CONFIDENTIAL SECURITY INFORMATION NOLR 1111

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ORDNANCE EXPLOSIVE TRAIN DESIGNERS' HANDBOOK

UNITED STATES NAVAL ORDNANCE LABORATORY

APRIL 1952 CONFIDENTIAL

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PREFACE

The purpose of this handbook is to bring together in concise form the principles in the art and the science of explosive train design. There has been no primary source of these data, as they have been scattered among a large number of sources, including letters, specifications, and private notebooks.

In the last 20 years many individuals have concerned themselves with ordnance design. During World War II certain scientists, particularly physicists and physical chemists, became interested in the science of the initiation of explosives and conducted valuable experiments both theoretical and specifically pertaining to ordnance. These data, as well as fundamental facts which have long been known, are presented in this handbook.

Where possible, an attempt has been made to establish a connection between the art and the science. It will become obvious that the art has the advantage of a great head start over the science. For instance, the properties and preparation of mercury fulminate have been known since the year 1800; for certain ordnance purposes this material has not been supplanted during the last century and a half.

A further purpose of this volume is to uncover serious gaps in the art as well as the science of explosive train design. The gaps will become obvious in perusal of the book, since it will be noticed that the material in various spots will fall short of the assigned goal of a complete description of design principles.

It is hoped that by use of this handbook the design work of those already acquainted with the field will be facilitated and improved by allowing the designer to review the entire art in one package. Further, this handbook is intended to help the newcomer to the field to accomplish design work with a minimum of false starts.

The contributors to this handbook are indebted to the Bureau of Ordnance for financial support. The list of acknowledgments of helpful advice and criticism would include the following names: S. W. Booth, R. J. Burke, A. H. Erickson, R. L. Graumann, A. Lightbody, and D. E. Sanford, all of the Naval Ordnance Laboratory staff; and N. A. MacLeod, of Old and Barnes, Inc., Pasadena, Calif.

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Chapter 1

INTRODUCTION

Problems of Explosive-loaded Ordnance

On April 24, 1862, Gen. D. H. Hill of the Confederate Army wrote the following blunt note to his Secretary of War concerning certain problems he was having with the explosive trains of his day. "There must be something very rotten in the Ordnance Department. It is a Yankee concern throughout and I have long been afraid that there was foul play there. Our shells burst at the mouth of the gun or do not burst at all."

One year later at the Battle of Chancellorsville, an artillery chief reported that on the basis of careful observation only one out of every fifteen of the shells that were fired exploded at all. "I was compelled to watch closely the effect of all of the projectiles," he said, "as if we were using entirely solid shot."

By 1905, performance of ammunition had been somewhat improved; however, in the most significant naval engagement of the Russo-Japanese war in that year, namely the Battle of Tsushima, it is reported that one of the most important factors leading to the utter defeat of the Russian Fleet at the hands of the Japanese was the failure of the Russian fuzes to explode the projectiles.

To bring the story up to the present, it can be stated that the functioning of explosive loaded ordnance is in general quite satisfactory. Taking, for example, antiaircraft ammunition, Admiral Hussey, in forwarding to the Undersecretary of the Navy in 1945 a recommendation that a Navy fuze designer be given a special commendation, stated "40mm ammunition which was produced to the extent of 250 million rounds during World War II, functioned better than 99 percent in ballistic tests."

Rounds of ammunition of all categories, perfect in all respects, were, however, still unavailable in World War II. Much in particular remains to be accomplished in developing explosive trains capable of withstanding severe surveillance conditions. Following the bombardments of certain atolls in the Pacific by U. S. Naval Units, it was in some instances disconcerting to note that not all of the ammunition was used to maximum effectiveness. In "Comments on Amphibious Operations" dated 1 March 1944, the following statement appears: "The next disturbing type of malfunction was the duds and low order detonations noted on all the islands. While the number of duds found was large, it is not alarming considering the quantity of fire delivered."

From the examples cited, it is evident that the problems of explosive loaded ordnance are of long standing. The solutions to such of these problems as involve the explosive train are the province of this book. Actually the art (and the term is used advisedly) of explosive train design is in a well-advanced stage at the present time. Not only have the on-target performance records been raised in most cases to figures above 90 percent, but in addition the safety records of ordnance have been greatly improved. For instance, during World War I, ammunition that gave no more than one bore premature in twenty thousand rounds of firing was considered to be about as good as could be expected. In World War II with, for example, 5"/38 base-fuzed ammunition, bore prematures occurred at the rate of less than one in one million rounds.

Scope of This Handbook

Ordnance design is a field of broad extent, and in it the unwary author is likely to wander far afield unless he marks out for himself a sharply defined domain. This handbook covers explosive trains as applied to the entire field of explosive loaded ordnance. In every case, the discussion is limited to the explosive trains. For instance, there is no discussion of the sources of energy, either electrical or mechanical, which serve to trigger the fuze of an explosive loaded round. There is a detailed discussion of the manner in which the sensitivity of a stab primer is affected by the weight and velocity of the firing pin. There is no discussion of the details of the mechanism which moves a shutter containing a detonator to arm or disarm a round; but there is a detailed discussion of the way in which the probability of firing the subsequent element in the train is modified as a function of the amount of dislocation of the detonator or of interposition of air gaps.

The explosive train designs treated in this book are applicable primarily to bomb and projectile fuzes. However, the same basic principles may be applied to a wide range of explosive loaded ordnance items. The following list of such items is not necessarily complete.

- Gun launched projectiles of all calibers.
- Rocket projectiles.
- Bombs.
- Underwater ordnance such as mines, torpedoes, and depth charges.
- Projectiles of advanced designs, including self-propelled and guided missiles.

Description of a Complete Explosive Train

A short over-all description of the explosive train of Base Fuze Mk 21 for major caliber projectiles is presented here in order to give the newcomer to this field a comprehensive view which he might not otherwise obtain by reading the detailed discussions of the various components which appear later. The function of this fuze is to initiate, following a delay of 0.035 second after impact with steel armor plate, a high-order explosion in the filler of projectiles from 6 to 16 inches in diameter. A cross section of Base Fuze Mk 21 is shown in figures 1-1 and 1-2. In this short description, attention is centered on the explosive train and the mechanical features of the fuze functioning are touched upon only lightly. The central axial assembly of the fuze, which is mounted on ball races, moves forward on plate impact against the **anticreep spring**, causing the **stab primer** to impinge on the **firing pin**. (See figs. 1-1 and 1-2.)

The **stab primer**, designed for maximum sensitivity to initiation on impact with this type of firing pin, is loaded with a priming composition consisting of a mixture of basic lead styphnate ($C_6H(NO_2)_3(OPbOH)_2$), antimony trisulfide (Sb_2S_3), barium nitrate ($Ba(NO_3)_2$), tetracene ($C_2N_{10}H_8O$), and lead azide (PbN_6); the explosion of this mixture forces the **delay element primer firing pin** into the **delay element primer.**

This primer is loaded with a priming mixture similar to that used in the stab primer except that it does not contain lead azide. It differs from the stab primer in two respects; firstly, its housing is stronger and is not punctured during actuation, a characteristic which makes possible maintenance of a gas seal on the next element, the **delay pellet**, and secondly, it is inherently less sensitive to impact than the stab primer.

The hot gases from the percussion primer permeate through the **baffle** and initiate the black powder **delay pellet**, which burns, under the reproducible pressure conditions which obtain within the delay housing, with a delay time of 0.035 second. When the black powder element has burned through, a spit of flame impinges on a lead azide-loaded **detonator**; a true detonation develops and progresses successively through the tetryl-loaded **lead out**, the tetryl-loaded **booster lead in**, the tetryl-loaded **booster**, and the **main charge** of the shell, explosive D (ammonium picrate).

Certain general remarks may be made concerning this explosive train, which hold in general for any train. As one proceeds down the train, the size of the elements in general increases while their sensitivity to initiation decreases. For instance, in decreasing order of sensitivity we have:

(*a*) Priming mixture.
(*b*) Lead azide.
(*c*) Tetryl.
(*d*) Explosive D.

As implied in the word "train," each element has two ends and

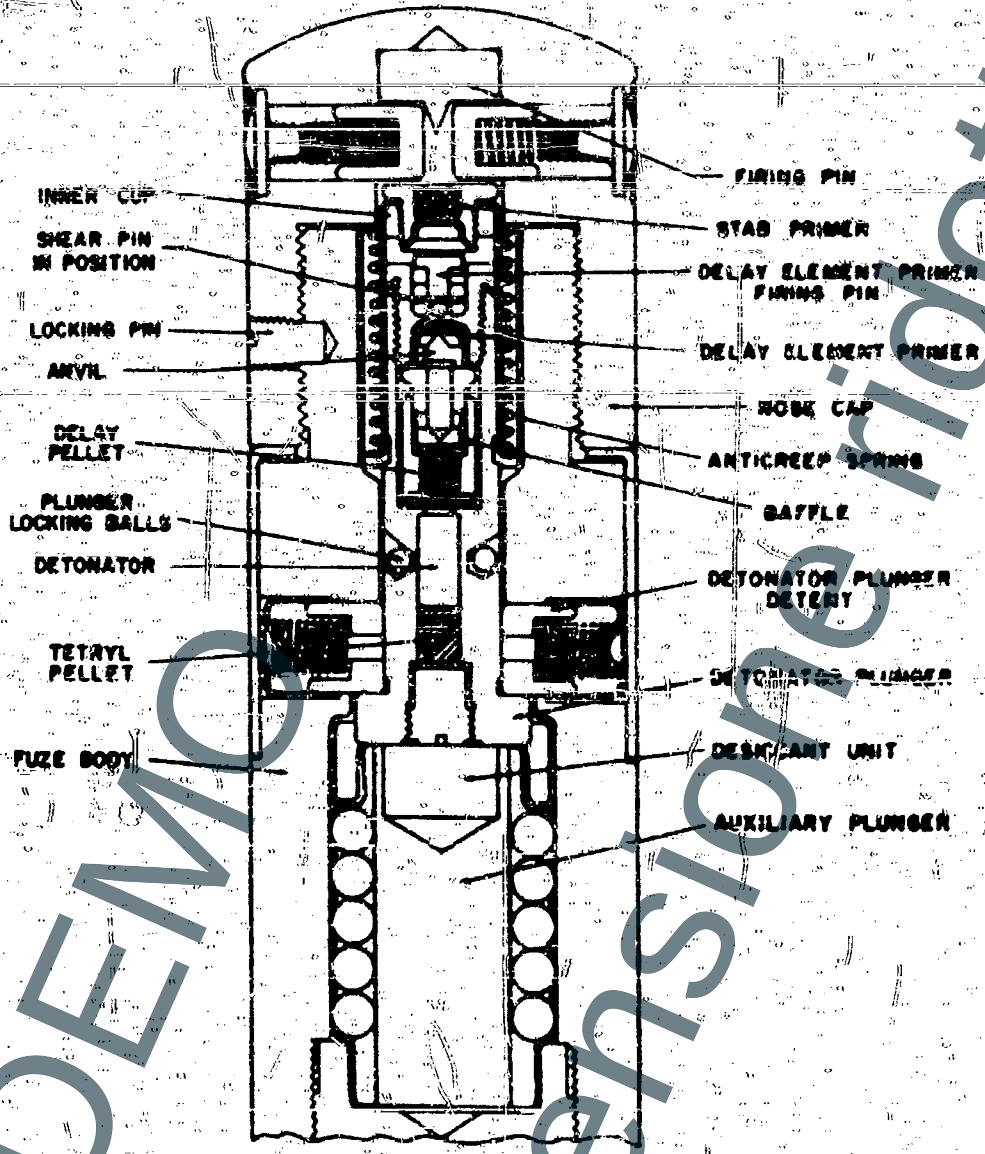

Figure 1-1. Base Fuze Mk 21, Assembled Position. Sectional View.

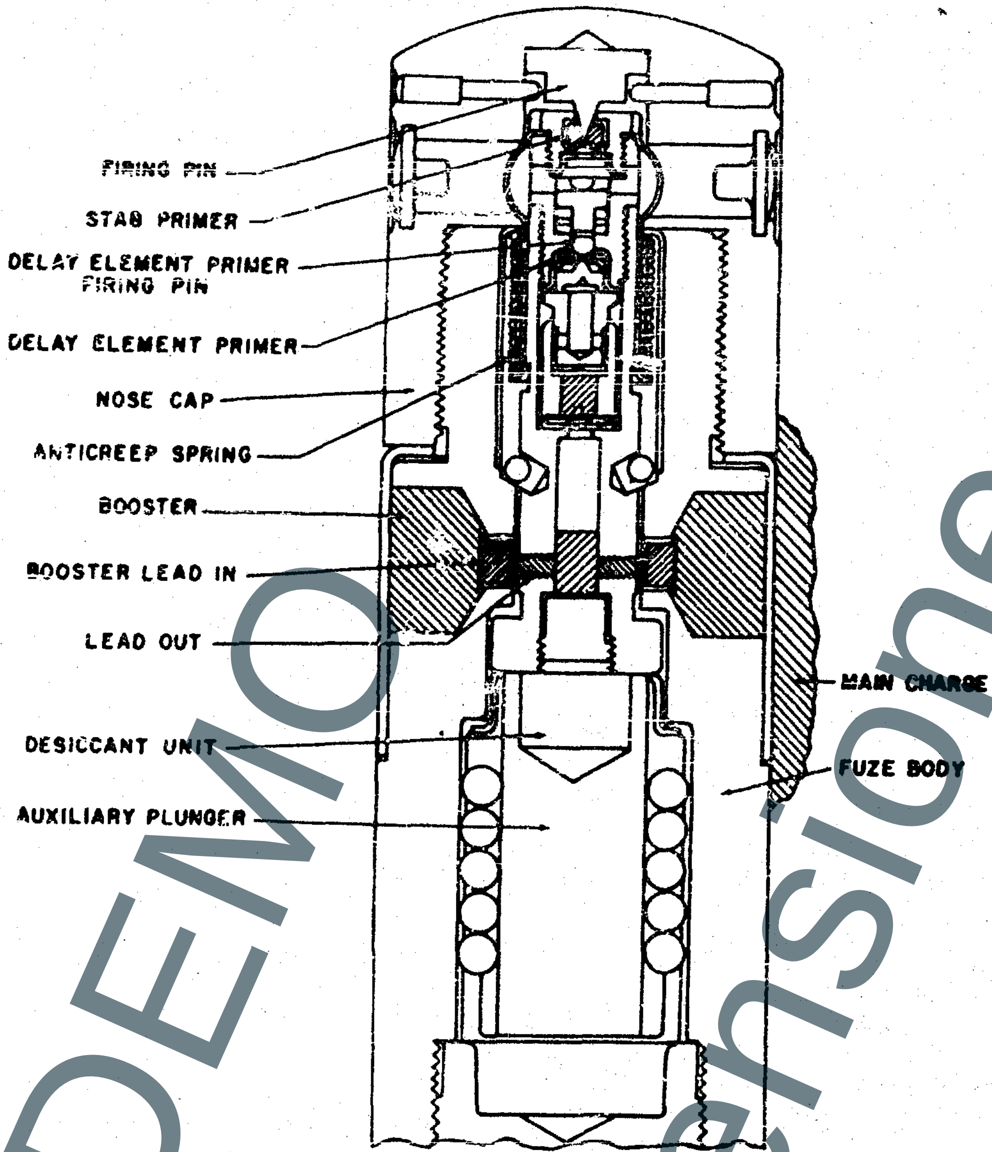

Figure 1–2. Base Fuze Mk 21, Firing Position. Sectional View.

concomitant with this fact has two characteristics, an input characteristic and an output characteristic. We characterize, for instance, the percussion primer with regard to its input characteristic by its drop weight sensitivity, and with regard to its output characteristic by the number of calories of heat which it develops on deflagration and which appear in its output flame. The lead azide detonator is characterized on its input end by its flame sensitivity (as measured, for instance, in the oxy-hydrogen bomb apparatus described on page 9–16) and on its output end by the peak pressure developed at its detonation front where it contacts the succeeding element in the train.

Chapter 2

CHARACTERISTICS OF EXPLOSIVE TRAIN MATERIALS

Explosive train materials have the common characteristic of being capable of reacting, when properly initiated, with the evolution of considerable energy. This reaction does not depend on the availability of any outside material such as oxygen; hence, the reaction can be made to occur in hermetically sealed components.

The materials used in explosive trains may, for convenience of discussion, be divided into explosives and delay materials. Explosives, in general, react more rapidly than do delay materials; however, in the case of short delays the difference in reaction rate tends to disappear, and in some cases a single material may be made to serve both purposes.

From the standpoint of composition, explosive train materials consist of an oxidant (oxidizing material) and a fuel (oxidizable material), held in intimate contact in a metastable condition. Delay materials usually consist of mechanical mixtures of oxidants and fuels, in the form of fine powders. In the case of explosives, the oxidant and fuel are usually incorporated into a single molecule, so that explosives are normally homogenous materials. There are numerous exceptions to the above generalizations, since a pure explosive compound may be used as a delay material, while explosives may consist of mechanical mixtures of explosive compounds and/or oxidizing and reducing chemicals. Other materials may be added to impart special characteristics; for example, wax may be added to a high explosive to decrease its sensitivity.

Section 1.—Explosives

An explosive may be defined as a metastable substance which, if activated by an external source of heat or shock, decomposes spontaneously to produce a large amount of energy. Results of this decomposition are the sudden production of a large volume of reaction gases at high temperature and a sudden rise in pressure in the immediate vicinity. This transformation normally takes place in a period of the order of a few microseconds.

An explosive may be regarded as a material containing stored energy and capable of releasing that energy upon activation. From the standpoint of thermochemistry, the energy released is the difference between the heat of formation of the original explosive and the heat of formation of the products of reaction.

TABLE 2-1.—*Physical Properties of Primary Explosives*

[Reference numbers at heads of columns indicate sources of data]

Explosive	Formula	(7) Mol. weight	Color	(7) Crystal density	Melting point (degrees C)	Oxygen balance (percent)
Mercury Fulminate	$Hg(ONC)_2$	284.6	White to gray	4.4	Explodes	−11.2.
Lead Azide	PbN_6	291	White to gray	4.68 to 4.72	Explodes	
Lead Styphnate, normal	$C_6H(NO_2)_3O_2Pb$	450	Yellow to brown.	2.9 (anhyd.)	Explodes	−16 to −19.
Diazodinitrophenol (DDNP)	$C_6H_2(NO_2)_2ON_2$	210	Yellow to brown.	1.63 (at 25°)	Explodes	−61.
Tetracene	$H_2NC(=NH)-NHNHN=N-C(=NH)-NHNHNO$	188	Pale yellow		Explodes	−59.6.
Nitromannite (Mannitol-Hexanitrate).	$O_2NOCH_2(CHONO_2)_4CH_2ONO_2$	452	White		112 to 113	+7.1.

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