. The Naval Surface Weapons Center was designated lead laboratory on the program.

In support of this program, the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) was tasked to investigate the historical origin and subsequent modifications to the ESQD standards for mass detonating explosives (especially as they relate to Navy munitions handling operations). The need for such a study grew out of the realization that no definitive compilation of the "when", and especially the "why", of such changes to these standards had ever been made. It was felt that such an effort might be of considerable use in providing the Navy with the background needed to establish a technical basis and rationale for seeking relief from the standards.

Data concerning the origin and subsequent modification of the ESQD standards currently applicable are available primarily in the files of the DDESB. The completeness and quality of these data were judged to be excellent; the quantity was extremely voluminous, almost overwhelming; the time period of interest exceeded 50 years. All of these data were investigated, the most promising documents being studied in some detail to answer the primary question addressed by this study.

This report summarizes the relevant data available in the documents studied related to the origins of the ESQD standards and the major changes made to them, the historical background of these changes, and the time-frame during which they occured.

Significant conclusions based on the data presented in this report related to the means by which the DDESB establishes and modifies the explosive safety standards imposed on the uniformed services are included at the end of the report.

The appendices contain a detailed summary of the materials studied at the DDESB (Appendix A); a tabular listing of all the relevant data uncovered from the study of DDESB historical volumes ("Minutes

of Meetings" of the DDESB) (Appendix B); a listing of the subject topics of a comprehensive index to these DDESB historical volumes Appendix C); and reproduced materials taken from the DDESB historical volumes that were considered especi[illegible] significant (Appendix D).

Due to the quantity of material [illegible] in the appendices, they have been published as a separate volu[illegible]

A list of references is included.

MATERIALS INVESTIGATED AND STUDIED

The primary sources of data investigated to document the origin and subsequent modifications to the ESQD standards consisted of the so-called "Minutes of Meetings" of the DDESB. These "Minutes of Meetings" are contained in 41 volumes at the offices of the DDESB and contain well over 20,000 pages of text. Despite their limiting appellation, these documents contain much information in addition to resumes and verbatim transcripts of formal Board meetings. Such data of historical value are included therein as (1) correspondence concerning activities and decisions of the Board, (2) correspondence about members of and consultants to the Board, (3) directives and formal papers related to Board activities, including early draft versions, (4) reference materials related to all Board deliberations and concerns, and (5) documents related to the enlargement of Board activities, including experimental and theoretical studies sponsored by the Board.

In addition to this extremely comprehensive and well-organized set of documents maintained by the DDESB, the mass of data existing at the Board was carefully searched to try and locate additional information that might also be directly or even peripherally related to the origin and subsequent modifications of the ESQD standards and to Board deliberations and decisions on this subject.

A summary of all the materials studied appears in Table 1 and is specified in even greater detail in Appendix A.** The information gleaned from these sources is presented below, starting on page 6, with substantiating materials presented in the various appendices to this report.** Items 1 through 4 of Table 1 all refer to the "Minutes of Meetings" of the DDESB, whereas items 5, 6, and 7 are less directly associated with formal Board deliberations and decisions relating to the genesis of the current ESQD standards.

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* Freund, D., "Origin and Subsequent Modifications of Explosive Safety Quantity-Distance (ESQD) Standards for Mass Detonating Explosives With Special Reference to Naval Vessels, Volume II - Appendices," DTNSRDC Structures Department Report SD-78/ [illegible] (May 1978).

**See Volume II.

Table 1 - Summary of Materials Studied at the DDESB

Item	Title	Time Period	Extent and Brief Description
1	Unclassified "Minutes of Meetings" of DDESB	Sept 1924 to present	Over 20,000 pp of DDESB deliberations, background, and substantiating information. 41 Vols.
2	Classified "Minutes of Meetings" of DDESB	Sept 1924 to present	Approximately 800 pp of confidential and secret deliberations and related background data, including restricted data. 4 Vols.
3	Overview Summary of "Minutes of Meetings" of DDESB	Sept 1924 to March 1976	Cursory summary of all data in DDESB's "Minutes of Meetings." Approximately 400 pp. 2 Vols.
4	Index to "Minutes of Meetings" of DDESB	Sept 1924 to present	Index of information by subject matter of various topics within "Minutes of Meetings." Approximately 1000 index topics, some entries filling more than one card.
5	DDESB Technical papers	July 1945 to July 1975	Twelve technical papers published; one unpublished (1 July 1948).
6	Minutes of Explosives Safety Seminars	June 1959 to present	40-60 papers were presented at each of the earlier seminars; more recently the number has grown to well over 100.
7	Remaining Contents of DDESB Library	1924 to present	Several hundred miscellaneous corporate and Government Laboratory documents related to explosives safety. Several hundred related military puiblications. Approximately 2500 accident/ incident reports.

The reason why it was necessary to study or at least address all these data, even though some were clearly ancillary to formal Board historical volumes, was that DDESB deliberations and decisions regarding ESQD standards are based on all currently available experimental data and theoretical studies as well as current service missions and requirements. Frequently data are incomplete or in conflict. Often safety considerations must be weighed against military requirements of the uniformed services. Such conflicting evidence and opposing needs must be borne in mind in order to address completely the subject topic of this report and delineate the complex background against which the DDESB proceeds. In this context, what may frequently seem initially to be a slow or circuitous route in making modifications to the ESQD standards appears on more careful analysis, to be a logical, conservative, and direct approach.

The verbatim transcripts of the meetings of the DDESB are considered privileged information* and for this reason, direct quotations from these documents were not used in the preparation of any of the materials summarized throughout this report.

ORIGINS AND MODIFICATIONS TO ESQD STANDARDS

GENERAL

The DDESB has the authority to establish safety standards and also to make changes thereto. Based on an opinion of the Attorney General[4] and resting on Congressional legislation,[5-7] these standards and changes have "binding legal force" as "minimum safety standards." This authority is exercised through votes of the three-man Board. Decisions are usually unanimous, but in the event they are not, the Chairman will vote and determine the outcome. Decisions of the Board are promulgated through DOD STANDARDS.

Current standards[1-2] for mass detonating explosives, such as may be stored on a submarine tender, specify a minimum distance of 1250 ft unless otherwise noted. This is considered to be that distance beyond which the blast hazards override the fragment hazards. DOD components are responsible for determining the fragment hazard distance where it is desired to use distances less than the 1250 ft minimum. In addition, in Meeting 260 held on 14 April 1971, the DDESB has defined (1) a hazardous fragment as one having an impact energy of 58 ft-lb or greater and (2) a hazardous fragment density as that which exceeds one hazardous fragment per 600 sq ft. These definitions are specified in reference 2, paragraphs 2-24 and 2-25.

Mass detonating explosives, those of primary concern to this study, have been defined by the DDESB in reference 2 (p. 5-2) as those for

* Meeting of 25 Nov 76, at DDESB, B.L. Knasel, T.A. Zaker, and D. Freund.

which practically instantaneous explosion or detonation of virtually the entire quantity may be expected. Examples of such explosives include torpedo and missile warheads, as well as bulk explosives, rockets, mines, bombs, and some propellants. These explosives represent but one aspect of the explosive hazard classification system. Such explosive classes have changed over the years and the current system, based on the system recommended for international use by the United Nations, is also specified in reference 2 (Figure 5-21).

In the remainder of this section are summarized (a) the rationale and (b) the historical evolution of current ESQD standards adopted by the DDESB for mass detonating explosives.

RATIONALE FOR HAZARDOUS FRAGMENT DENSITY BEING DEFINED[2] AS A DENSITY OF HAZARDOUS FRAGMENTS EXCEEDING ONE PER 600 SQ FT

The most recent DDESB technical summary paper relating to fragment and debris hazards gives the areal density of injurious fragments considered acceptable under the current U.S. standards as one such fragment per 600 sq ft of surface area, corresponding to an injuring probability of about one percent.[8]

The one percent "acceptable" injury probability figure cited appears to have been chosen arbitrarily as a convenient one; no objective rationale for its acceptance has been found other than its prior acceptance in the U.K. and NATO countries for the 10-year period prior to the time that it was adopted by the DDESB, at its 260th meeting on 14 April 1971.

The areal density figure for injurious fragments of one per 600 sq ft is mentioned in the technical literature several times during the past dozen years and in various contexts. Jarrett[9] noted that the minimum distance adopted for public buildings in Britain exposed to fragment attack were themselves derived from U.S. sources (unnamed in reference 9), and presented an average fragment hazard of one strike per house (600 sq ft presented area) at the U.K. minimum public building distance of 150 ft. This 150 ft distance figure has previously been used as the minimum quantity-distance for the British category X explosives. Such explosives are defined as those causing missile and slight blast effects, providing that no mass effects (explosion or fire) occur. Further, nearby firefighting facilities must be adequate.

Study of the crater ejecta from explosions in contact with the ground surface have also been used as a measure of the hazard from debris to exposed persons. Vortman[10] found that the maximum range of such missiles from test explosions appeared to scale as the 0.4 power of explosive weight for rock and soil media (with proportionality coefficients of 70 and 30, respectively).

Based on an exposed area of 6.2 sq ft (0.58 sq m), corresponding to the projected area of a standing man (face-on or back-on orientation to the impacting missile), references 11 and 12 extended the Vortman data[10] for crater ejecta number density as a function of distance to obtain curves for one percent probability of strike by one or more such missiles, as functions of distance. The resulting computations showed that approximately one percent of the people would be struck by ejecta for specific areas of 600 (i.e., one strike per person per 600 sq ft).

The only other work noted related to this topic was a very early study published by the DDESB in 1945.[13] This report discussed the missile hazard from four large accidental explosions. The resultant information was not considered useful because of the generally poor quality of the data collected, viz., the discarding of most missiles weighing less than one pound.

RATIONALE FOR HAZARDOUS FRAGMENT BEING DEFINED[2] AS ONE HAVING AN IMPACT ENERGY OF 58 FT-LB OR GREATER

This very old criterion appears to have been borrowed initially from German Army doctrine at the beginning of the present century.[14]* In its crudest form, this criterion stated that missiles with less than 58 ft-lbs of kinetic energy do not kill, and that those with more than 58 ft-lbs do kill. Sterne[15] suggests that this criterion was perhaps never intended to be more than a rule of thumb applicable to lead spheres weighing about half an ounce and about half an inch in diameter.

Even earlier measurements of the wounding power of missiles, in terms of their penetration through wood, appear to rest upon no more valid a foundation than some Danish experiments using pine boards and live horses as targets for missiles. These tests were performed sometime before 1867 when they were quoted without detailed reference in a textbook intended for cadets of the U.S. Military Academy.[16]

Quantitative scientific work appears to have started with Burns and Zuckerman in England, who made an analysis of the quantitative requirements for wounding.[17]

During World War II, a criterion of a missile with weight and velocity sufficient to give it 58 ft-lb of kinetic energy was used in practice. Although it was generally recognized that the adoption of

* On page 68, this reference states: "To put a man out of action, according to the views prevailing in the German Artillery, a kinetic energy of eight meter-kilograms is sufficient." This equates to 57.74 ft-lbs in English units.

the figure was arbitrary or empirical, it was much more practical than using the penetration of pine boards or other inanimate objects for the purpose.[18] Selection of the figure was in a measure substantiated by the work of Gurney.[19] The figure was also reasonably corroborated by the efforts of McMillen and his associates.[20]

Reference 18, a definitive work on this topic, sums up the situation (pp. 93-94) by stating that "...while this 58 ft-lb figure ...has not been fully substantiated as a fair criterion, it is well supported and is definitely superior to pine boards. No doubt, under optimal conditions, a missile with considerable less energy than 58 ft-lb can produce a serious wound, but on the average it is probable that this amount of energy will insure a casualty."

RATIONALE FOR 1235, 1245, or 1250-FOOT* NOMINAL MINIMUM DISTANCE TO INHABITED TARGETS FOR CLASS 1, DIVISION 1 (MASS-DETONATING) EXPLOSIVES FOR QUANTITY OF EXPLOSIVES UP TO 30,000 LBS (REFERENCES 1,2)

The original rationale for the use of the minimum distance of 1235 ft was based on extensive study by the DDESB staff. Such studies were most explicitly referred to in Board meetings 94 (17 March 1947), 100 (24 Nov 1948), and 114 (19 Jan 1950). These studies included an unpublished review of approximately 300 explosions in order to reassemble data to appraise the minimum distance required for inhabited buildings from explosion operations (referred to in the minutes of meeting 100). References for this distance also include Technical Papers 1 through 7, inc., of the DDESB.[13,20,22-26] Technical paper 6 ("The Port Chicago, California Ship Explosion of 17 July 1944")[21] and the explosion of the USS MOUNT HOOD, Seeadler Harbor, Manus Island, 10 November 1944[27] were especially considered of great importance to the DDESB in its considerations.

Subsequent lengthy and complex deliberations of the DDESB, where the quantity-distance regulations for mass detonating explosives were discussed occurred in meetings 123, 143, 144, 146, 147, 148, 176, 178, 184, 186, 189, 197, 209, 210, 216, 223, 229, 233, 239, 245, 250, 252, 253, 254, 255, 258, 260, 265, and 274 between 14 May 1952 and 18 Nov 1975. The underlying data sources for these extensive discussions are the explosion reports contained in the files of the Board as well as test reports, historical files, military sources, and industry sources catalogued at the Board's library.

Of these data sources referred to above, those most heavily relied upon by the DDESB and frequently referred to at the above-mentioned

* These three numbers may be considered identical for practical purposes. The use of one or another over the years by the DDESB was primarily a matter of administrative convenience, not of technical significance.

meetings are the tests conducted at Aberdeen Proving Ground of 320 rounds of 3-in ammunition and referred to in the 209th Board meeting (24 Nov 1961), as well as the work done by both the Illinois Institute of Technology Research Institute (IITRI)[28-30] and the General American Transportation Corporation[31] in the early 1970's. This latter work, especially, led directly to the provision in the Board standards for mass-detonating explosives for all amounts of explosive up to 30,000 lbs to protect against fragments and debris, and to a minimum distance of 1245 ft (see Board meeting 258, 16 June 1970). This 1245 ft distance was subsequently changed to 1250 ft (see footnote, previous page) in accordance with a memorandum dated 19 Sept 1974 of the Board. The rationale for this admittedly non-substantial change is not given in the memorandum cited. No other reference to it has been found in the files of the DDESB.

Prior to the adoption of the 30,000 lb explosive quantity limit adopted in 1970, lesser quantities were the rule, most commonly 15,000 lbs (discussed during Board meetings 106 through 109 during the first six months of 1950). This quantity was also based on a minimum distance of 1235 ft and use of the $KW^{1/3}$ formula. Use of a value of K=50 corresponded to a quantity of explosives of approximately 15,000 lbs (Reference Board meetings 146, 147, 148, 176, 178; 26 Aug 1955 through 24 Feb 1958), whereas the newly adopted value of K=40 corresponded to an explosive quantity of 30,000 lbs (Board meeting 258, 16 June 1970).

HISTORICAL EVOLUTION OF ESQD STANDARDS ADOPTED BY THE DDESB

The current standards relating to ESQD have evolved over the years of the DDESB's existence and such evolution is documented in detail in the reference materials noted in Table 1. The documents most carefully reviewed in preparing this summary of the origin and subsequent modifications to these standards were the 41 unclassified and the 4 classified volumes containing the official history of the DDESB in over 20,000 pages of text. This exhaustive and lengthy study is presented in Tables B-1 and B-2 of Appendix B.* Table 2 presents a condensed summary of the documents and events considered of special significance to the modifications made over time to the ESQD standards.

These modifications are no less interesting or significant than the evolution of the DDESB itself. Changes in the composition of and procedures employed by the Board have contributed to these ESQD changes, as have external events occurring during the years since the Board's creation. Wars, catastrophic accidents, and changes in national priorities have affected safety standards, as have analytical and theoretical research studies.

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* See Volume II.

From the inception of the DDESB in 1928 until the middle of World War II, explosives safety standards closely followed the guidelines of the American Table of Distance (ATD) developed in reaction to the Lake Denmark, N.J. disaster of 1926 and adopted for use by the Board following its creation. During and immediately following the war, the Board stated that it believed the ATD to rest upon inadequate, insufficient data and recommended tests to develop a table of greater accuracy. Such tests were started in 1945 and recommended changes to Board standards were proposed as early as 1947. During the period from 1948 to 1950, further changes were recommended to Board standards, based on all data then available, especially the Arco, Idaho tests following World War II. The 1 April 1950 Board standard for inhabited buildings, public railways, and highways were accepted by the Navy and Air Force, but not by the Army.

Modifications and discussions concerning the 1 April 1950 standards continued almost unabated until adoption of new standards on 1 Feb 1955. As new problems arose, newer analytical or experimental data became available, and accidental explosions occurred and were analyzed, Board discussion about modifications to the ESQD standards continued. As problems arose and changes to the standards seemed warranted, a pattern seemed to emerge. A Board-appointed work group quantitatively stated the problem, analyzed it, and made recommendations for its solution. Such efforts were usually presented to the Board both as an oral presentation and written report. Modifications to the report were next made in an effort to achieve unanimous agreement by the Board members, followed by formal approval by each service. Where unanimous Board agreement was not forthcoming, a decision (subject to appeal) would be made by the Chairman.* Thus, although reference may be made to Board standards for quantity-distance separation as adopted as of a specific date, long and often-involved study, discussion, and compromise decisions usually precede such rulings. Disagreements occur because data are frequently incomplete or ambiguous and service needs for mission fulfillment are often at odds with the Board's primary concern for protection to life and property.

There have been a few meetings of the DDESB where the subject of quantity-distance standards was treated at some length (e.g., Board Meeting #264) or even occupied an entire meeting. Far more common, however, is the strong pattern in Table 2 and Appendix B of slow evolution over time of Board standards as newer experimental or accidental data became available, Service or Board practices were modified, and objective conditions changed. Such unusual events as the acceptance by the Board of the ATD, the Port Chicago explosion in 1944, and the massive Arco, Idaho experimental tests have impacted greatly upon the Board. But at least equally significant to the history of ESQD changes have been the small, myriad, less spectacular occurrences through the years that have warranted Board consideration and been the subject of discussion at formal meetings.

*For example, see Appendix B, ruling made at Board Meeting #178, Vol 11 of DDESB historical files.

Table 2 - Condensed Summary of Origin and Subsequent Modifications of Explosive Safety Quantity-Distance Rules, from DDESB Official Historical Volumes[a]

Reference[b] Vol/Pp/Date	Document Identification	Fact/Datum (usually abstracted and/or paraphrased)
1/1-337 Dec 1927 to Dec 1940	Meeting #1 of Joint Army-Navy Board on Ammunition Storage (JANASB)[c]	Joint Army-Navy Board first convened on 2 Jul 1928 in compliance with appropriate provision in Act of Congress approved 29 May 28 (Second Deficiency Act, fiscal 1928). Act passed in response to Lake Denmark, N.J. ammunition explosion disaster.
2/370-1/24 Mar 43	Minutes of Meeting #54, JANASB	Board tentatively adopted the Ordnance Safety Manual (O.O. Form 7224) and Ammunition General (TM 9-1900) as standards and directed that they be submitted to the Navy Department for consideration by the Bureau of Ordnance.
2/374-5/22 Mar 43	Ltr to Sec of War and SecNav from JANASB	Board stated that it believed American Table of [illegible]ances, upon which present safety regulations are largely based, rested upon inadequate, insufficient data and that tests should immediately be undertaken to develop a table of greater accuracy.
4/1121-2/12 Jan 45	Letter to Sec of War and SecNav from President, JANASB	Board President states that to accomplish its mission, the JANASB has adopted minimum explosives safety standards for the handling and storage of ammunition and explosives. States that these are in substantial agreement with those used by the operating agencies, but revised and changed based on new data from accidental and research efforts.

FOOTNOTES: (a) These volumes are generally referred to by DDESB personnel as the "Minutes of Meetings" of the Board. However, they contain much information in addition to resumes and verbatim transcripts of formal Board meetings (see text and additional explanatory data in Appendices, footnote p. ii). In addition to these unclassified documents, volumes also exist in which classified matters related to the DDESB are discussed. See text and Appendix B, Vol. II).

(b) "Vol" refers to the volume number of the "Minutes of Meetings" (see footnote, above) of the DDESB. "Pp" refers to the page number(s) in the volume cited. "Date" refers to the date noted on each cited document. (See footnotes, Appendix A, Vol. II).

(c) The current DDESB has had several different names (as well as varying tasks and responsibilities) since its inception in 1928. The identifying letters shown in this table are those appropriate to each time period.

Table 2 (Continued)

Reference Vol/Pp/Date	Document Identification	Fact/Datum (usually abstracted and/or paraphrased)
5/1981-2/19 Jan 48	Memo for Chief of Ordnance (each of Uniformed Services) from President, ANESB	Memo stated that barricaded quantity-distance relations specified in the ATD did not provide for reasonable and practical protection against loss of life, severe injuries, etc. It lists new barricaded distances recommended by the Board to the Secretaries of War and Navy Departments.
6/2447-69/1 Apl 50	Letter to Service Secretaries from ASESB	Letter suggests recommended changes in safety standards for explosives and ammunition storage. Changes began with Board recommendation of 11 Apl 47 and ends with attached enclosure entitled "Quantity-Distance Standards for Mass-Detonating Military Explosives and Ammunition."
7/3001-39 to 3001-55/22 Sep 54	Minutes of Meeting #136 of ASESB	It has taken since 1947 to prepare the currently Board-accepted quantity-distance table and the Chairman stated that this safety standard (of 1 Apl 50) applies as far as the Board staff is concerned. However, since it has not been accepted by the Services, it is not a Defense Department standard.
8/3011-23/11 Oct 54	Memo for Chmn, ASESB from Chmn, Work Group on Q-D Standards	States that mission is complete of reconsideration of Phase I quantity-distance standards dated 1 May 53. Vote taken at meeting of 11 Oct 54 recommending submission of these standards as a uniform standard to replace previous ones.
8/3050-3/16 May 55	Resume of Meeting #144 of ASESB	States that 1 Feb 55 quantity-distance standards were accepted by Navy and Air Force, possibly subject to minor revisions. Enclosure was (pp. 3054-65, dtd 1 Feb 55) "Quantity-Distance standards for Mass-Detonating Explosives and Ammunition Applicable to Separation of Magazines and Intraline Separations."
8/3080-2/21 Jul 55	Resume of Meeting #145 of ASESB	Army has accepted the 1 Feb 55 standards with no revisions. Board states recommendations of its Military Staff with regard to Q-D factors:0-10,000 lbs, the 1953 ATD at a factor of 40; 100,000-500,000 lbs, a factor of 50; 10,000 to 100,000 lbs, gradually increasing factor from 40 to 50. (These "factors" refer to the constant (K) in the formula $D=KW^{1/3}$, where "D" is the distance (ft) and "W" is the net explosive weight (lbs).)

Table 2 (continued)

Reference Vol/Pp/Date	Document Identification	Fact/Datum (usually abstracted and/or paraphrased)
9/3148-57/11 Oct 55	Memo for Members, ASESB from Chmn.	States background of quantity-distance rules which the Navy and Air Force put into effect in 1950, difficulties in interpretation and impracticality of application. Members are not in complete agreement and Chairman exercised his power of decision and approved inhabited building quantity-distance tables for mass detonating explosives.
9/3238-69/28 Jun 56	Minutes of Meeting #156 of ASESB	Enclosure #4 presents 15 Jun 56 proposed revision of ASESB for "Quantity-Distance Standards for Mass-Detonating Military Explosives and Ammunition."
10/3359-62/27 Nov 56	Resume of Meeting #161, ASESB	Note made that comments were received on proposed manual on piers and wharves and difficulties resolved unanimously. Manual was accepted by working group except for Chapter 4, dealing with quantity-distance and which had just been drafted.*
10/3437-1 to 3437-5/20 May 57	Meeting #167, ASESB, Verbatim Transcript	Piers and wharves manual discussion dealt with unresolved problem of inhabited building distance from the piers. Difficulty lay in choice of distance factor. Resolution obtained using 70 for new pier installations, 50 for old, existing installations where the 70 factor was unobtainable.
11/3458-9/22 Jul 57	Resume of Meeting #170, ASESB	Board approved changes to criteria for on-site evaluation of piers and wharves. Changes stated in ASESB Memo 226/57/6 of 5 Apl 57, were developed because former parameters were judged unrealistic.
11/3525-6/10 Mar 58	Resume of Meeting #178, ASESB	Chairman briefed Board on study made of appropriate safety factors for use in piers and wharves manual. Chairman decided on use of factor of 50.
14/4563/15 Aug 60	Meeting #202, ASESB, Verbatim Transcript	First mention noted here of minimum fragment density of one/600 sq ft of area and fragment energy of 58 ft lbs at impact (used in German regulations). Discussions also ensued on new schedule of quantity-distance classes (from 12 to 7), but no radical changes expected in spread of distance requirements.

* This manual was published early in 1957. Data contained therein was subsequently incorporated as part of ref 1 (Chapter 6-6) and ref 2 (Chapter 7).

Table 2 (continued)

Reference Vol/Pp/Date	Document Identification	Fact/Datum (usually abstracted and/or paraphrased)
15/5379-01/13 Mar 62	Memo for Members, ASESB, from Chmn, ASESB	Discussion of blast and fragment hazards indicates that there are presently no nationally-recognized standards which give full consideration to the damage which may be caused by secondary fragments. Concluded that determination needs to be made as to what constitutes a hazardous fragment in terms of size, velocity, and range, and the density of such hazardous fragments which may be accepted in any given area.
18/6677-8/3 Dec 63	Resume of Meeting 0225, ASESB	Interim standards agreed upon for recommendation to Services relating to fragmentation distance requirements and hazards for large missile and weapon systems.
19/7233-5/22 Oct 64	Resume of Meeting 0229, ASESB	Extensive review made of DOD Directive 4145.18, "Quantity-Distance Standards for Pier and Wharf Facilities Handling Explosives and Ammunition." Change approved making it inapplicable to combatant ships ("These standards are inapplicable to ammunition or explosives stowed in ships' magazines and intended for the service of the shipboard armament or aircraft. They do, however, apply to the loading, off-loading, stowing or shifting of such ammunition or explosives").
20/7371-3/1 Dec 64	Resume of Meeting 0230, ASESB	Board agreed that determination of quantity-distance table for magazine, intraline, inhabited buildings should be based upon the nature of the operations being performed at both the site under consideration and its relationship to adjacent facilities.
21/8171/7 Dec 65	Memo for Members from Chmn, ASESB	Memo deals further with application of Para. V,B DOD Directive 4145.17 of 7 Dec 1956. Board staff proposed that Para. V,B,1 be changed to read: "These distances, based on damage from blast effects, also provide a high degree of protection from missiles, except for quantities below 3500 lbs. For this lower region...a safety distance of 1200 ft should be provided...."
23/9195-7/7 Jun 67	Resume of Meeting 0246, ASESB	Draft publication noted of one document containing all ASESB directives and instructions. (DOD 4145.27M)

Table 2 (continued)

Reference Vol/Pp/Date	Document Identification	Fact/Datum (usually abstracted and/or paraphrased)
24/9405-9544/ 20 Feb 68	Meeting #250, ASESB, Verbatim Transcript	Discussion held relating to problems of storage of small quantities of Class 7 items wherein predominant hazard is from fragments rather than blast. Members agree that better guidelines are vital. Chairman states that accurate definition of acceptable fragment hazard was issue sidestepped years ago. Mention made here again of kinetic energy figure of 58 ft-lb, and also density figure of one fragment/ 600 sq ft.
26/10,541-5/ 20 Jul 69	Resume of Meeting #255, ASESB	Board members voted to adopt interim quantity-distance standards in the event barricades are proved ineffective. For 0-10,000 lbs used a factor of 40 for barricaded and 865 ft unbarricaded; for 10,000-100,000 lbs used factor of 40 whether or not barricaded; for 100,000-250,000 used a factor of 40 increasing to 50; and the latter factor from 250,000-500,000 (the latter two situations for barricaded or not).
28/340-64/10 Mar 70	Meeting #257, ASESB, Verbatim Transcript	Pending formal change to DOD Manual 4145.27M, following policy was approved...For Class 7, minimum separation distance of 865 ft from the concentration of explosives to inhabited buildings, or the appropriate missile distance, whichever is greater. Difficulties associated with this vote are detailed in these minutes.
29/11,738-40/ 6 Jul 70	Resume of Meeting #258, ASESB	Table of recommended quantity-distance standards for inhabited buildings, passenger railroads, public highways, and airfield facilities jointly used by the DOD and other organizations was presented to the Board. This table uses a minimum separation distance of 1245 ft for all quantities of mass detonating explosives up to 30,000 lbs (indicated in the Memo for ASESB Members of 11 Jun 70 from the Chmn, ASESB: pp. 11,894-916).

Table 2 (continued)

Reference Vol/Pp/Date	Document Identification	Fact/Datum (usually abstracted and/or paraphrased)
30/12,441-2/ 10 May 71	Resume of Meeting #260. ASESB	Summary given of Secretariat's reasons for recommending minimum distances to protect against fragments from mass detonating ammunition. Discussion presented of different problems presented by fragment hazards to exposed personnel as compared with inhabited building protection against blast. Board voted unanimously to accept definition of hazardous fragment and acceptable density of hazardous fragments and also, in lieu of minimum distances for inhabited buildings, distance zones similar to those used for non-mass detonating items. Rationale given for 1235 ft nominal minimum distance to inhabited targets, 58 ft lb fragment minimum kinetic energy, and fragment density of one fragment per 600 sq ft.
33/14,498-599/5-7 Nov 73	Meeting #264, DDESB	Discussion of Navy tenders and Navy request for exemption from application of ESQ-D standards to such ships.
34/14,683-737 8 Nov 73	Meeting #265. DDESB, Verbatim Transcript	Approved compatibility grouping for ammunition and explosives similar to that adopted by NATO and UN. Discussed changes to replace in its entirety DOD Manual 4145.27M by new DDESB Standard 5154.4S.
34/14,994-5/ 1 Mar 74	Memo from Chmn, DDESB, to DCNO (Logistics)	Discusses possible application of suppressive shielding for control of explosion hazards aboard tenders. Suggests that suppressive shielding might help alleviate a Navy problem by eliminating risk of communication of explosion from workship spaces to the much larger quantity of explosives in magazines.
36/15,549-791/ 18-24 Feb 75	Meeting #269, DDESB, Verbatim Transcript	Meeting's main purpose was discussion of construction projects at NAVSTA, Charleston, S.C., but more generally entire topic of Navy's hopes of revising some of Board's instructions, especially from 1967 to 1/75 was raised. No resolution to problems at this meeting.
38/16,200-49/ 5 Oct 75	Meeting #272, DDESB, Verbatim Transcript	Board Chairman states that governing directives do not mention any defense conditions and generally explosives safety standards apply regardless of such conditions. However, the Service Secretaries are allowed for strategic or impelling reasons or operational necessity to take whatever risk they desire and deem necessary.

Table 2 (continued)

Reference Vol/Pp/Date	Document Identification	Fact/Datum (usually abstracted and/or paraphrased)
39/16,827/1 Dec 73	Memo for SECNAV from DASD(I&L)	States that DDESB has advised DASD(I&L) that ESQ-D rules should continue to be met as applied to tenders, and where these distances cannot be met, the operations of tenders should be appropriately limited.
40/16,949-17,024/18-19 Feb 76	Meeting #275, DDESB, Verbatim Transcript	Discussed ESQ-D standards applicable to Navy ships. States that very significant differences exist between Navy interpretations regarding application of ammunition and explosives standards to Navy pier and wharf scenarios and views of the Chairman, DDESB. The Board's views were also shared by the Army and Air Force Members.

During the years from 1965 to 1969 (and continuing with less intensity to the present time) the Board addressed itself more vigorously to the quantity-distance rules and the related problem of fragment hazards from mass-detonating explosives. Following this period, definition of hazardous fragments were agreed upon by the Board (see Meeting #260). These accepted definitions were based upon data sources similar to those used in quantity-distance determinations, as well as battle casualties and a rather extensive literature going back over 100 years.[15,18,32] Highlights are summarized in Table 2 and detailed in Appendix B. Significant documents which form part of the historical files of the DDESB related to this topic also appear in Appendix B,* especially reproduction #8.

CONCLUSIONS

1. Agreement in DDESB Formal Voting: The original ESQD standards were based upon the ATD, adopted early this century. Significant changes have been made to these standards in 1950, 1955, and during the 1970's. It seems abundantly clear from study of the DDESB's historical files that complex negotiations are conducted before the Board reaches any final decision regarding rule changes. Much effort is devoted to overcoming conflicting viewpoints in reaching the desired unanimous agreement that is common in formal Board votes.

2. Resolution of Conflict Situations by the DDESB: The mandate of the DDESB is explosives safety. Their primary concern relates to the protection of personnel and property. The uniformed Services, subject to Board standards and inspection of their explosives' caches by Board personnel, are aware of and responsive to the dangers involved in the manufacture, storage, and handling of live munitions. Conflict situations do arise, however, when the Services' overriding need to fulfill their assigned missions within both budgetary and time constraints is at odds with the Board's greatest concern for explosives safety.

One of the most important functions of formal Board meetings is the resolution of such conflict situations. Board members are drawn from each Service and are all high-ranking military personnel (Navy Captain, Army and Air Force Colonel). They frequently have similar backgrounds in explosives safety as well as considerable experience in balancing the stringent mission requirements of their respective Services against the restrictions inherent in the careful administration of large caches of explosives. This similitude of background and experience probably helps explain the fact that most Board decisions are unanimous.

3. Modifications to Safety Standards by the DDESB: Study of the complete historical record of the DDESB indicated that modifications to

* See Volume II

the ESQD standards are based on deliberations and judgments that tend to be quite prudent. In those cases where experiential information is available or theoretical analyses warrant, standards have been appropriately relaxed or tightened. In the absence of complete data, however, the Board has tended to maintain current standards which have previously resulted in acceptably safe explosives-handling and storage experience.

4. DDESB Safety Standards Vs. Service Needs. Within the constraints of (a) limited monies available for explosives research studies, (b) difficulties associated with the modification of safety rules based on structures which have already been built, (c) changes over time in weapons' manufacturing which may involve ever larger quantities of explosives with newer and more complex characteristics, and (d) service requirements from higher Command which may vary independently of current prescribed safety rules, the current procedures employed at the DDESB seem to function in an efficient and harmonious fashion. It appears as if a reasonable balance is nearly always struck between the frequently conflicting goals of maximizing personnel safety, minimizing property damage, and fulfilling the missions of the uniformed Services.

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